DRAFT ENVIRONMENTAL IMPACT STATEMENT

ON

THE COOLING WATER DISCHARGES

IN KIIKII STREAM

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INTRODUCTION

Waialua Sugar Company, Inc. has been discharging condenser cooling waters into Kiikii Stream since the middle of 1967 when a new and larger power plant was constructed. Prior to that time, the power plant utilized a small quantity of fresh waters for cooling and reused it for cane washing and ultimately for irrigation. However, the new plant required larger quantities of cooling water which was available as brackish groundwaters. Because of its brackish nature, the water could not be reused as before in the mill and in the cane fields. Consequently, the cooling waters were discharged into Kiikii Stream.

Groundwaters are pumped and used to extract heat from the condensers. There is no mass transfer in this process; only energy which gives rise to the higher temperatures. Disposal of the cooling waters then raises questions on the effects of elevated temperatures on Kiikii Stream. The receiving water does not now conform to the regulatory temperature restrictions of the Water Quality Standards. A zone of mixing is required to allow continued discharges as long as the impact is not ultimately detrimental to the beneficial uses of the receiving waters.

Since the advent of thermal discharges, crabbing and fishing in Kiikii Stream near the outfall have been continuing and fishermen claim good catches. The beneficial uses of the waters of Kiikii Stream are apparently unimpaired but to better document the effects of the cooling water discharges, more detailed environmental impact evaluation was undertaken by sampling and analyses of the receiving water and its biological communities.

PHYSICAL FACTORS

Kiikii Stream is formed by the confluence of Kaukonahua and the Poamoho Stream. Kiikii Stream is about one mile long to Kaiaka Bay and about 150 feet wide. In the estuarine portion, the average low tide depth is about 5 feet.

Kiikii Stream joins a neighboring Paukauila Stream at the head of Kaiaka Bay. Paukauila Stream is itself formed by the confluence of two streams, the Opaeula and Helemano Streams which have their headwaters in the Koolau Mountain Range. The four tributary streams forming Paukauila and Kiikii Streams are perennial, but the upstream flows are diverted for irrigation. During the dry summer months, the flows are extremely small and water movement in the estuarine portions of the streams depends principally upon tidal action. However, during the rainy winter months, storm flows may reach flood proportions and override all other factors affecting water quality.

About two decades ago, the mouth of Kiikii Stream was open to the sea and not blocked with a sand bar as it is today. It was then possible for large fish to enter the stream. Changes occurred, however. Fifteen years ago the City and County constructed a flood control project at the mouth of Kaiaka Bay. The mouth of the stream was widened and a rock retaining wall was constructed, all of which apparently altered the equilibrium condition which may have existed at that time and led to the conditions found today.

Fishermen claim that papio, aholehole, lae, mullet, oio, oopu, crabs, hammerhead sharks, and shrimp were present in the river for many years and the fishing pressure has been high over the years. Since its introduction to Hawaii in 1951, Tilapia in Kiikii Stream proliferated in large numbers.

Swimming is virtually non-existent in Kiikii or Paukauila Streams. Turbidity, muddy bottom layer, and heavy organic debris on the bottom may be contributing factors, but more important perhaps is the accessibility of nearby swimming beaches. Boating in the streams is rare, except for crab fishing. Public health is not an issue; the discharges do not involve mass emissions other than those normally occurring from groundwater. Therefore, the major considerations are aesthetics, fishing, and crabbing.

ORGANIZATION OF THIS REPORT

The Environmental Impact Statement is prepared as a summary of the findings and evaluations of the sampling program. More detailed descriptions and data are given in the Appendix.

ENVIRONMENTAL IMPACT

The environmental impact of the cooling water discharges into Kiikii Stream has been evaluated from data developed by sampling in Kiikii Stream and in the neighboring Paukauila Stream. Since Paukauila Stream forms a fork with Kiikii Stream and is subjected to the same hydrologic and oceanographic factors, it serves as a good analytical control for comparisons in water quality and biological communities.

Sampling and field studies were made in May 1972, corresponding to the dry season when stream flows are the lowest. The results, therefore, would represent conditions prevailing over most of the year. During the rainy winter months, stream flows become significant and the water quality in the streams would then be dictated by these flows.

The effect of temperature on the biological communities is complex. There is a tolerance range, above or below which inhibition or death occurs. Organisms may also regulate their life processes according to seasonal changes in temperature, for example, spawning. Other biochemical factors play a part. Metabolic rates increase with higher temperatures within the tolerance range. Hence, growth rates should increase accordingly.

Different organisms respond in different ways to changes in temperature, salinity, and other water quality factors. The communities in question are estuarine, and because of this, the organisms found in Kiikii Stream would be naturally adapted to more extreme conditions in salinity and temperature than an open ocean community would. The fact that fishing and crabbing are continuing indicates that the thermal discharges in Kiikii Stream have not abruptly affected the biological community. The changes, however, may be subtle, but it is believed that after five years of discharges, trends should have been established and that a comparative sampling program would provide insight into the changes that might have occurred from the discharges. The frame of reference is the neighboring Paukauila Stream where the major difference between boundary conditions is the cooling water discharge.

Temperature Variation in the Discharge and in Kiikii Stream

The cooling waters are pumped from the brackish groundwater reservoir at a rate of 14 mgd. The temperature in the cooling waters varies, depending mainly upon the operation of the mill processes. Using records from the mill for the period from October 22, 1970 to October 21, 1971, the median discharge was determined to be 92.4^{o}F, and 90% of the time the temperature was less than 98.5^{o}F. Higher temperatures occur in the summer months when sugar processing at the mill is most intense. November to March is the off-season period when the mill is shut down and no thermal discharges occur.

Therefore, the receiving water temperatures, even with the discharges, would tend to follow the seasonal trend: high in summer and low in winter. This is critical to aquatic organisms that depend on seasonal variations in temperatures to regulate their life processes. However, the high temperatures in the summer would be higher than what it would be from the natural trend as a consequence of the thermal discharges. The natural temperature variation in Kiikii Stream as well as in Paukauila Stream would be dependent principally on meteorological factors of sunshine, wind, humidity, etc. Solar radiation perhaps is the most significant single factor which would affect temperatures, especially for the confined condition of the two streams. As a consequence, the receiving water temperatures, with the superimposed thermal discharges from the condenser cooling waters, would vary in a complicated way.

To illustrate the magnitude of changes to be expected, with and without thermal discharges, the record for 1971 was evaluated from meteorological data maintained by the Waialua Sugar Company and from records of temperatures of the discharges. The temperature of the stream resulting from the meteorological factors can be computed on the basis of a model of energy balance and verifying the results by measurements of actual stream temperatures. This was the procedure followed in estimating the natural variation in stream temperatures.

Once these procedures are established, the effect of the thermal discharges can be superimposed on the natural effects, again verifying results by field measurements of the present discharges. With these results, the variation in temperature from natural causes as well as the increase in temperature from the thermal discharges can be estimated for other conditions (see Appendix for more detailed information of procedures.)

The results of these evaluations are shown in Figure 1 (page 6). The natural variation in stream temperatures, based on meteorological data, is shown by the solid lines. During the winter months, high stream flows may have occurred which would mean that the temperatures would be lower than predicted by the meteorological factors alone. However, the operating season of the sugar mill coincides with the dry periods when stream flows are insignificant. As shown in the Figure, the weekly average temperatures in the stream vary considerably because of the changing meteorological conditions throughout the year.

The upper dashed line labeled "B" indicates the resulting temperatures from the thermal discharges. The peak in this curve does not necessarily correspond to peaks for the natural conditions. The reason is that temperatures of the discharge vary independently of the meteorological factors. In general, there is a 10^{O}F rise in temperature as a consequence of the thermal discharge.

Another condition was tested by the model and that is the effect of cooling the thermal discharges by 10^{O}F by treatment. The expected temperatures are shown as a dashed line labeled "C". The corresponding results show that the stream temperatures would be either less than or greater than the natural stream temperatures. Where the curves cross, the temperature would be the same as it would be from natural conditions. At these times the 1.5^{O}F restriction in the Water Quality Standards would be met. Otherwise, it would not be met most of the time, even with treatment. Temperatures would be either too high or too low.

Impact on Water Quality

In general, the impact on water quality by the condenser cooling water discharge is to increase the temperature, decrease salinity, and decrease the residence time of various constituents in the water. These changes of the magnitudes observed do not affect the aesthetic qualities of the water. Temperature increase on the order of 10^{O}F can be expected throughout most of the year during the operating season. Salinity in Kiikii Stream is also affected, favorably it seems for estuarine biota. Residence time is related to flushing of the estuary by the continual discharges during the operating season, in addition to tidal exchanges.

FIGURE 1

WEEKLY EQUILIBRIUM TEMPERATURES FOR KIIKII STREAM WITH AND WITHOUT HEAT INPUT, 1971

The salinity of the condenser cooling waters measured during the course of this study ranged from 7.1 to 12.1 ppt. As a consequence of this discharge, the salinities in Kiikii Stream are lower than they are for Paukauila Stream. Salinity data for surface and bottom samples in both streams indicated that a lower salinity zone persisted on the surface and higher salinity on the bottom. This is common for estuaries with poor vertical mixing. Near the mouth of both Paukauila and Kiikii Streams at the head of Kaiaka Bay, the salinity was higher and near seawater salinities. In Kiikii Stream, the salinities of the bottom zone ranged from about 35 ppt at the mouth to 15 ppt 4,000 feet upstream. The surface salinities in Kiikii Stream ranged from 34 ppt to 9 ppt. In the neighboring Paukauila Stream, values on the bottom ranged from 35 ppt to about 24.5 ppt, and on the surface from 35 ppt to 17 ppt.

Other water quality parameters, nitrogen, phosphorus, and turbidity, have been measured. The results of nitrogen and phosphorus analyses show that differences in concentrations between the two streams were not significantly different. Turbidity, however, in terms of Jackson Turbidity Units (JTU) was higher in Kiikii Stream than it was in Paukauila Stream. A reason for this is shown by the particle size analyses of the sediment samples. In general, Kiikii Stream has a higher percentage of clay in the sediments compared to samples from Paukauila Stream. Much more clay would be resuspended by hydraulic disturbances in Kiikii Stream than it would be in Paukauila, giving rise to higher turbidities.

Ecological Impact

The biological communities sampled included the infauna by Eckman dredge, phytoplankton by chlorophyll-a measurements, zooplankton by day and night plankton net tows, juvenile fishes by nehu nets, the larger fish by gill nets, and crabs by netting as normally done by crab fishermen.

Rationale of the Sampling Program

Energy or food input into an aquatic ecosystem begins with primary production, phytoplankton being one form and terrestrial organic debris being another. From the primary producers, energy is cycled through the higher trophic orders and an important link in this chain is the zooplankton, most prominantly the copepods. Crabs are known to be scavengers. They enter a different food chain and may utilize primary producers washed in with runoff from land or feed on fish and other aquatic animals.

The interaction among organisms in different trophic levels is difficult to quantify, but conceptually it is known that the biomass of organisms in one trophic level must be higher than the next succeeding level in order to be consistent with the concept of energy. This means that ecological assessment can best be made by sampling organisms in as many different trophic levels as sampling techniques allow and compare the diversity and abundance of organisms in one level to the next, and for each level between the Kiikii and Paukauila Streams. If any one level appears to be seriously stressed, it would mean that the succeeding trophic levels in turn would be stressed. The "health" of the community may be thereby indicated and correlated with changes in water quality from the discharge.

Attention is also given to organisms for their value as a recreation potential or a food source. Mullet and aholehole are usually favored over Tilapia, and Samoan crabs over others, according to fisherman frequenting Kiikii Stream.

Lower Trophic Orders

Sampling stations are shown in Figure 2 (page 9) and the results of chlorophyll-a and zooplankton densities are shown in Table 1 (page 10). The median chlorophyll-a concentrations for both streams are comparable, but the extremes are different. For Paukauila Stream, the low value corresponds to the station nearest the mouth and the high to the innermost station. Flushing seems to be a significant factor.

Copepods make up the greatest number of individuals of zooplankton and all values are high as they should be from densities of phytoplankton. Copepods feed directly on phytoplankton and so do the other zooplankton shown in Table 1.

The median values for copepods differ significantly between streams, but the maximum values are of the same order of magnitude. The range is large and shows a "patchy" distribution among stations.

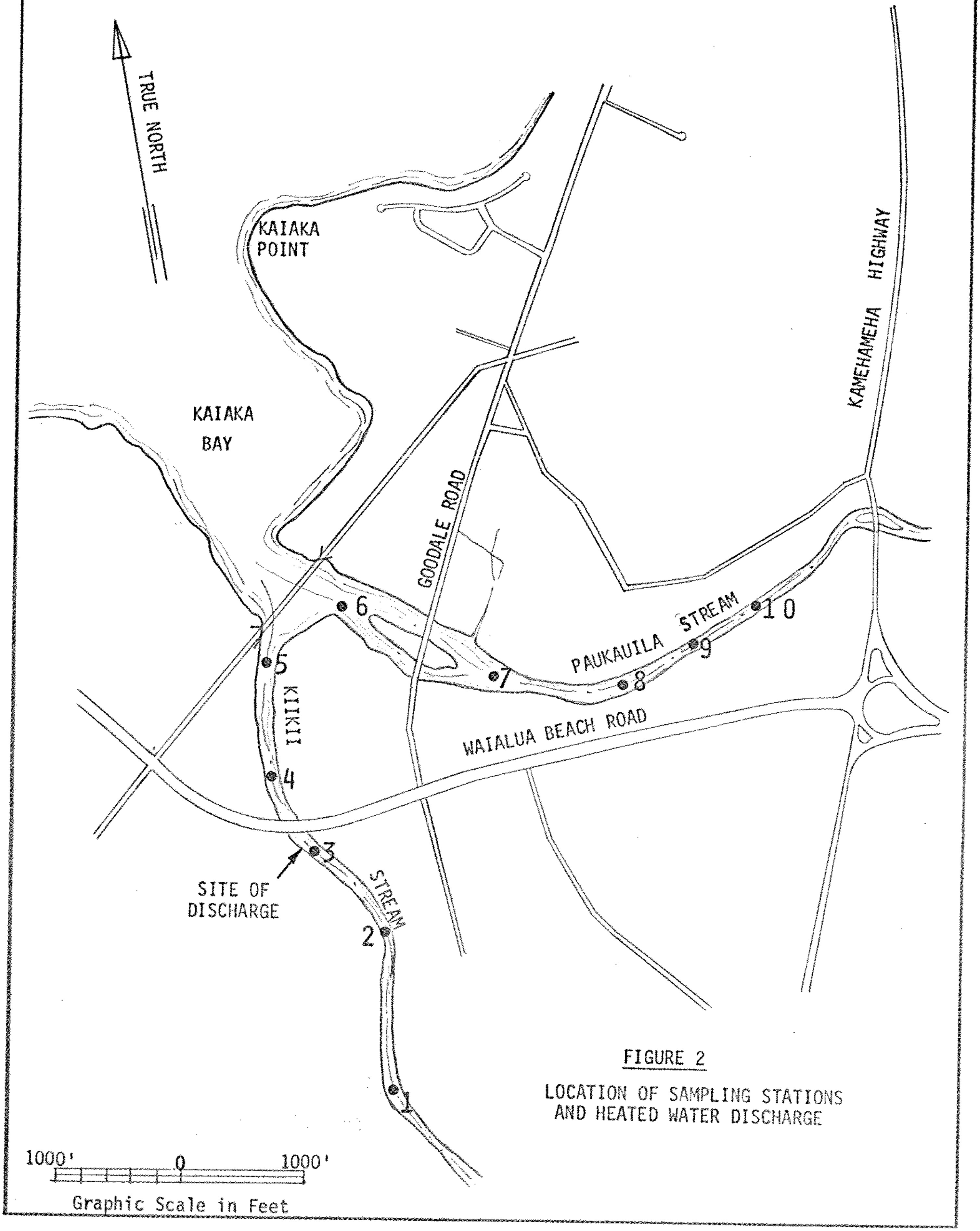


FIGURE 2

LOCATION OF SAMPLING STATIONS AND HEATED WATER DISCHARGE

TABLE 1

CHLOROPHYLL-A AND ZOOPLANKTON DENSITIES IN KIIKII AND PAUKAUILA STREAMS*

	Kiikii Stream		Paukauila Stream	
	median	range	median	range
Chlorophyll-a (mg/m^3)	21.2	15.2-43.0	25.6	7.7-76.1
Zooplankton ($no./ft^3$)				
Copepods	57,500	6170-283,000	213,000	94,200-583,000
Fish Larvae	75	25-750	0	0-50
Crab Larvae	25	0-170	0	0-330
Shrimp	166	83-275	166	100-250
Amphipods	583	166-2300	25	0-3000

* Zooplankton from night sampling.

The lower value may be due to grazing by fish and other animals in higher trophic levels, to flushing which is greater by the continuous discharge in Kiikii Stream, or it may be that the results simply represent a transient state when the ratios of biomass of phytoplankton and zooplankton are changing with time. In situ growth rate, or in general, kinetics, is an aspect which should shed light on the phenomena, but more basic research is needed. Nevertheless, the trend in copepod densities is high in both streams, in line with high chlorophyll-a concentrations.

Other zooplankton data show interesting results. Fish larvae occur generally in higher densities in Kiikii Stream. The highest density, $750/ft^3$, occurs at the cooling water outfall. It would seem that temperatures are important, but it is equally likely that salinity is the significant factor. Many fish are known to require low salinities during the pre-hatching and larval stages. Whatever the reason may be, it is clear that fish larvae are more prominant in Kiikii Stream where the discharge occurs.

Crab larvae were detected more consistently in Kiikii Stream than in Paukauila Stream. None were detected in one station in Kiikii near the mouth of the stream, but in Paukauila Stream, three of five stations were devoid of crab larvae. Two of these stations occurred in the innermost reaches of the stream where flushing is not a likely reason.

Shrimp larvae were found in similar densities throughout both streams. Apparently, differences in temperature and salinity have not affected the distribution of the larvae. However, amphipods generally occurred in higher densities in Kiikii Stream, indicating that conditions were more to their favor here than in Paukauila Stream.

The distribution of organisms in the lower trophic orders have not shown detrimental effects of the thermal discharges. On the contrary, shrimp larvae seemingly showed an indifference to the different conditions in the streams as indicated by their even distribution in both streams. The other zooplankton occurred in greater abundance in Kiikii Stream, indicating a more favorable environment there. Copepods were the exception, but densities were nevertheless high in relation to chlorophyll-a.

Higher Trophic Orders

Fish sampling was performed by different types of netting adapted to different parts of the stream. Procedures and results are detailed in the Appendices.

Fish catches were best in Kiikii Stream upstream from the outfall. The numbers of the most prominant types are summarized in Table 2.

TABLE 2

SUMMARY OF PROMINANT FISH CATCHES*

Fish	Kiikii Stream (numbers)	Paukauila Stream (numbers)
Aholehole	213	0
Mullet	56	2
Goby	471	15
Barracuda	11	3
Tilapia	334	62

* See Appendix for data on other fishes.

The results of fish sampling show greater catches for the same effort in Kiikii Stream by a factor of ten. These large differences are believed to be well beyond sampling errors, recognizing that fish sampling is most difficult.

Of the catches in Kiikii Stream, the greater portion occurred at or upstream from the outfall. Temperatures are higher in Kiikii and salinity is lower than it is in Paukauila Stream. However, it is not possible from the data to separate the effects of temperature from those of salinity or from any other factor. Aholehole and mullet are commonly seen in waters of low salinity, but they are capable of surviving in normal seawater. However, the goby, Oxyurichthys, is found in estuarine waters throughout its life history. Barracuda may occasionally enter estuarine waters perhaps for feeding and/or completion of reproductive processes. Tilapia are found in both estuarine and fresh waters, but only for short periods in sea water. In view of this, it seems that the greater abundance of fish in Kiikii Stream can be explained qualitatively by the lower salinities in Kiikii Stream.

Although both the Kiikii and Paukauila Streams show high energy levels in the lower trophic orders (phytoplankton and zooplankton), it is Kiikii Stream that is significantly more abundant in fish. This is also true specifically for the more valued food fishes, mullet and aholehole.

Therefore, the conditions of lower salinity and higher temperatures created in Kiikii Stream by the cooling water discharges are certainly not detrimental to the ecosystem described. On the contrary, evidence leads to the conclusion that the discharges have apparently created a more favorable aquatic environment for the estuarine organisms.

Benthic Organisms

Duplicate sediment samples were obtained by Eckman dredge from each of the ten stations in Kiikii and Paukauila Streams and examined for infaunal organisms. These samples were generally devoid of benthic animals.

Besides the infauna, crabs were sampled by net to compare their relative abundance in the streams. Crabbing has been a major recreational use of the waters.

Crabs are scavengers and either enter a different food chain or continue in the same chain described earlier. They may function as organisms in a trophic order above fish since fish is a food source for crabs. Another energy source is terrestrial plant debris which is abundant in the stream sediment from runoff. In this way, the stream serves as a transporting link between terrestrial primary production and the aquatic ecosystem.

Both streams therefore should not be limited in food for crabs, and the different salinity, temperature, and habitat should normally be the factors which dictate the diversity and abundance of crabs in the streams. However, the crabbing pressures on Kiikii Stream have been much greater than they have been on Paukauila Stream, and the crab population should therefore be lower in Kiikii.

Crabs were sampled by 30-inch nets using fresh aku heads as bait. Nets were set at each of the ten stations. A set consisted of 45 minutes or 90 minutes, depending on the run, from the time the net was placed in the water to the time it was pulled up for the catch. A total of 336 sets were made in Kiikii Stream and 90 in Paukauila. The results of unit catches are shown in Table 3 for all crabs and for Samoan crabs specifically. The composition and average sizes of crabs are shown in Table 4.

TABLE 3

UNIT CATCHES OF CRABS IN PAUKAUILA AND KIIKII STREAMS

	Kiikii Stream median	Kiikii Stream range	Paukauila Stream median	Paukauila Stream range
Unit catches at stations (all crabs) (no/set)*	0.12	0.10-0.24	0.22	0.13-1.66
Samoan crabs (gm/set)	13.1	4.1-20.6	17.1	4.3-69.5

* Based on 336 sets in Kiikii Stream and 90 sets in Paukauila Stream

TABLE 4

COMPOSITION AND AVERAGE SIZES OF CRABS CAUGHT

Crabs	Kiikii Stream % of total number	Kiikii Stream ave size* (cm)	Paukauila Stream % of total number	Paukauila Stream ave size* (cm)
Samoan	44	9.8 (190 gm)	32	8.8 (140 gm)
Blue Claw	56	5.6	23	6.3
White	0	-	45	6.9

* Carapace width. Samoan crab size is that size corresponding to average weight. Other crabs, arithmetic average width.

The catch per unit of effort for Paukauila Stream is higher than it is for Kiikii Stream, and this is not surprising considering the fishing pressures on Kiikii Stream. Conversely, the station which appears most inaccessible, except by wading or by small boat, is the station near the mouth of Paukauila Stream showing the highest unit catches of 1.66/set and 69.5 gm Samoan crabs/set.

However, the Samoan crabs are more prominant in Kiikii Stream and although lower in number of catch, the crabs are larger. The average weight of Samoan crabs caught in Kiikii Stream was 190 grams while it was 140 grams for Paukauila Stream. The largest crabs caught were Samoan crabs, one at the outfall and one downstream near the mouth, each weighing 330 grams (12 cm width).

The smaller numbers of Samoan crabs but larger individuals caught in Kiikii Stream suggest that crabbing pressure has an effect on numbers but something is stimulating growth. Increased temperatures can do this by increasing metabolic rates, but this line of reasoning does not hold true with similar data on Blue crabs. These crabs were smaller in Kiikii Stream.

Other sources of information on crabbing are the fishermen who regularly fish there. Testimonies included in the Appendices from three fishermen attest to the good catches of Samoan crabs in Kiikii Stream despite the discharges and in general express the sentiments of other fishermen interviewed casually during the field studies.

The predominance of Samoan and Blue Claw crabs in Kiikii Stream suggests that low salinity is the governing factor, but the catches of these crabs as well as white crabs at the station in Paukauila Stream where salinity is much higher, suggest other factors, perhaps habitat, as being critical. White crabs, however, were caught only in Paukauila Stream at one station at the mouth where salinity values were among the highest.

In summary, the results on crab sampling show differences in numbers of catch which can be attributable to the crabbing pressures, but Samoan crabs were larger in Kiikii Stream. The lower salinities in Kiikii Stream seem to be a contributing factor for the predominance of Samoan and Blue Claw crabs. White crabs were prominant only at one station in Paukauila Stream near the mouth.

The discharges apparently have had a beneficial effect of lowering salinities and contributing to a more favorable environment for Samoan crabs and other estuarine animals. Temperature effects have not been delineated from the others. Considering the life processes related to tolerance and stimulated growth from higher metabolic rates, the heavy crabbing by fishermen in Kiikii Stream shows that a large enough population of crabs is present, therefore the elevated temperatures must not be detrimental. Rather, the larger sizes of Samoan crabs caught in Kiikii Stream compared to Paukauila Stream lead one to suspect that the elevated temperatures might be contributing to higher growth rates.

The Impact

Cooling water discharges occur with variable temperatures. The median temperature is 92.4^{o}F, and for 90% of the time the temperatures are equal to less than 98.5^{o}F. The stream temperatures, because of low flow conditions, are influenced by meteorological factors, most significantly by solar radiation. The resulting stream temperatures would therefore also vary independently of the discharge. The overall effect is an increase in stream temperatures by about 10^{o}F above what would be considered to be normal. These temperature differentials would be found most consistently during the summer months when mill operations are most intense. During other times the differentials would be lower, and during the winter months when the mill is shut down, no discharges occur and the temperatures vary according to natural factors. Therefore, the seasonal temperature trends are maintained for those organisms that depend on these seasonal changes to regulate their life processes.

Salinity is lowered in Kiikii Stream as a consequence of the discharge. Salinity otherwise would be closer to that of seawater most of the year when stream flows are lowest. During the rainy winter months stream runoff may be extremely high, and at that time stream flows would override all other factors affecting water quality in Kiikii Stream.

The changes in water quality parameters of temperature and salinity from the discharge would in some way affect the rest of the ecosystem.

The sampling program for the biological communities was designed to provide data on organisms in different trophic levels, following the concepts of energy processing in the ecosystem. The control, or frame of reference, was the neighboring Paukauila Stream which forms a fork with Kiikii Stream.

Primary production from phytoplankton in both the Kiikii and Paukauila Streams is high, indicating that the basic energy source is ample in both streams. In the next level, zooplankton, mainly copepods which feed on phytoplankton, are high in both streams as well, but the diversity is greater in Kiikii Stream. Fish and crab larvae and amphipods were more abundant here, indicating a more favorable environment. Shrimp larvae were evenly distributed and seemed indifferent to the water quality conditions in the streams. Although energy sources in the lower trophic orders seem comparable in both streams, fishes, especially mullet, aholehole, goby, and *Tilapia*, were far more abundant in Kiikii Stream.

The catches of crabs were less in numbers per unit effort in Kiikii Stream. This is attributed to the high crabbing pressure there. But the catches of Samoan crabs were bigger in Kiikii (ave. 190 gm) compared to Paukauila Stream (ave. 140 gm). The largest Samoan crabs (330 gm, 12 cm) were caught at the outfall and at the downstream station near the mouth of Kiikii Stream.

Dissolved oxygen values for the condenser cooling water discharge were 5.9 and 6.6 mg/l as measured in the field. Since the discharge has negligible oxygen demand itself, it allows for a more favorable D.O. condition to exist in Kiikii Stream, both by adding oxygen and reducing the mean residence time.

On the basis of these results, it is concluded that the environmental impact of the cooling water discharges into Kiikii Stream is a favorable one leading to a more productive ecosystem.

ADVERSE EFFECTS

Adverse effects on the beneficial uses of the waters are not apparent. Salinity and temperatures are the key parameters affected, and as previously described, the changes apparently lead to a more productive estuarine ecosystem.

There may be many different types of reactions which can be conjectured to be adverse. For example, dissolved oxygen concentrations are affected by temperatures. Higher temperatures reduce the solubility of oxygen in water, which in turn plays a part in governing the oxygen transfer rates to oxygen deficient portions of the waters. However, the discharges lower the salinity levels, which tends to increase solubility of oxygen and thereby offset the opposite tendency of higher temperatures.

Nonetheless, observations made on water quality and biological communities indicated no apparent adverse effects of the cooling water discharges.

ALTERNATIVES

From the standpoint of engineering, several alternatives seem possible, but with knowledge of the favorable effects of the present practice, the other alternatives become less desirable for one reason or another.

The thermal discharges can be diverted to waters off the beaches where dispersion would be greater, and therefore more closely conforming to the specifications of the Water Quality Standards. However, there are reef formations there and corals would then become the issue. Corals have been reported to be sensitive to salinity and temperature changes. Therefore, this alternative is undesirable.

Waialua Sugar Company has investigated the desirability of underground disposal of the thermal discharges. Working with Stephen Bowles, consulting hydrologist, they dug test wells in several locations. The results show that from hydraulic and geologic reasons, well injection is not a viable alternative.

Another alternative is to pump more groundwater for cooling to give lower temperatures. But the quantity of additional water required to significantly lower temperatures would in turn appreciably lower the salinity in Kiikii Stream. The ecosystem may then be seriously affected. Besides that, the Water Quality Standards would still not be met most of the time because of the independently varying factors controlling stream and discharge temperatures.

Treatment is another alternative. Attempts to meet the Water Quality

Standards by cooling can involve such methods as spray ponds and cooling towers, but conformance with the Standards would be a chance occurrence. Cooling by $10^{o}F$ would result in temperatures which would be either too high or too low from the 1.5^{o} specification. Figure 1 on page 6 shows that for the 1971 condition the temperature would be too high by $3.0^{o}F$ and too low by $3.5^{o}F$ at the extreme cases from the natural ambient temperature curve. More detail discussions of the various alternatives and their implications are included in Appendix D.

More important is the probable effect on the ecology. At the present time, a productive ecosystem exists in Kiikii Stream where the discharge occurs. Salinity is an important factor, but the role of temperature has not been clearly delineated. It is not a question of tolerance to temperature; the diversity and abundance of organisms in the different trophic levels show this. But the high productivity of the ecosystem could well be the result of elevated temperatures also, in keeping with the principle that metabolic rates increase with increasing temperatures within the tolerance range. Therefore, cooling should not be attempted.

SHORT-TERM AND LONG-TERM USE OF MAN'S ENVIRONMENT

The impact on Kiikii Stream is localized to the estuarine portion and the surrounding areas. Water quality degradation as a consequence of the discharge is negligible. Temperature and salinity gradients are no longer discernible at the boundaries of the estuary.

However, such is not the case with the biological systems. The estuary supports a vital part of the life cycles of many organisms, perhaps the most critical being the reproductive phases of their life histories. Observations on the biological communities indicated a highly productive system. Therefore, the numbers of organisms completing their life cycles elsewhere should be enhanced as well.

In examining questions on short-term and long-term uses of the waters in Kiikii Stream on a broader scale beyond the boundaries of the estuary, it is clear that a favorable effect on the ecosystem in Kiikii Stream would in turn have a favorable effect on other ecosystems and on the beneficial uses of the waters.

REVERSIBILITY

The effect of the cooling water discharges on Kiikii Stream is not an irreversible commitment. A principle of physical chemistry states that when a system is stressed from an external source, the system adjusts to that stress. Conversely, when that stress is removed, the system reverts to the original state. Other ways of summarizing this phenomenon are the stress-strain or action-reaction relationships in physical science.

As described earlier, changes in salinity and temperature occur as a consequence of the discharge and the biological communities adjust to these changes. The end result for Kiikii Stream is considered to be more favorable than before from the standpoint of beneficial use. That earlier state is believed to be approximated by the conditions now observed in the neighboring Paukauila Stream.

APPENDIX

APPENDIX A

METHODS AND PROCEDURES

During the period of May 19 through May 26, 1972 sampling and field observations were carried out on Kiikii and Paukauila Streams. Physical, chemical, and biological characteristics were measured under various tidal conditions including one period of night sampling for zooplankton. The sampling stations are indicated in Figure 2.

PHYSICAL AND CHEMICAL CHARACTERISTICS

The condenser cooling water being discharged into Kiikii Stream is slightly heated brackish groundwater and consequently has several characteristics which are different from the ambient conditions of the stream. The most notable of these are temperature, salinity, and turbidity. Samples were obtained from various depths by the use of a pump operated by a portable electric generator.

Temperature

The temperature of the discharge and the streams were measured using a temperature probe which was lowered from a boat to the desired depth. The temperature was read to the nearest 0.1°C.

Salinity

The field measurements of salinity were made using a conductivity meter. Laboratory samples were titrated for chlorosity using the method described by Strickland and Parsons (1968).

Turbidity

Secchi disk visibility measurements were conducted at the sampling stations *in situ* while laboratory measurements were made by a turbidimeter on samples collected.

Dissolved Oxygen

A dissolved oxygen electrode was lowered to the desired depth and the D.O. was read to the nearest 0.1 mg/l.

Sediment Characteristics

Bottom samples were obtained by using an Eckman dredge. The composition of the sediment was determined by treatment with a blender, dispersing agent, and classifying particulates into three sizes: clay, <2 microns; silt, $2\mu \leq d \leq 50\mu$; and sand, $> 50\mu$ using a modified ASTM method. The method modification consisted of the elimination of the digestion step. The bottom samples were preserved with a 10% formalin in sea water solution for assays.

BIOLOGICAL CHARACTERISTICS

The effect of the discharge on the ecosystem of the receiving water was evaluated by biological parameters developed in a biological sampling program for both Kiikii and Paukauila Streams. The program included the identification and enumeration of organisms from several trophic levels of the food web.

Plankton

The relative concentration of phytoplankton was determined by chlorophyll-a measurements performed according to Strickland and Parsons (1968) using a 90% acetone extract and the trichromatic equation. Zooplankton samples were obtained by towing a 5-inch diameter fine mesh plankton net a specified distance through the surface layer. Both day and night samplings were performed. The sampled organisms were preserved in a 10% formalin in sea water solution, identified, and enumerated.

Crabs

Estimates of the species and number of crabs in the two streams were obtained by using 30-inch crab nets with fresh aku heads as bait. The sampling time was about 45 minutes during the first run and about 90 minutes during the second. The crabs caught were identified, their size measured, characterized according to sex, and counted.

Fish and Shrimp

Three netting techniques were employed at each station to sample the fish and shrimp population. An opae net was used for the smaller organisms while a 40-foot nehu net with a 6-foot pocket and two gill nets were used to sample the larger organisms.

Five passes with the opae net were made at one bank of each station. A pass consisted of dragging the net up the bank from the bottom and included the scraping of any organisms from the stems of any plants encountered.

The nehu net was used by stationing one end at a point near the bank and sweeping the other end in an encircling pattern toward the stationary end and then gathering the net by the two ends.

Sampling for the larger fish with the gill nets was accomplished by enclosing for approximately an hour a stretch of the stream of about 100 to 200 feet, depending on the width, and disturbing the enclosed water (pa'ipa'i) so as to drive the fish into the nets. The caught fish were then identified, measured, and counted.

APPENDIX B

PHYSICAL AND CHEMICAL DESCRIPTION

Kiikii Stream, the receiving body of water for the Waialua Sugar Company condenser cooling water, is located in northern Oahu. The headwater for this stream is the Wahiawa Reservoir and consequently the flow and water quality in the stream are partially regulated by the operation of the reservoir spillway.

Kiikii Stream joins Paukauila Stream, a similar parallel stream, and together they flow into Kaiaka Bay, a very shallow bay which opens into the ocean. During most of the year, except for periods of flood flows, the portions of interest of these two streams are estuarine and tidal. Estuaries often serve as nurseries for several organisms and it is this function that is critically studied here.

The physical and chemical characteristics of the receiving water can affect the aesthetic quality as well as the balance of the aquatic ecosystem. The characteristics of the Waialua Sugar Co. discharge are such that the aesthetic qualities of Kiikii Stream are not detrimentally affected. The discharge does not increase the oxygen demand of the stream and it is of a higher clarity than the ambient water.

The physical-chemical portion of this investigation considers the temperature, salinity, clarity, nutrients, and bottom characteristics of Kiikii and Paukauila Streams. The sampling stations referred to in the following discussions are shown in Figure 2.

HYDRAULIC DESCRIPTION

Kiikii and Paukauila Streams flow significantly only during the rainy season (November through March). During the dry season, which coincides roughly with the period during which the condenser cooling water is being discharged, the two streams are estuarine. The salinity during the dry period is greatly influenced by the amount of fresh and brackish water inflow that does occur. In the existing case the condenser cooling water discharge into Kiikii Stream is the most significant input and constitutes a major difference between the two streams.

The depth and volume characteristics of the estuarine portions of the two streams at low tide are indicated in Table B-1. Kiikii Stream on the average is a half foot shallower and has about one-third less volume than Paukauila Stream. Using volume data, salinity measurements (discussed later), the cooling water inflow rate (14 mgd), and the concept of mass balance it is possible to estimate the average theoretical hydraulic residence times in the two streams. The estimated average value for Kiikii Stream is less than one day while that for Paukauila Stream is approximately three days. There is, of course, a wide distribution of residence times along the length of each stream with the longest times being at the upstream end.

In summary, the inflow of condenser cooling water into Kiikii Stream decreases both the average salinity and the average residence time while raising the temperature relative to these characteristics in Paukauila Stream. These different conditions in turn affect the makeup of the biological communities in the two streams. The difference in the two ecosystems will be discussed in the next chapter.

TEMPERATURE

Temperature was the primary variable of concern at the initiation of this study. Figure B-1 shows the frequency distribution of the average daily condenser cooling water temperature at the point of outlet from the condenser. The data for this graph include the period of October 22, 1970 to October 21, 1971 with the exception of the time between November 26, 1970 to March 1, 1971 when the power plant was not operating. Those few points of original data that correspond to three pumps operating were adjusted to reflect the temperature that would result if all four pumps had been supplying cooling water (in both cases the same amount of heat is being discharged). It can be seen that the median discharge temperature was 92.4^{o}F and that 90% of the time the temperature was below about 98.5^{o}F. The data on the actual discharge temperature at the point of entrance into Kiikii Stream consist of a relatively few spot measurements which do not indicate any consistent or significant drop of temperature in

TABLE B-1

DEPTH AND VOLUME CHARACTERISTICS OF KIIKII AND PAUKAUILA STREAMS

Stream	Station	Ave. Depth (feet)	Ave. Length of Reach (feet)	Ave. Width of Reach (feet)	Volume X10^3(feet)^3	
	5	4.0				
			1000	125	656	
	4	6.5				
			650	100	358	
Kiikii	3	4.5				
			1000	90	450	
	2	5.5				
			1000	100	475	Total Volume:
	1	4.0				
			1300	100	455	2,394 x 10^3 (ft)^3 or 17.9 MG
	End	3.0				
	6	2.0				
			1200	300	1350	
	7	5.5				
			1200	110	825	
Paukauila	8	7.0				
			800	90	486	
	9	6.5				
			500	80	280	Total Volume:
	10	7.5				
			1400	80	588	3,529 x 10^3(ft)^3 or 26.4 MG
	End	3.0				

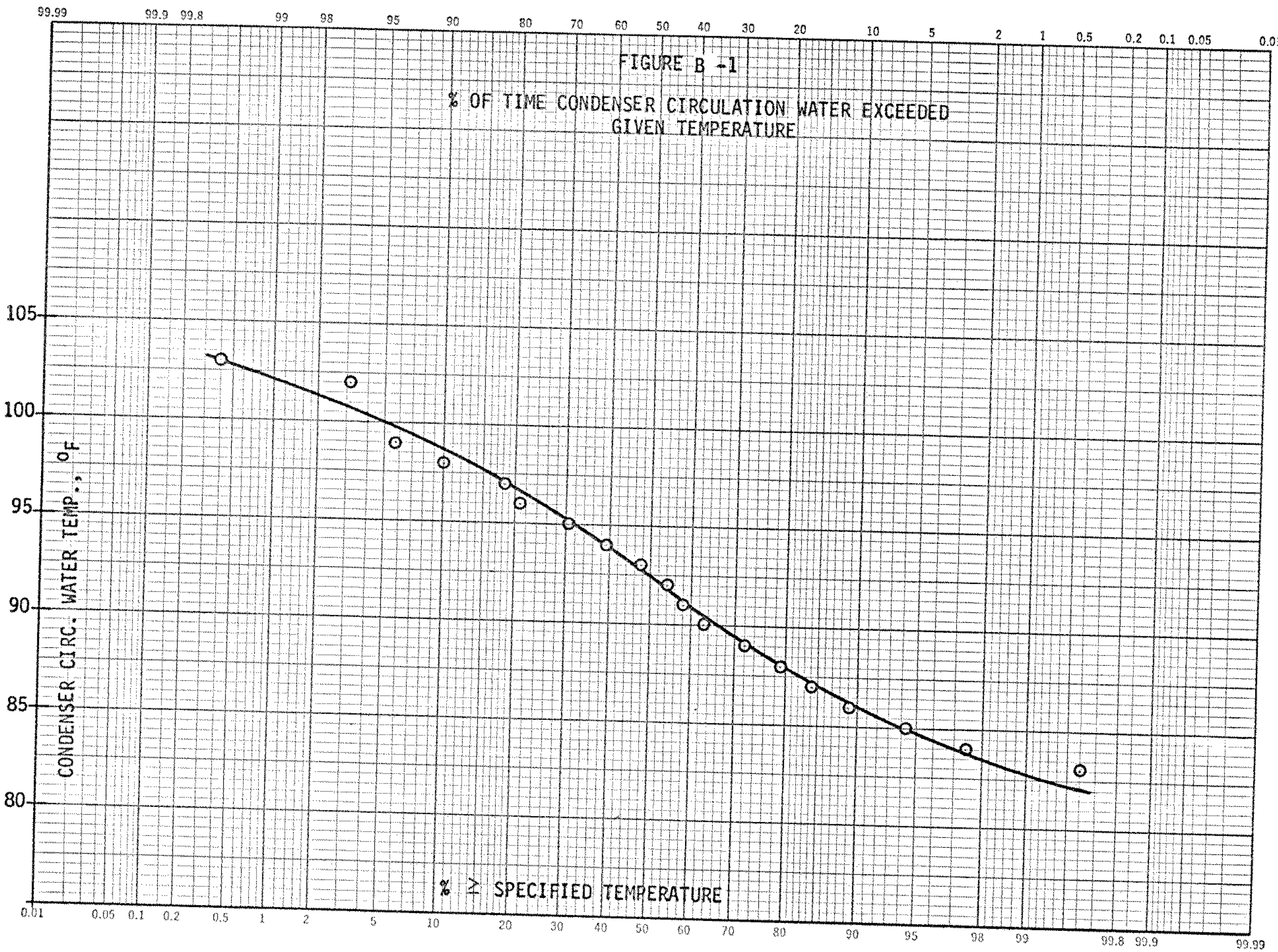


FIGURE B -1

% OF TIME CONDENSER CIRCULATION WATER EXCEEDED GIVEN TEMPERATURE the discharge line from the condenser. Therefore, it was assumed for calculation purposes that the temperature does not change in the discharge line.

The temperature variations due to natural conditions and as altered by the thermal discharge in Kiikii Stream were evaluated by the method of heat budgets discussed in EPA Project No. 16130 FDQ (Water Quality Office, Environmental Protection Agency, "Effect of Geographical Location on Cooling Pond Requirements and Performance," March 1971). In general the method is an energy budget incorporating climatological data to calculate the net or total heat exchange of a body of water consisting of 1) solar radiation, 2) atmospheric radiation, 3) back radiation, 4) evaporation, and 5) conduction. The equilibrium temperature of the body of water can be defined as that temperature at which the net effect of the five components cancels so that the total heat exchange is zero. The equilibrium temperatures as calculated were correlated to actual temperature measurements in the Paukauila Stream which receives no thermal discharge and to temperatures measured by Waialua Sugar Co. personnel in the mouth of the stream draining into Kaiaka Bay.

The method of heat budgets calculates the net, or total surface heat exchange, H_t, of a body of water as:

$$H_t = H_s + H_a + H_b + H_e + H_c$$

where H_s is the absorbed solar radiation, H_a the absorbed longwave radiation, H_b the longwave back radiation of the water body to space, H_e the heat lost by evaporation, and H_c the heat gained or lost by conduction.

Solar radiation data were gathered by the Waialua Sugar climatological station in units of gram-calories/week/cm^2. The instrument used to measure the solar radiation was a wig-wag meter, developed by the Hawaiian Sugar Planters' Association.

The longwave atmospheric radiation is a function of the variation of temperature, moisture, carbon dioxide, ozone, and other constituents of the air column over the site. The following empirical relationship was used:

$$H_a = \sigma \beta (T_a + 460)^4 (1 - \omega)$$

in which H_a is the longwave atmospheric radiation in BTU/square foot per hour, σ is the Stephan-Boltzman constant, β is a constant dependent on the height and type of cloud cover and the saturated atmospheric vapor pressure in inches Hg, T_a the air temperature in ^oF, and ω the reflectivity of the water surface, taken as 0.03. The climatological station at Waialua provided sunshine hour data and ambient temperature readings from which the cloud cover and vapor pressure were calculated.

Longwave radiation from the body of water to space is calculated as

$$H_b = -0.97 \sigma (T_w + 460)^4$$

Again, H_b is in BTU/sq. ft./hr, 0.97 the emissivity of the water surface, and T_w the temperature of the water surface in ^oF.

Evaporation is calculated from the formula

$$H_e = -CU (e_w - e_a)$$

where C is an empirical constant which depends on the size, shape, and exposure of the water body (taken as 19.5 in this study), U the wind speed in mph, e_w the saturated vapor pressure of the air at the temperature of the water surface, and e_a the vapor pressure in the air, both in inches of Hg.

Heat conducted through the water surface is calculated as

$$H_c = 0.00543 UP (T_a - T_w)$$

where P is the atmospheric pressure in inches of mercury (29.92 for Kiikii Stream).

The equilibrium temperature (stream temperature) is determined by calculating H_t, the net heat exchange from the surface. The equilibrium temperature is that temperature at which H_t equals zero.

A similar method was used to calculate the equilibrium temperature of the stream with additional heat input from the condenser cooling water discharge. A sixth and separate component, H_{input}, in BTU/sq. ft./hr. can be calculated as

$$H_{input} = \frac{\rho Q C_p}{A} (T_{cond} - T_w)$$

where ρ is the density of water in lbm/cu. ft., Q the discharge rate of cooling water in cu. ft./hr., A the area of the water surface in sq. ft., T_{cond} and T_w the condenser discharge and stream temperatures, respectively, and Cp, the specific heat of water at constant pressure.

The equilibrium temperature can be determined in the same way as for the natural condition, by trial and error.

A computer program was written to facilitate computations using iterations for equilibrium temperature. The equilibrium temperature was converged to within one degree of the previous iteration, then interpolated, and H_t recomputed to check if its value was in fact zero.

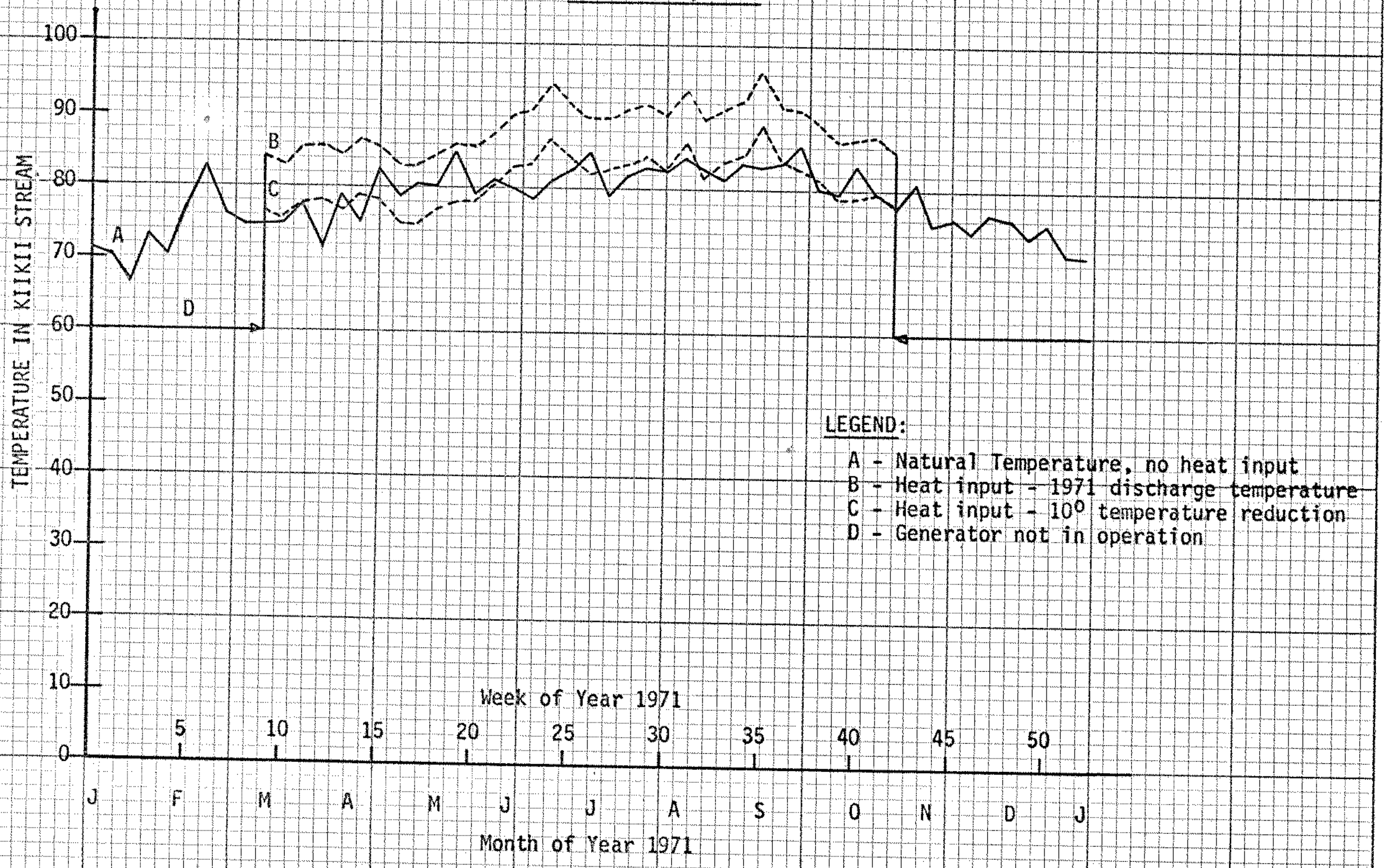
The equilibrium temperatures were correlated to actual field-measurements of temperature at the mouth of the stream and in the neighboring Paukauila Stream. The correlation was satisfactory (to ±2.0°F) considering the effects of daily variation in temperature and tidal exchange of cooler water into the stream.

Weekly climatological data for 1971 were then incorporated into the program and the equilibrium temperatures calculated for the "natural condition" with no heat input. The results are presented in Figure B-2. Similarly, the weekly average condenser cooling water temperatures for 1971 were incorporated in the program. Additionally, the effect of cooling the discharge 10°F was evaluated. These two curves are also plotted in Figure B-2.

The 1971 conditions shown in Figure B-2 show that the limiting standard of 1.5°F change from ambient was exceeded. It is also shown that if the discharge temperature had been lowered by 10°F the standard would not have been met except occasionally. The natural ambient temperature variation of such a small, shallow body of water as Kiikii Stream is

FIGURE B-2

WEEKLY EQUILIBRIUM TEMPERATURES FOR KIIKII STREAM WITH AND WITHOUT HEAT INPUT, 1971



great enough that it would be almost impossible to design a system that would consistently meet the 1.5°F limit. Furthermore, the ecosystems of small, shallow bodies of water such as Kiikii and Paukauila Streams are necessarily adapted to a wider natural temperature range and do not need the protection of the 1.5°F limitation.

Field temperature measurements were made on three occasions. The results are shown in Figures B-3 through B-7. At the time of these measurements the condenser discharge temperature was about 88°F. According to the frequency plot for 1971 (Figure B-1). the discharge temperature is greater than 88°F 80% of the time. The measurements were therefore not made under average conditions. At the time of these measurements, there was no consistent temperature stratification in either stream and the average temperature of Kiikii Stream was 86.3°F (range 79.5 to 90.7°F) while Paukauila Stream averaged 83.8°F (range 79.2 to 90.0°F). The large differences in the average temperatures between the three sampling days illustrate the natural variability to be expected in such small water bodies.

SALINITY

Field measurements with a conductivity meter were calibrated with laboratory chlorosity measurements on grab samples. The chlorosity measurements were in turn converted to salinity values by using the U.S. Oceanographic Tables. The correlations between conductivity, chlorosity, and salinity are shown in Figure B-8 and accounts for instrumental differences.

The salinity range of the condenser cooling water encountered during this study was 7.1 to 12.1 ppt, reflecting the brackish nature of the groundwater. As a result the discharge of the condenser cooling water into Kiikii Stream served to significantly lower the salinity relative to that found in the neighboring Paukauila Stream.

The results of field salinity measurements on three different days are shown in Figures B-9 through B-13. There was a consistent salinity stratification in both streams but not for temperature. The salinity

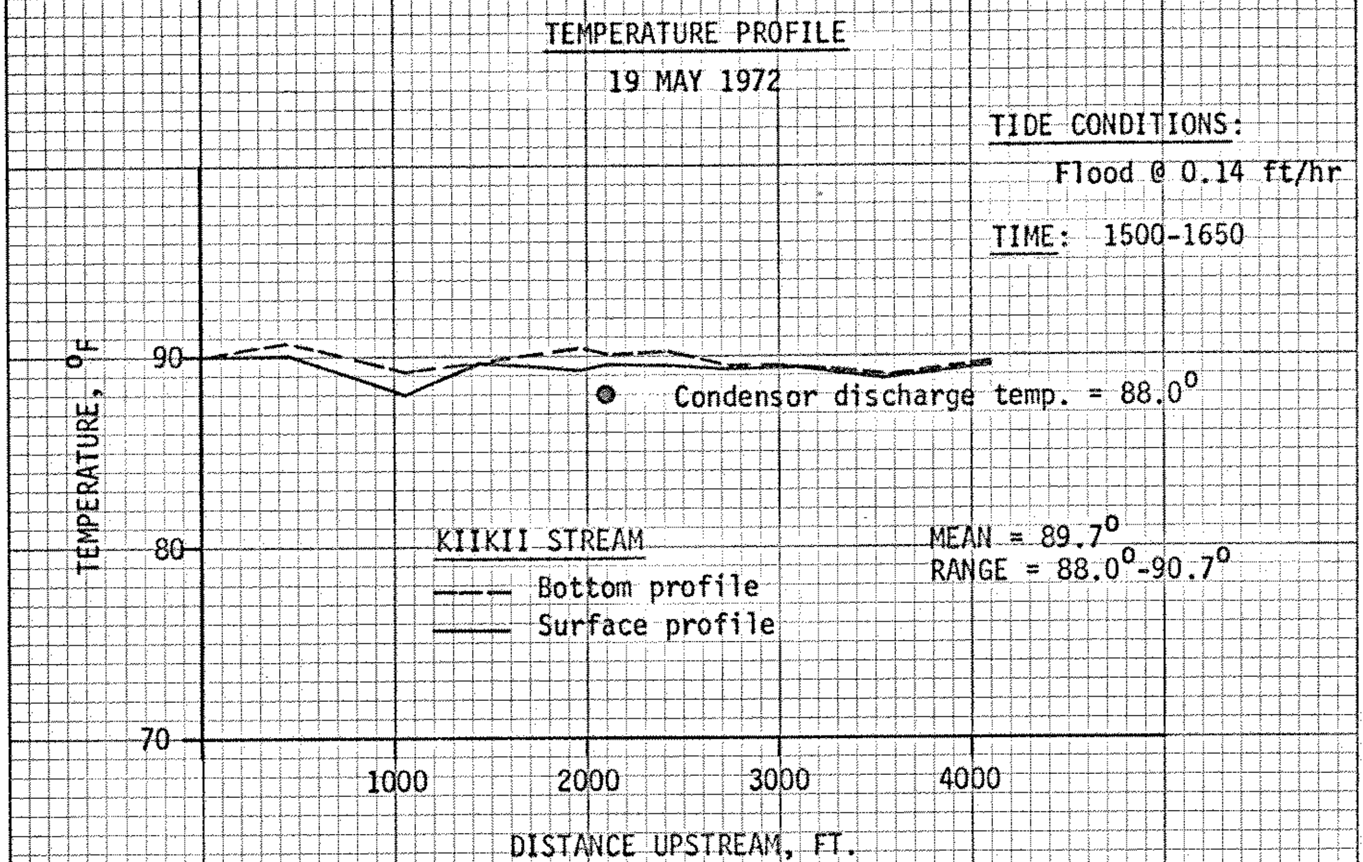


FIGURE B-3

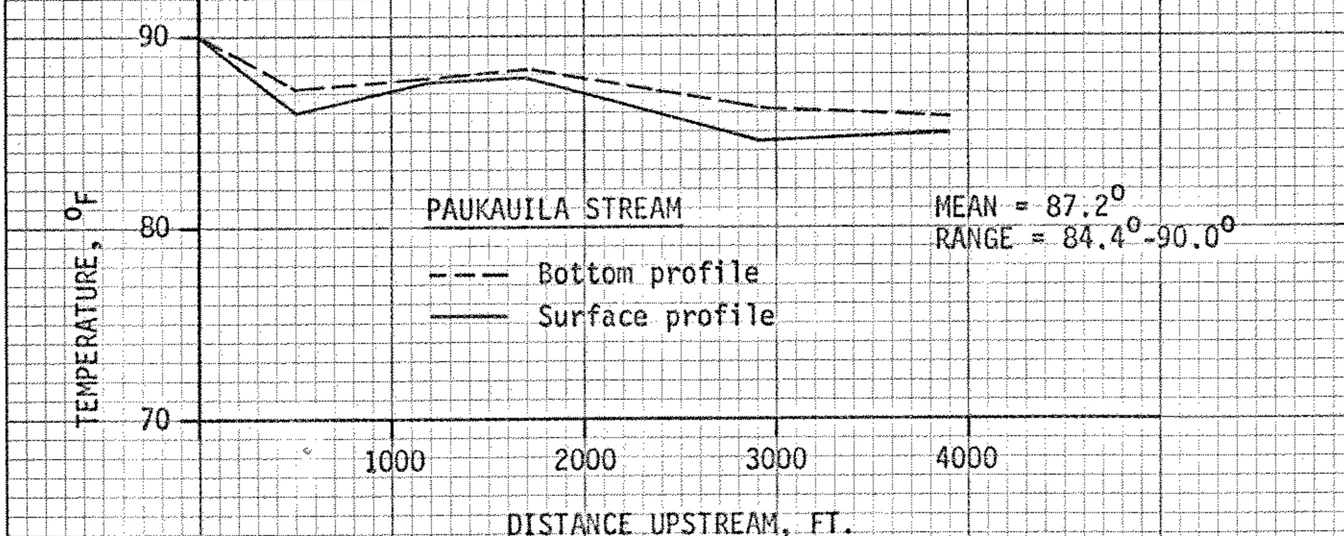


FIGURE B-4

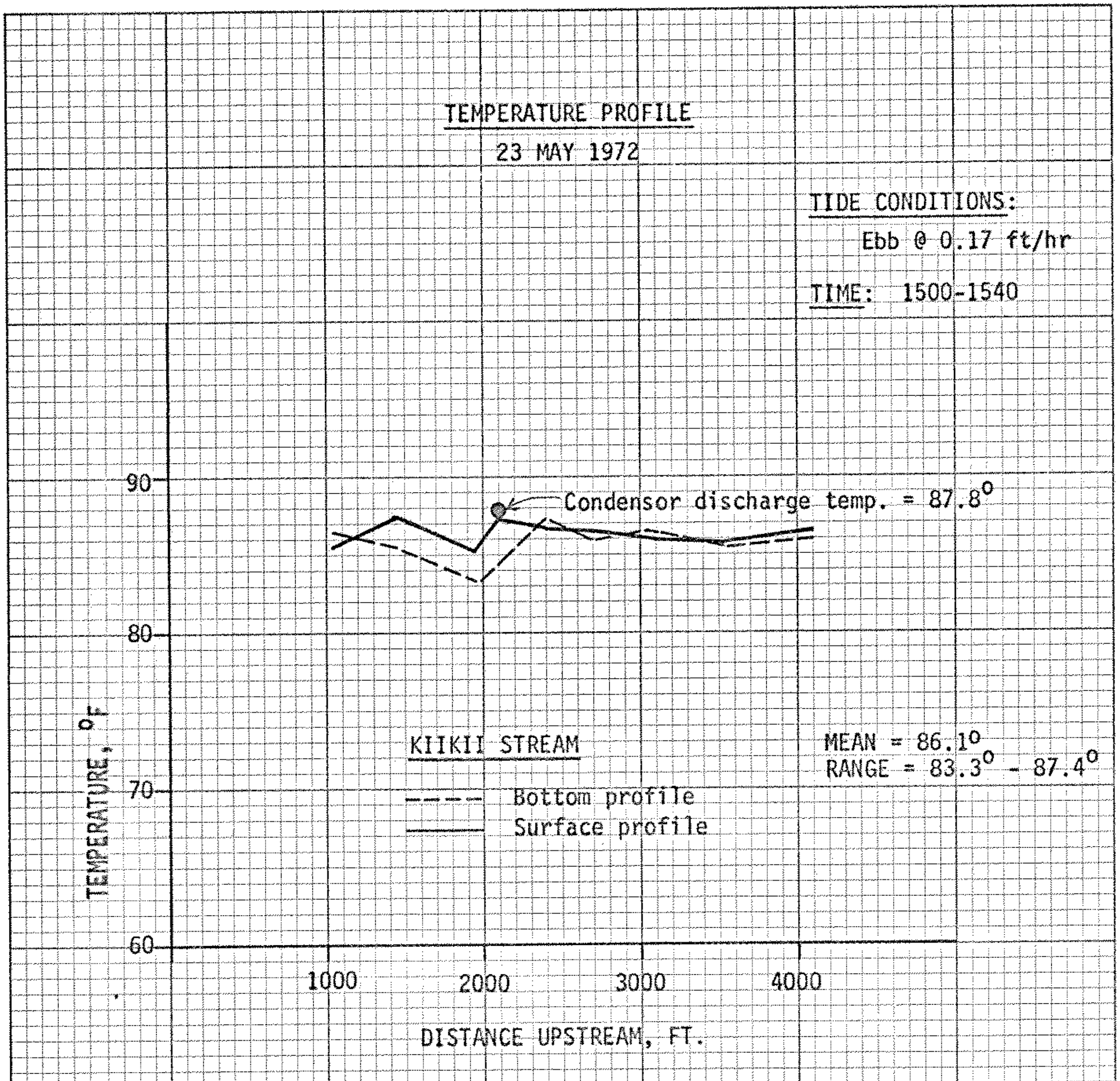


FIGURE B -5

7 X 10 INCHES
KEUFFEL & ESSER CO.
MADE IN U.S.A.

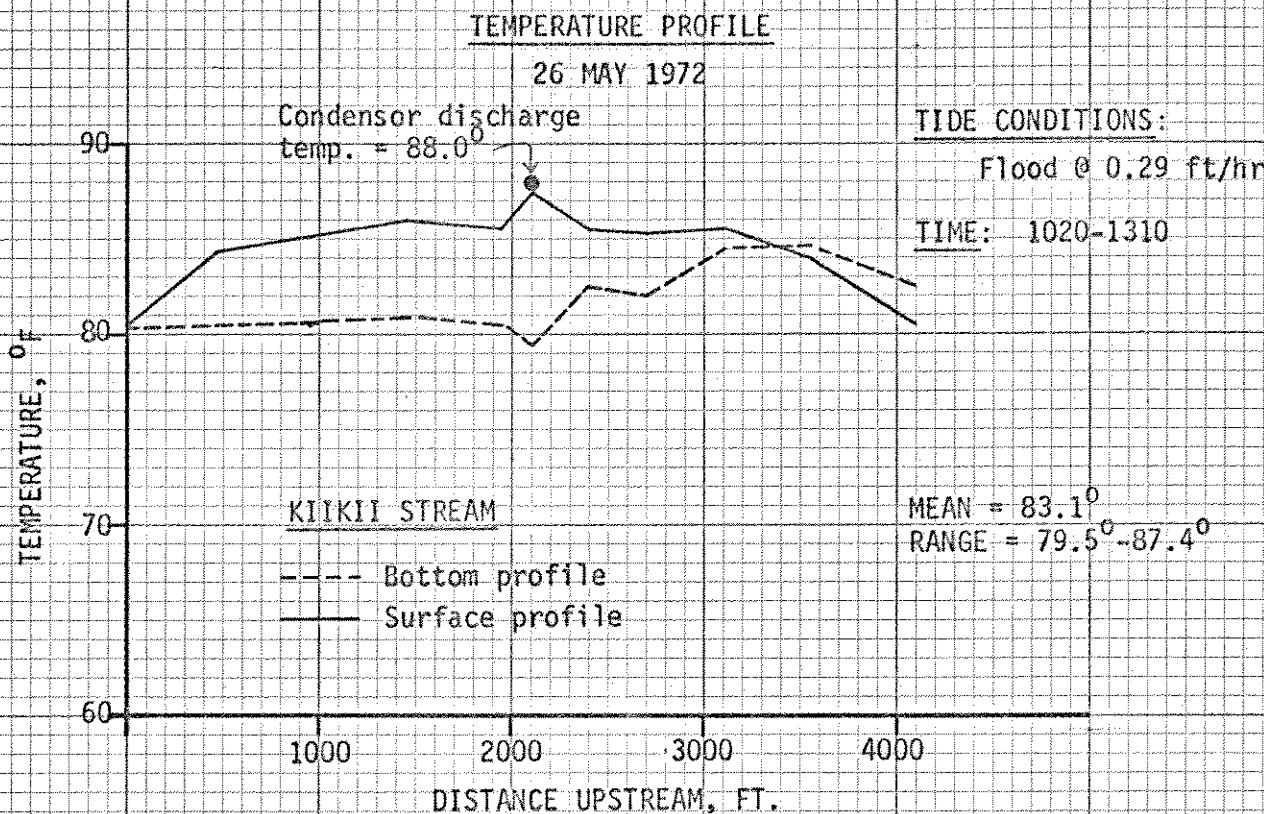


FIGURE B -6

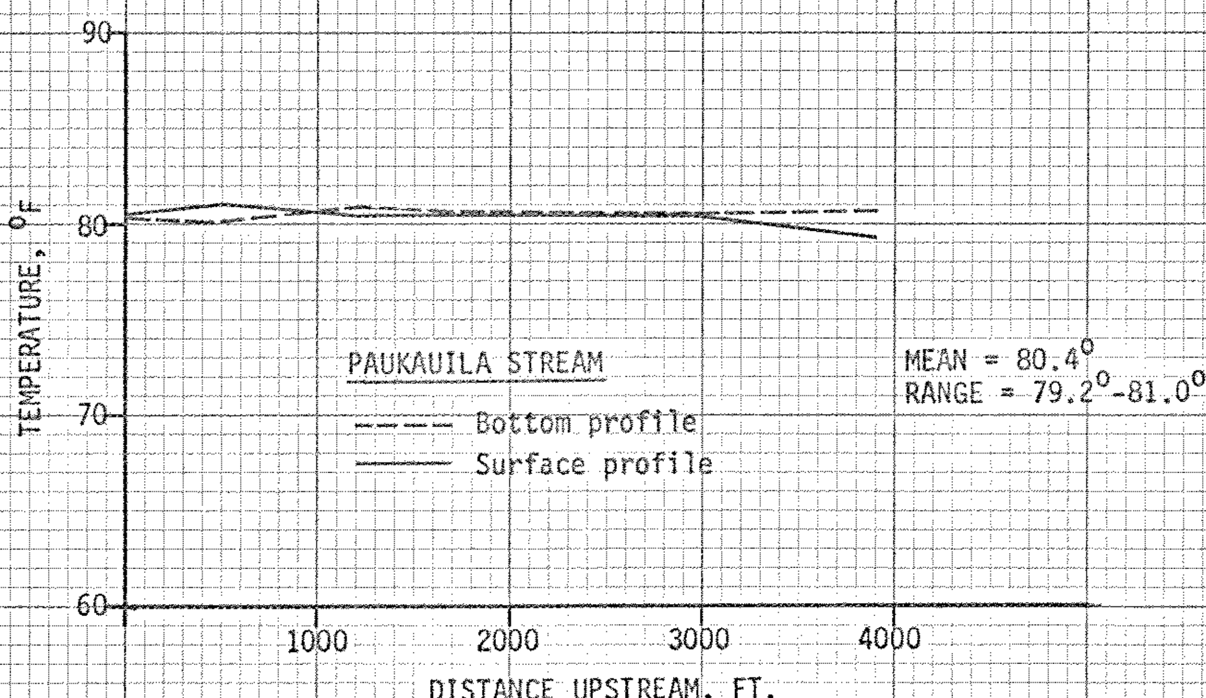
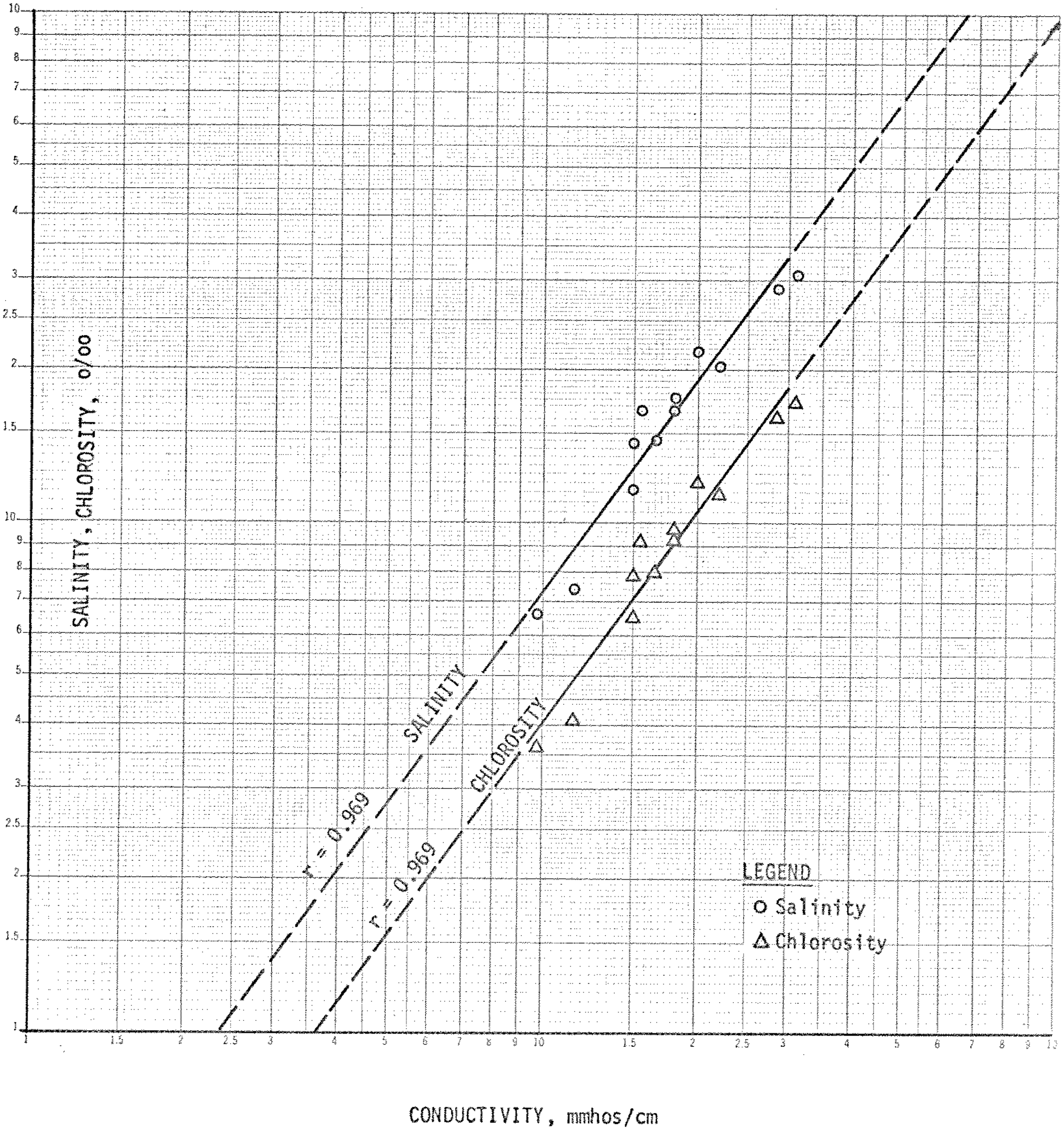


FIGURE B -7

FIGURE B-8

CHLOROSITY & SALINITY FROM CONDUCTIVITY



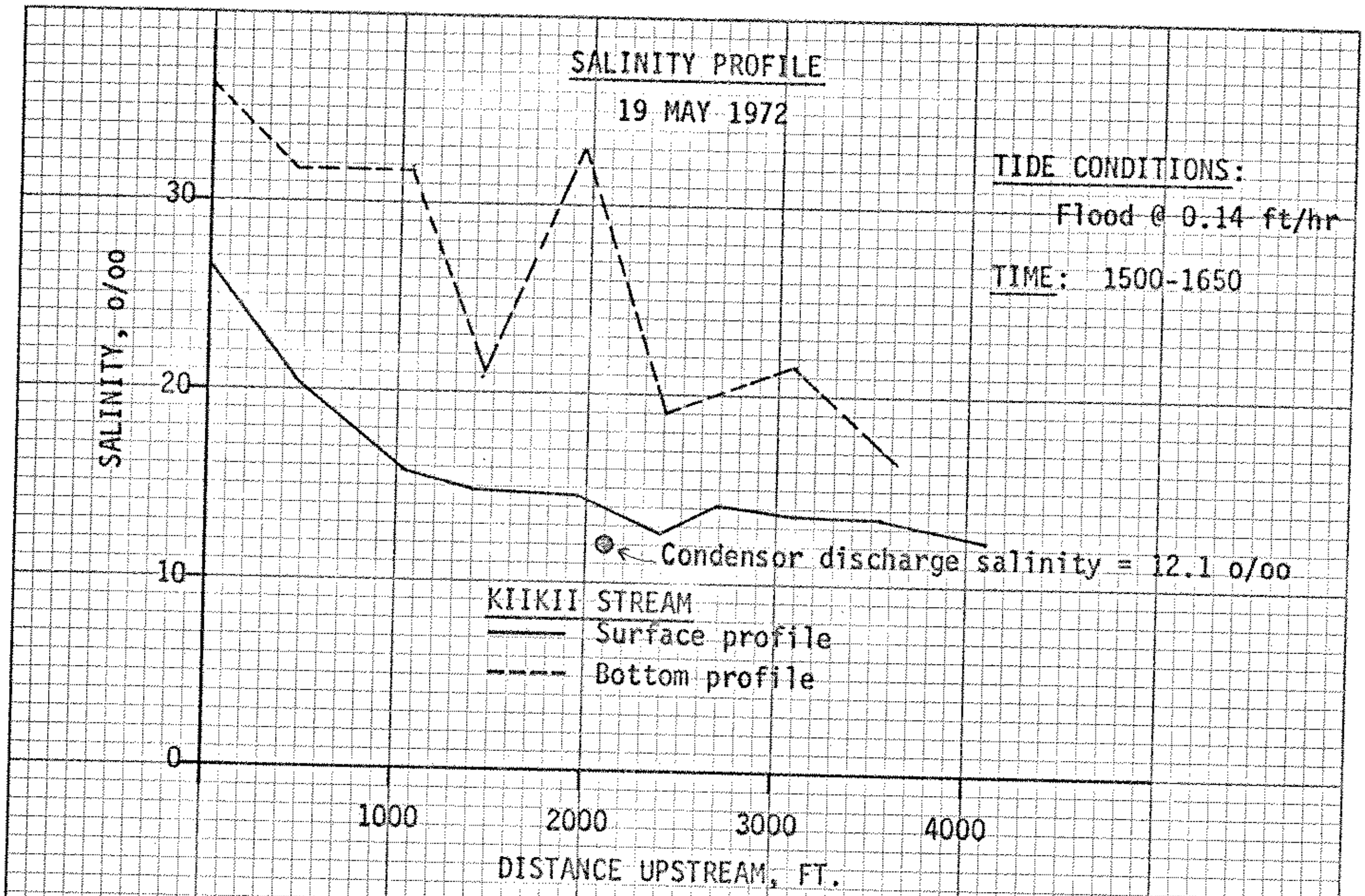


FIGURE B-9

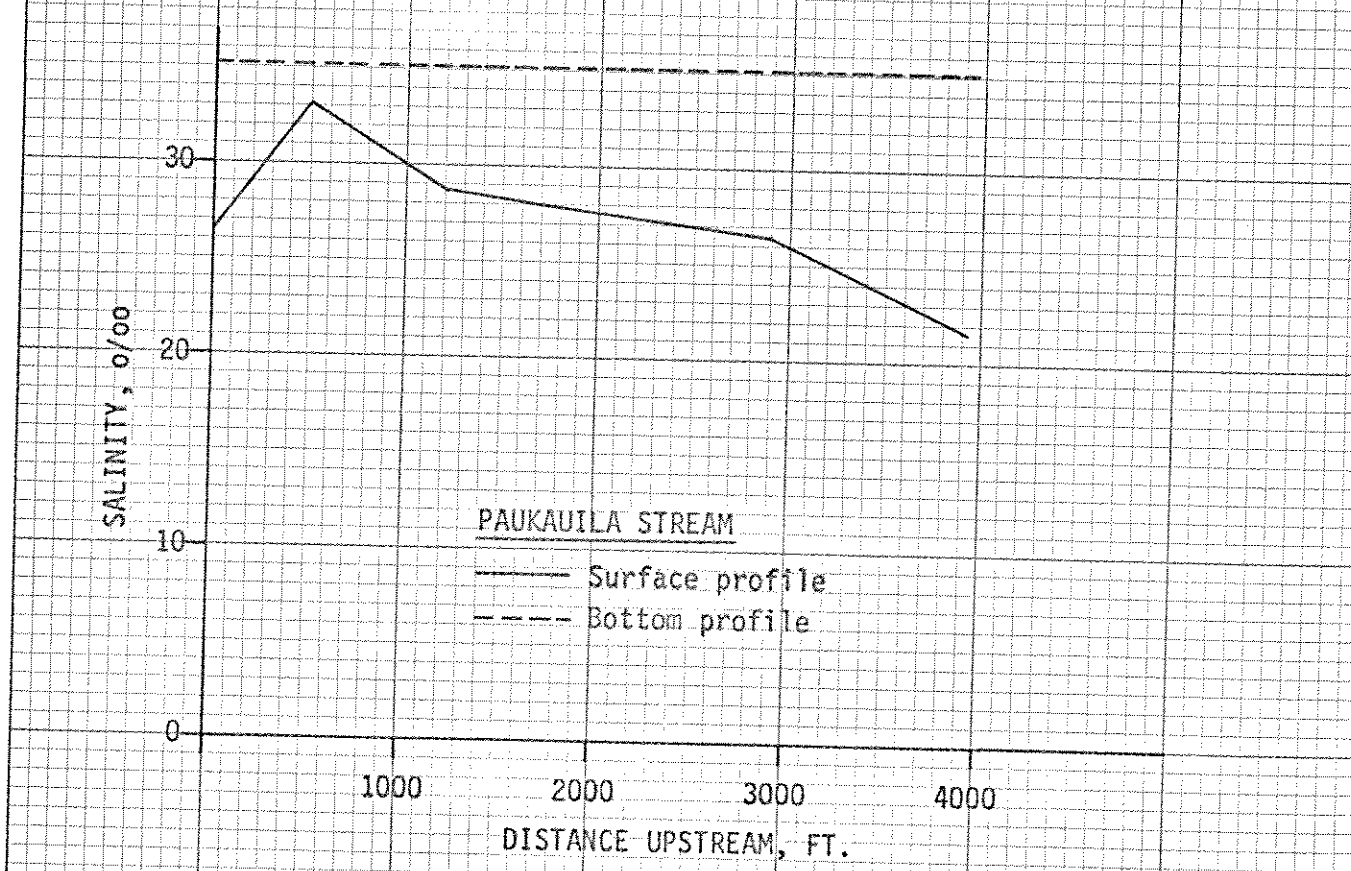


FIGURE B-10

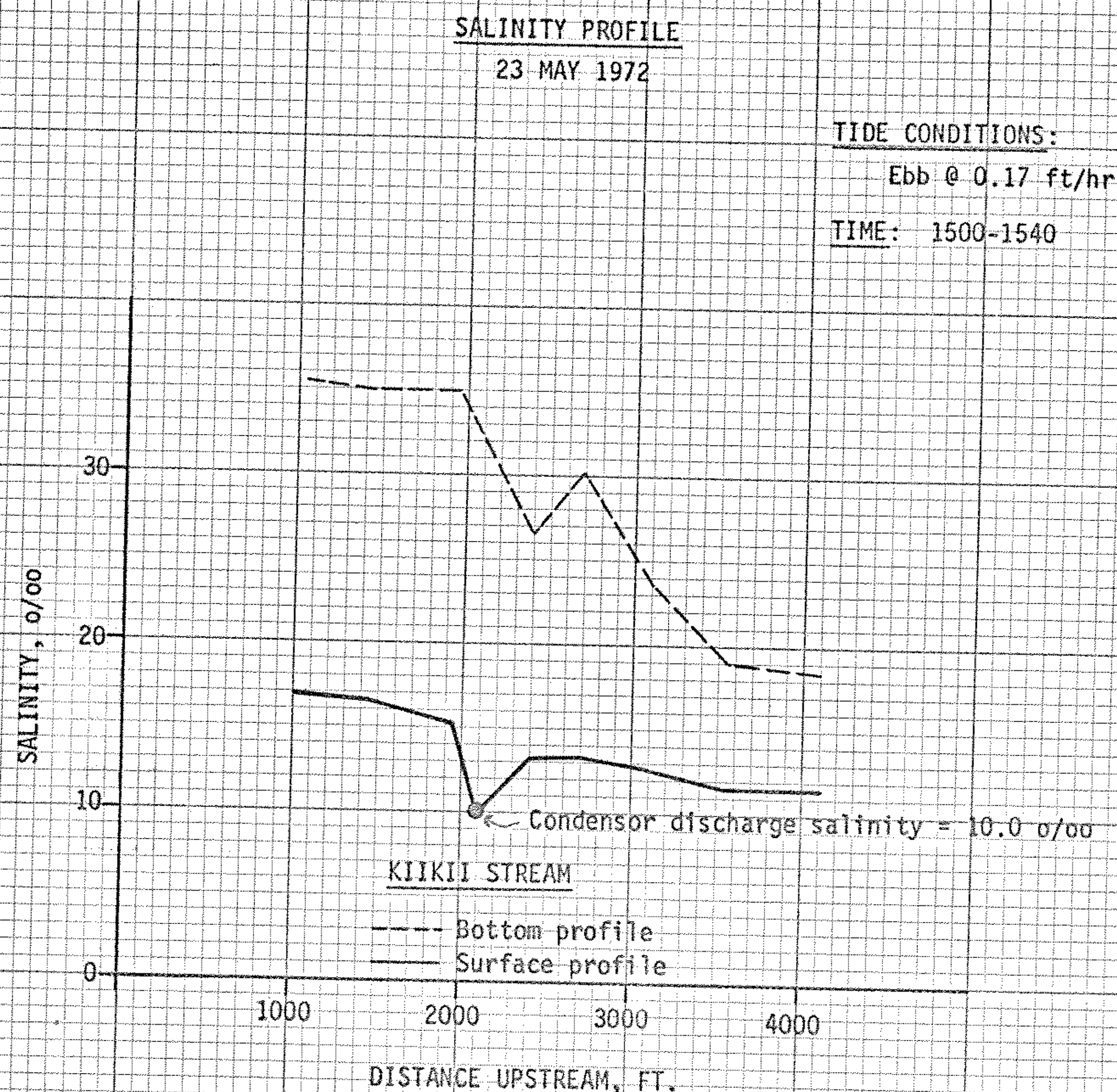

SALINITY PROFILE
23 MAY 1972
TIDE CONDITIONS:
Ebb @ 0.17 ft/hr
TIME: 1500-1540
SALINITY, o/oo
30
20
10
0
Condensor discharge salinity = 10.0 o/oo
KIIKII STREAM
Bottom profile
Surface profile
1000
2000
3000
4000
DISTANCE UPSTREAM, FT.

FIGURE B-11

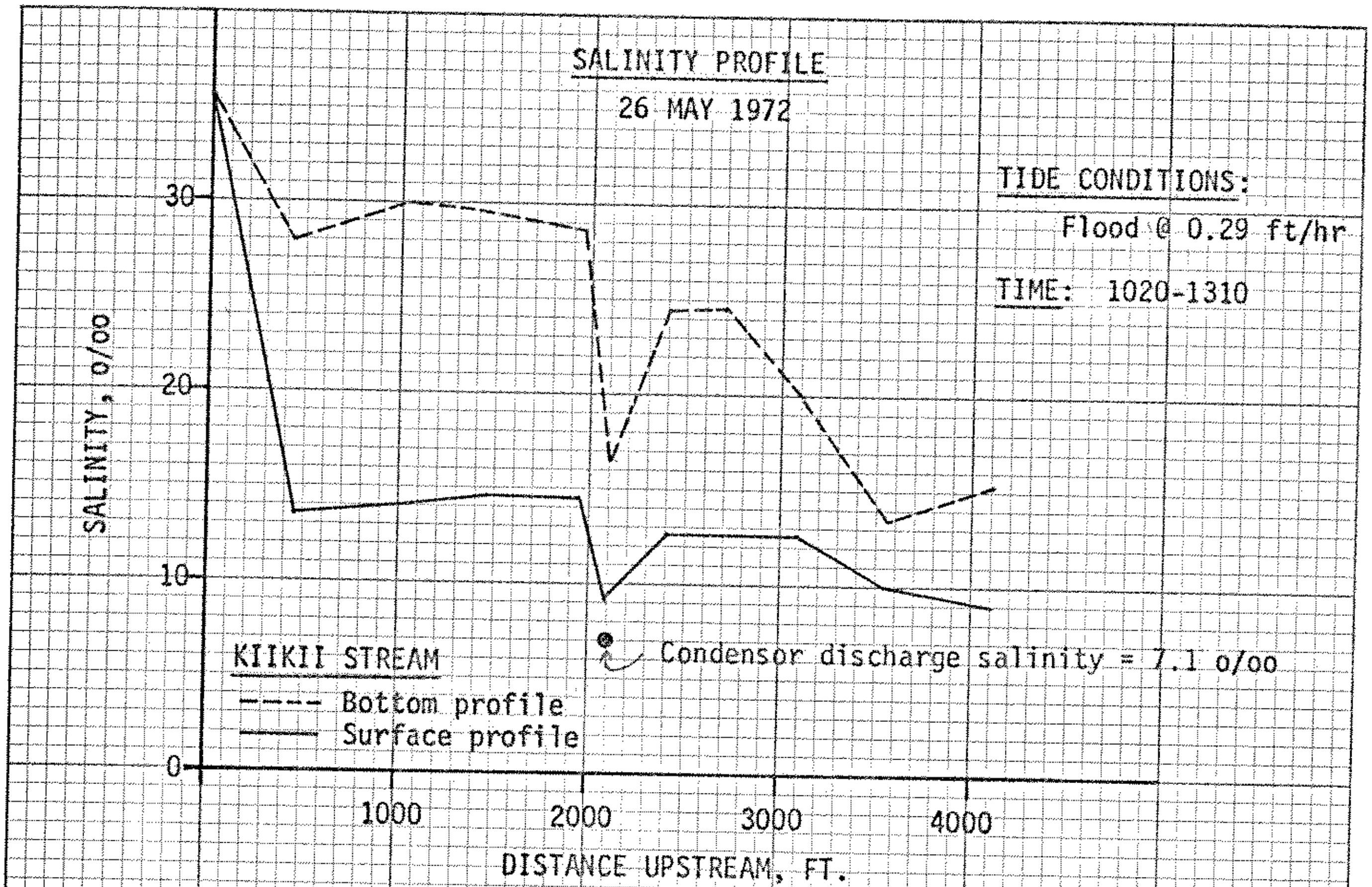


FIGURE B-12

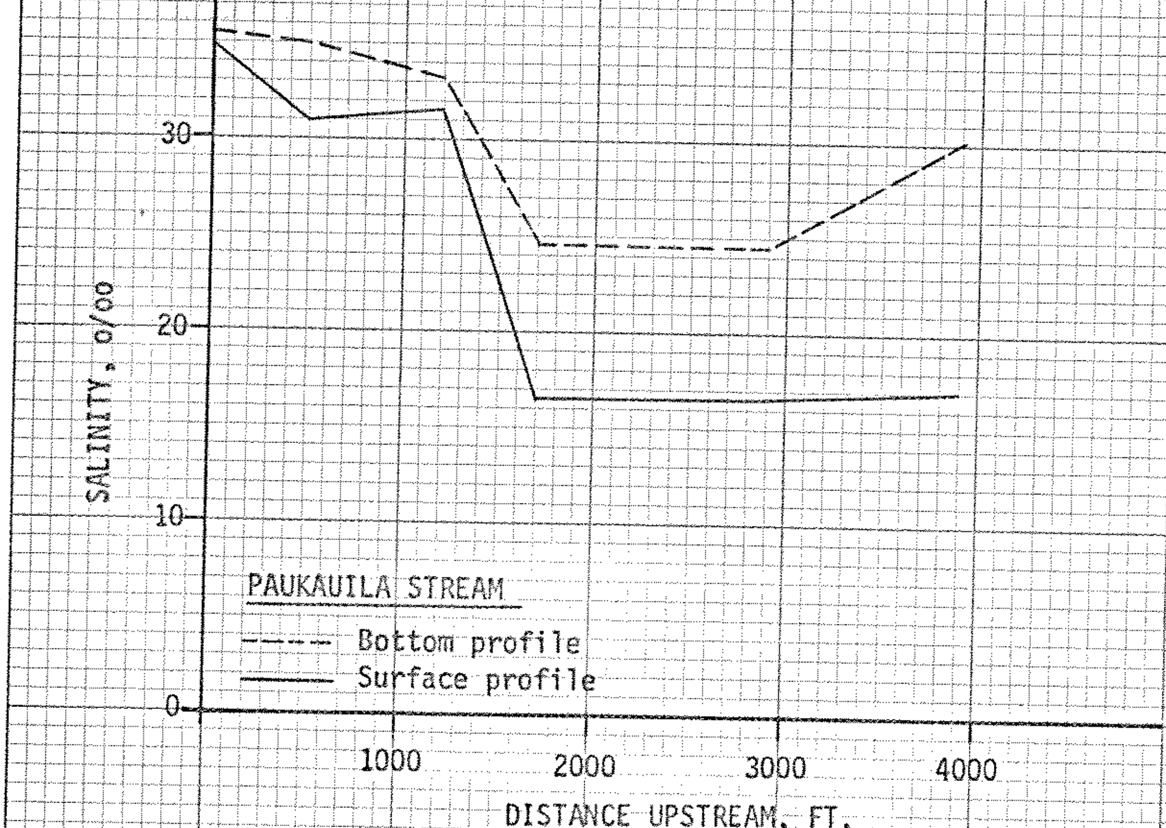


FIGURE B-13

generally decreased upstream and was significantly lower in Kiikii Stream than in Paukauila Stream.

The difference in salinity between the two streams probably has a greater ecological effect than the difference in temperature. The more estuarine character of Kiikii Stream provides a more optimum habitat for the many species of organisms that require a lower salinity during the juvenile portion of their life cycles.

DISSOLVED OXYGEN

The dissolved oxygen measurements were made on two occasions in Kiikii Stream and once in Paukauila Stream. The measurements were made during flood tide in the daytime by lowering a D.O. probe to the desired level and reading the results to the nearest 0.1 mg/l of oxygen. Figures B -14 through B-16 show that there is a dissolved oxygen gradient with depth and that the upstream surface values tended to be higher. These higher upstream values along with the generally higher D.O. concentrations in Paukauila Stream correlate with the higher chlorophyll values (discussed later) found upstream in both streams and generally in Paukauila Stream. The longer residence time in Paukauila Stream allows for the development of a higher concentration of plankton and thus higher daytime D.O. values. These same conditions probably result in a greater nighttime oxygen demand in Paukauila Stream and may be part of the reason why less fish are found in Paukauila Stream. However, two daytime bottom D.O. measurements in Kiikii Stream were below 5.0 mg/l, the generally accepted desired D.O. level for fish. The oxygen demand of the large amount of detritus on the bottoms of both streams and especially in Kiikii Stream undoubtedly results in these occasional low D.O. concentrations near the bottom.

The condenser cooling water discharge had D.O. values of 5.9 and 6.6 mg/l at the times of the two field measurements. Since the discharge has negligible oxygen demand itself, it allows for an overall more favorable D.O. condition to exist in Kiikii Stream both by adding oxygen and by reducing the mean residence time.

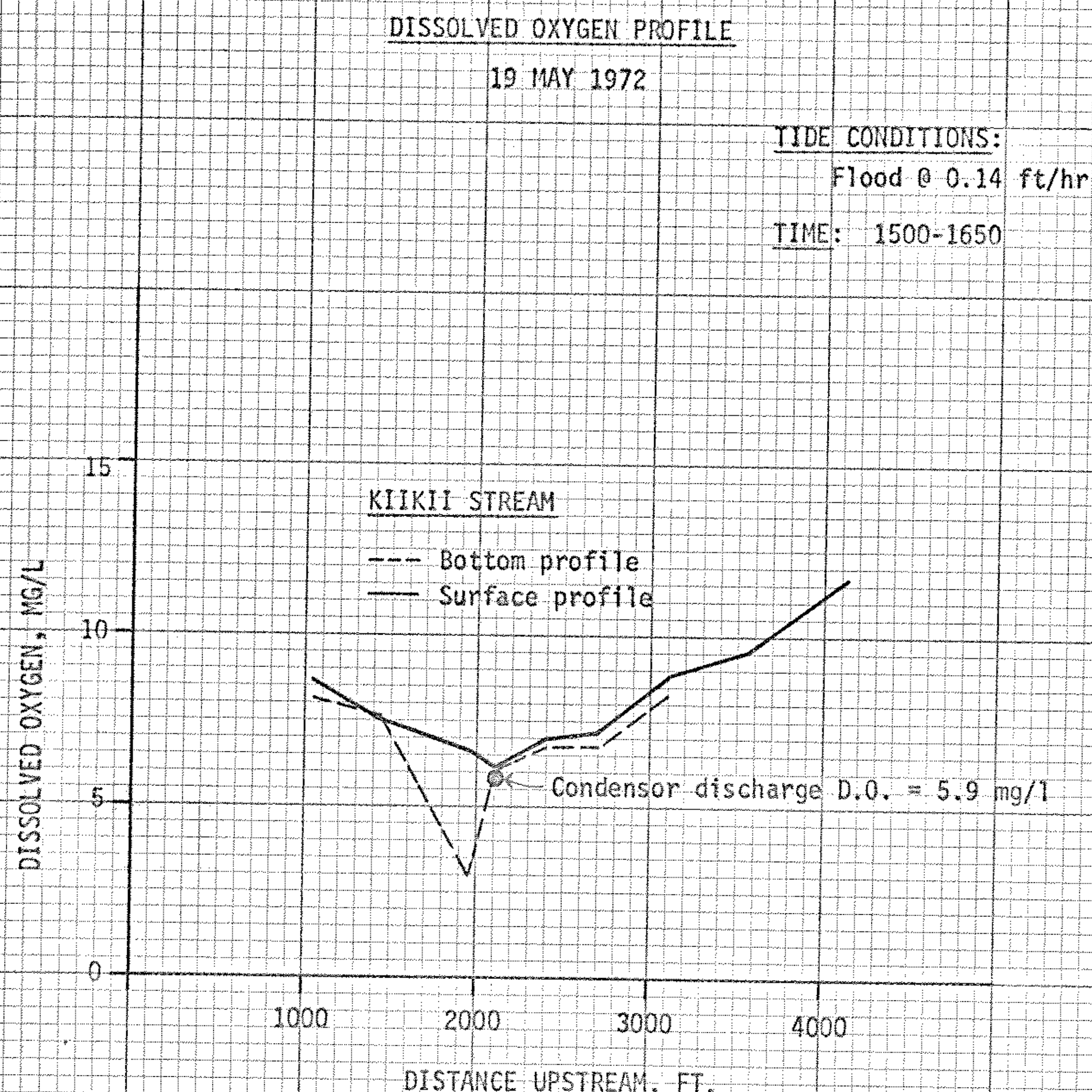

DISSOLVED OXYGEN PROFILE
19 MAY 1972
TIDE CONDITIONS:
Flood @ 0.14 ft/hr
TIME: 1500-1650
KIIKII STREAM
Bottom profile
Surface profile
Condensor discharge D.O. = 5.9 mg/l
DISSOLVED OXYGEN, MG/L
15
10
5
0
1000
2000
3000
4000
DISTANCE UPSTREAM, FT.

FIGURE B -14

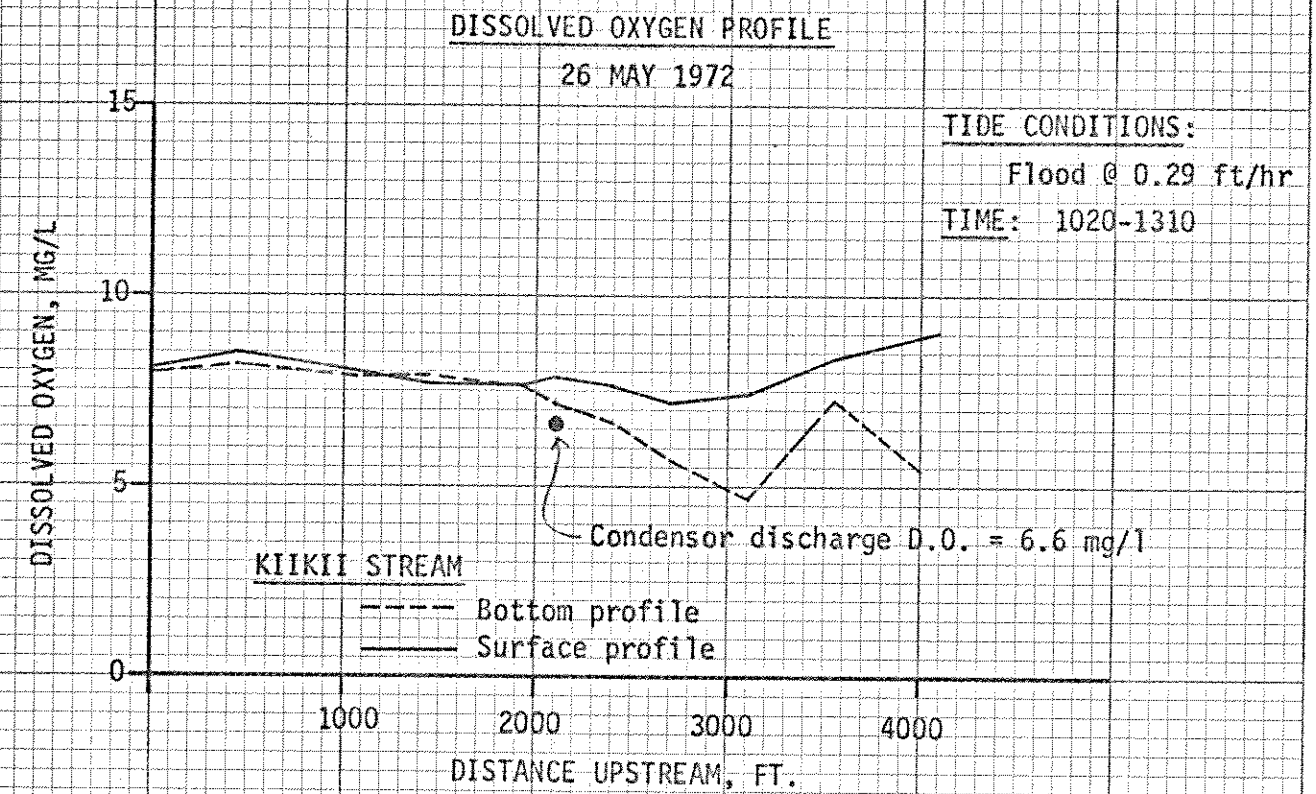


FIGURE B -15

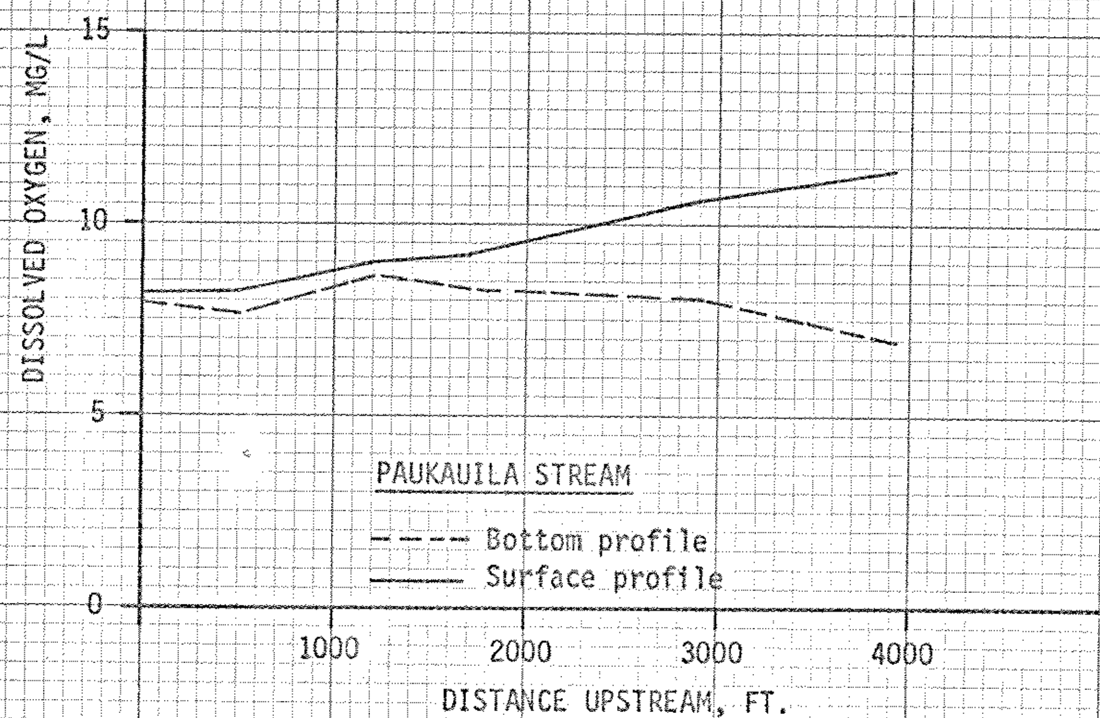


FIGURE B-16

NUTRIENTS AND CLARITY

Analysis of total Kjeldahl nitrogen, phosphorus, and turbidity were performed on one set of samples taken near the bottom at each sampling station of both streams. The results are shown in Table B -2.

TABLE B -2

TOTAL KJELDAHL NITROGEN, TOTAL PHOSPHORUS AND TURBIDITY VALUES FOR KIIKII AND PAUKAUILA STREAMS

	Kiikii		Paukauila	
	Mean	Range	Mean	Range
TKN mg/l N	.38	.25 - .54	.32	.16 - .60
Total Phosphorus mg/l P	.074	.045 - .138	.064	.032 - .095
Turbidity JTU	41	22 - 76	28	12 - 55

The values for the two streams are not significantly different. The average values for Kiikii Stream are, however, slightly but consistently higher than those for Paukauila Stream. This small difference may be due to the somewhat shallower depth and shorter residence time of Kiikii Stream which would result in greater flow velocity and a consequently greater amount of suspended material. The slightly higher nutrient values do not correlate with the lower plankton concentration in Kiikii Stream. However, the greater turbidity may result in less available light for phytoplankton development and the higher nutrient values may reflect the shorter residence time and consequent lower phytoplankton activity.

Secchi disc measurements made in the field tended to confirm the laboratory turbidity measurements in that Paukauila Stream had slightly more clarity than Kiikii Stream.

SEDIMENT CHARACTERISTICS

Eckman dredge samples were taken at each sampling station in the middle and near one edge of the stream. Samples taken near the edge were given an "A" designation after the station number. The detritus was separated from each sample and characterized. The remainder of the sample was then separated into three size categories corresponding to clay, silt, and sand.

Significant amounts of detritus were found at stations 2A, 3, 4A, 5, 5A, 9, 9A, and 10. At stations 5 and 10 nearly all of the sample was detritus. The detritus consisted of leaves, pieces of wood, berries and kukui nut shells all in various stages of decay. The somewhat greater amount of detritus in Kiikii Stream is probably a contributing factor to the lower daytime D.O. levels near the bottom noted earlier for Kiikii Stream as compared to Paukauila Stream. It may also serve as a larger food reservoir for the crab population in Kiikii Stream.

The characterization of the dredge samples without the detritus is shown in Table B-3. Kiikii Stream in general has a higher fraction of fine sediments than does Paukauila Stream. This may be due to finer sediment in the Kiikii drainage area and/or to a lower flow velocity in Kiikii Stream during times of flood.

TABLE B-3

KIIKII AND PAUKAUILA STREAM DREDGE SAMPLES CHARACTERIZATION WITH DETRITUS REMOVED

Stream	Station*	Clay % $\leq 2\mu$	Silt % $2\mu < d \leq 50\mu$	Sand % $> 50\mu$
Kiikii	1	48	40	12
	1A	40	41	19
	2	34	47	19
	2A	40	60	0
	3	35	42	23
	3A	25	46	29
	4	48	51	1
	4A	43	46	11
	5	32	54	14
	5A	56	42	2
Paukauila	6	31	41	28
	6A	35	43	22
	7	32	23	45
	7A	9	29	62
	8	14	33	55
	8A	21	55	24
	9	38	62	0
	9A	28	56	16
	10	40	49	11
	10A	32	44	24

* "A" Designation indicates sample taken near edge of stream

APPENDIX C

BIOLOGICAL ASPECTS

SAMPLING METHODS

Due to the nature of the sampling techniques, only certain portions of the faunal community were observed. For each biological sampling station, five types of nets were used, each in a different portion of the station. Crab nets were set in the center and at each side of each station, a gill net was stretched across the stream at each station, a pocket sein was swept across a portion of each side of each station, a hand-held opae net was used to sample a portion of the bank of each station, and finally a plankton net was used to sample organisms in the surface waters of each station. Organisms small enough to pass through 1/4-inch mesh, which do not inhabit the surface layers of the water, were not sampled. Estimates of the phytoplankton present were obtained by a determination of the amount of chlorophyll-a per unit volume of water.

Field sampling provided information on the distribution and abundance of the following organisms:

(1) Fishes

- *Tilapia mossambica* (Tilapia)
- *Kuhlia sandvicenis* (Aholehole)
- *Mugil cephalus* (Mullet)
- *Oxyurichthys lonchotus* (Goby)
- *Sphyraena barracuda* (Barracuda)
- *Chanos chanos* (Milkfish) (Awa)
- *Gnatholepis anjerensis* (Goby)
- *Strongylura gigantea* (Needlefish)
- *Scomberoides sancti-petri* (Lae)
- *Eleotris sandwicensis* (similar to Goby)
- *Saurida gracilis* (Lizard Fish)
- *Etrumeus micropus* (Miki Awa)
- *Stolephorus purpureus* (Nehu)
- *Ctenogobius tongarevae* (Goby)
- *Gnathanodon speciosus* (Yellow Ulua)

(2) Shrimps

Leander debilis (Opae)
Leander pacificus (Opae)
Palaemonella tenuipes (Opae)
Penaeus marginatus (Opae lolo)

(3) Crabs

Thalamita crenata (Blue claw)
Metopograpsus messor (Shore crab)
Scylla serrata (Samoan crab)
Portunus sanguinolentus (White crab)

(4) Zooplankton - Common Names

Copepods (Crustaceans)
Fish larvae
Mysids (Shrimp larvae)
Amphipods (Crustaceans)
Zoea (Crab larvae)
Polychaete worm larvae
Brachiopods (Crustaceans)
Nematods (Round worms)

Plankton

A comparison of the amount of chlorophyll-a present in the water at each sampling station suggests that the highest concentration of photosynthetic organisms inhabit the upstream areas of both the Kiikii and Paukauila Streams (Table C-1). Such concentrations may be the result of water quality parameters that include lower salinity values, higher detention times, and higher concentrations of utilizable nitrogen and phosphorus.

The chlorophyll-a concentration of the water decreases significantly with sampling stations in the downstream portions of both streams. Such decreases are partially brought about by changes in water quality, reduction in residence time, and grazing by zooplanktonic organisms. The copepods, which make up the greatest portion of the zooplankton samples,

TABLE C-1

SALINITY, CHLOROPHYLL-a, AND COPEPODS DISTRIBUTION

	Station	Salinity, o/oo	Chlorophyll-a mg/m^3	No. of Copepods/ft^3*
Kiikii	1	7.4	43.0	283,000
	2	11.7	15.2	137,000
	3	14.4	21.8	49,100
	4	14.5	21.2	6,170
	5	16.6	21.1	57,500
Paukauila	6	29.0	7.7	167,000
	7	16.7	15.1	583,000
	8	17.6	25.6	272,000
	9	20.4	76.1	213,000
	10	21.7	62.9	94,200

*Night Sample

feed directly on the phytoplankton. All of the remaining organisms present in the zooplankton samples (with the possible exception of the nematod and polychaete worms) are also known to utilize phytoplankton as an energy source. Where the concentrations of zooplankton are greatest there is generally to be expected a greater amount of chlorophyll-a present. Such a relationship appears to exist in both Kiikii and Paukauila Streams.

Zooplankton

Table C-2 shows the approximate numbers and distribution of the various zooplanktonic organisms collected at each sampling station.

It appears that of all the zooplanktonic organisms only two types, the copepods and mysid shrimps, are distributed throughout the sampling areas of both streams. Of the remaining zooplankton, fish larvae, crab larvae, amphipods, and nematod worms are more abundantly distributed in Kiikii Stream while polychaete worms and brachiopods are more abundant in Paukauila Stream.

Salinities are generally lowest in Kiikii Stream and this characteristic may strongly influence the distribution of larval fish, many of which are known to require lowered salinities during their prehatching and larval stages. Similarly, many species of adult fishes migrate into less saline waters during the breeding season where the eggs are shed and fertilized.

Larval fish, larval crabs, and amphipods all utilize phytoplankton as an energy source yet these organisms appear to be more abundant in Kiikii Stream where chlorophyll-a concentrations are somewhat less. This would again suggest that reduced salinity is important with respect to the distribution of these organisms. Conversely, copepods, Polychaetes, and branchiopods are more abundant in Paukauila Stream where chlorophyll-a concentrations and salinity values are highest.

Crabs

Figure C-1 represents the total numbers and distribution of the three species of crabs sampled at each station. The white and blue claw crabs occur in greater abundance in the downstream portions of both

TABLE C-2

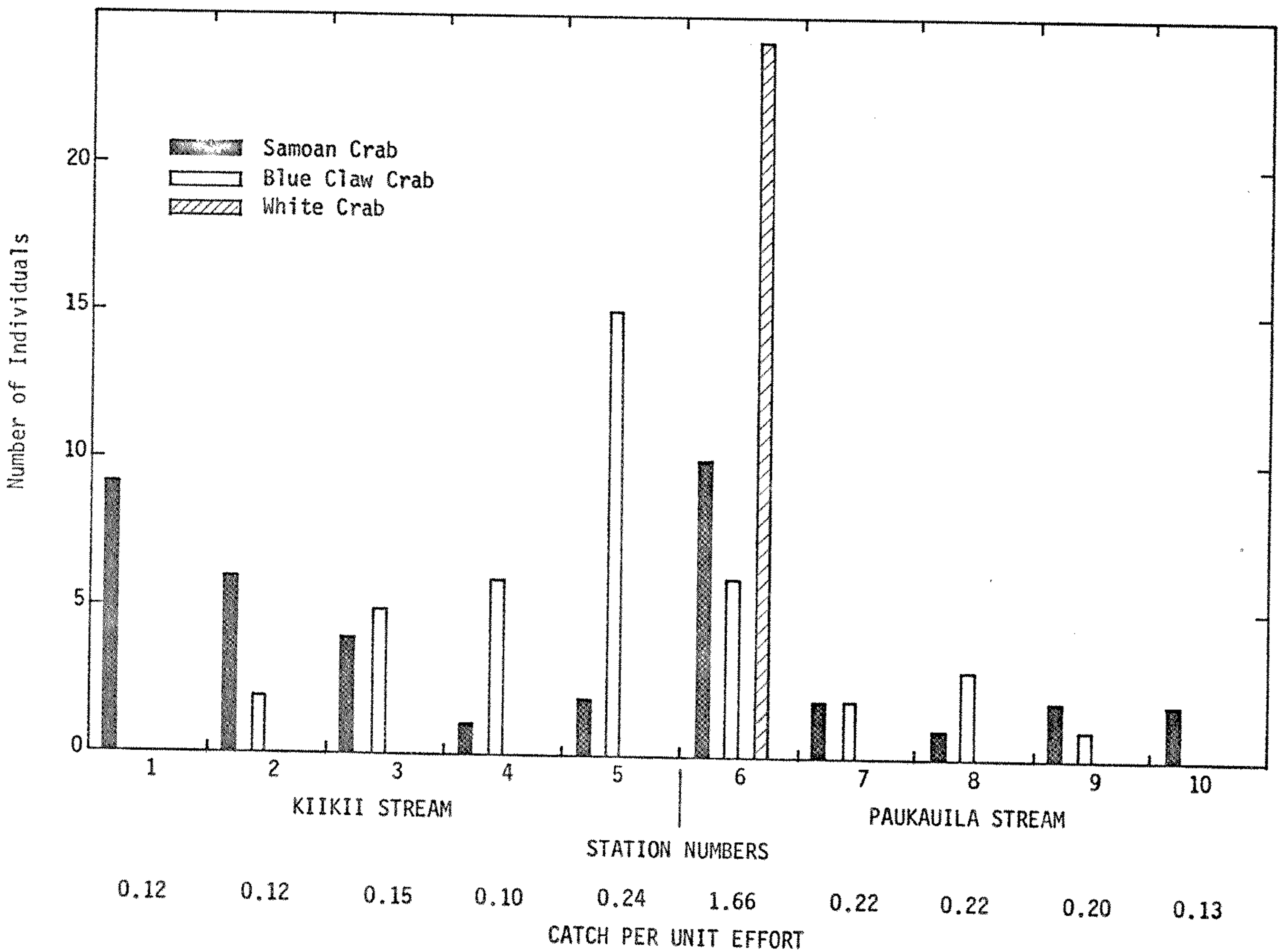
DISTRIBUTION AND ABUNDANCE OF ZOOPLANKTON (NIGHT SAMPLES)

	Station No.	TYPES AND ABUNDANCE (no./ft^3)							
		Copepods	Fish	Crabs	Shrimps	Amphipods	Polychaetes	Nematodes	Brachiopods
Kiikii	1	283,000	50	170	275	166	ND	ND	ND
	2	137,000	75	170	166	666	ND	25	ND
	3	49,100	750	25	250	250	25	ND	ND
	4	6,167	100	25	83	583	ND	42	ND
	5	57,500	25	ND	100	2,333	ND	75	ND
Paukauila	6	166,833	ND	ND	125	3,000	166	333	ND
	7	583,333	50	330	125	275	ND	ND	ND
	8	271,666	25	ND	100	25	166	ND	50
	9	213,333	ND	25	166	ND	325	ND	25
	10	94,166	ND	ND	250	ND	500	ND	125

ND = None Detected

FIGURE C-1

TOTAL NUMBERS AND DISTRIBUTION OF CRABS AT EACH STATION



streams where salinity values generally would be maintained at higher levels. The Samoan crabs appear to be less salinity dependent and are found throughout the sampling range used in this study. The results show that relatively high numbers of Samoan crabs are found in areas of lowest (7.4 0/00) and highest (29.04 0/00) salinities. This type of distribution suggests that the stream depths and substratum characteristics may be the more significant influences on the location of Samoan crabs in either streams. Both stations 1 and 6 encompass areas of stream substratum characterized by relatively large expanses of mud covered by shallow water. Samoan crabs regularly excavate burrows in the substratum which may become more or less permanent shelters. The presence of mud and clay in the substratum may have a stronger influence than salinity on distribution of Samoan crabs.

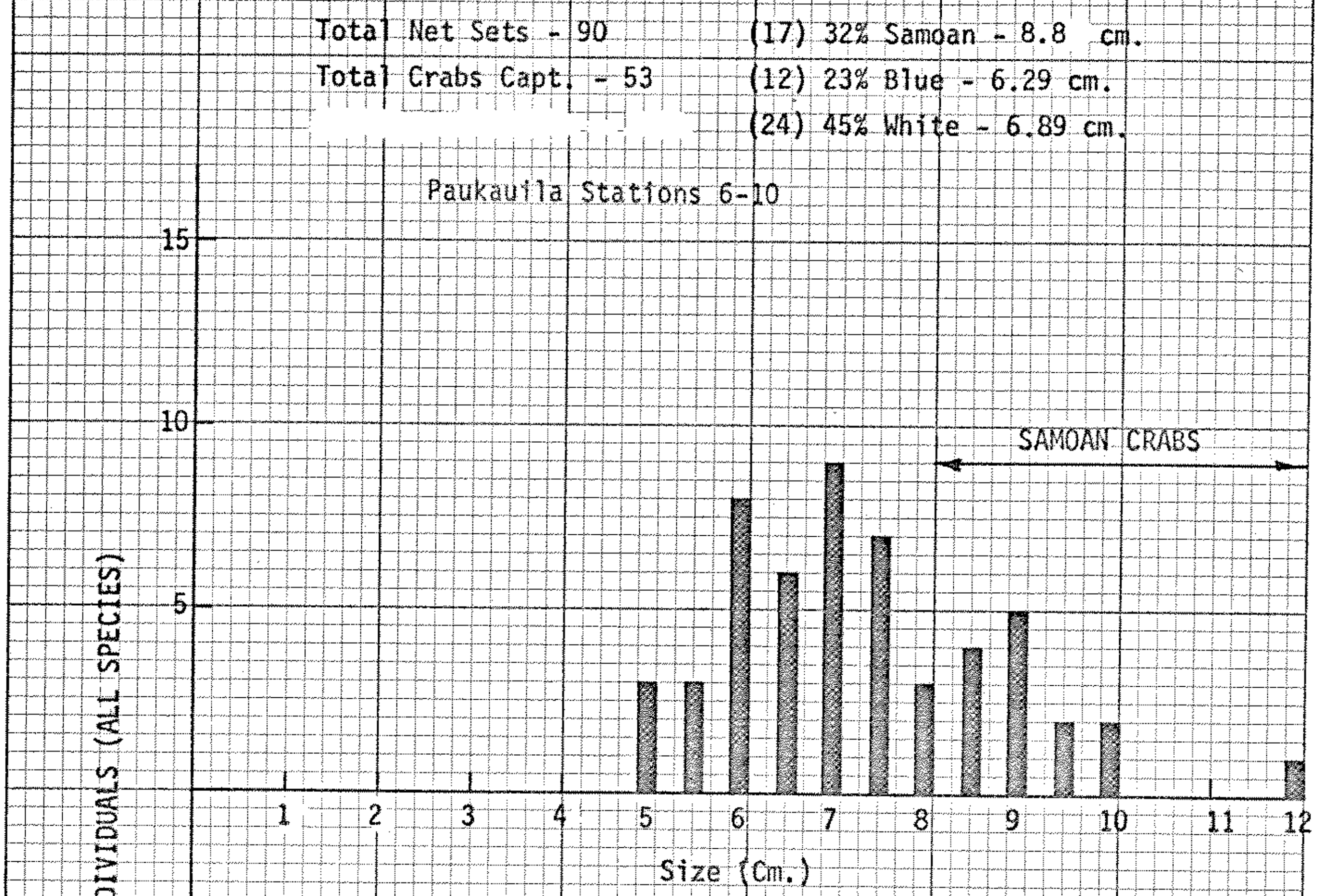
Figure C-2 summarizes the crab sizes and percent composition of the pooled samples from each station. It is interesting to note that although a similar number of crabs were captured from each stream, nearly four times (3.7) the fishing effort was expended in the Kiikii Stream. Such results may be partially explained by the increased fishing pressure on Kiikii Stream as a result of public access to its banks. Public fishing is more restricted with respect to Paukauila Stream since the banks are bordered more completely by private land and only those fishermen with small boats have access to all parts of the stream.

An estimate of the Samoan crab biomass was made for the stations of both streams using data provided by Robert W. Brick, a graduate student of the University of Hawaii at the Hawaii Institute of Marine Biology. Figure C-3 summarizes the average carapace width - crab weight relationship from which estimates of the biomass were made. Table C-3 summarizes the total Samoan crab biomass sampled at the stations and the mass of crab caught per unit effort. From the total biomass for each of the streams the arithmetic average crab weight and carapace width could be found, the latter by interpolating from Figure C-3.

Although Kiikii Stream receives the greater fishing pressure, the Samoan crabs captured there averaged 1.0 centimeters larger in carapace width than those captured in Paukauila Stream. Conversely, the blue claw

FIGURE C-2

SIZE FREQUENCY DISTRIBUTION FOR CRABS IN EACH STREAM



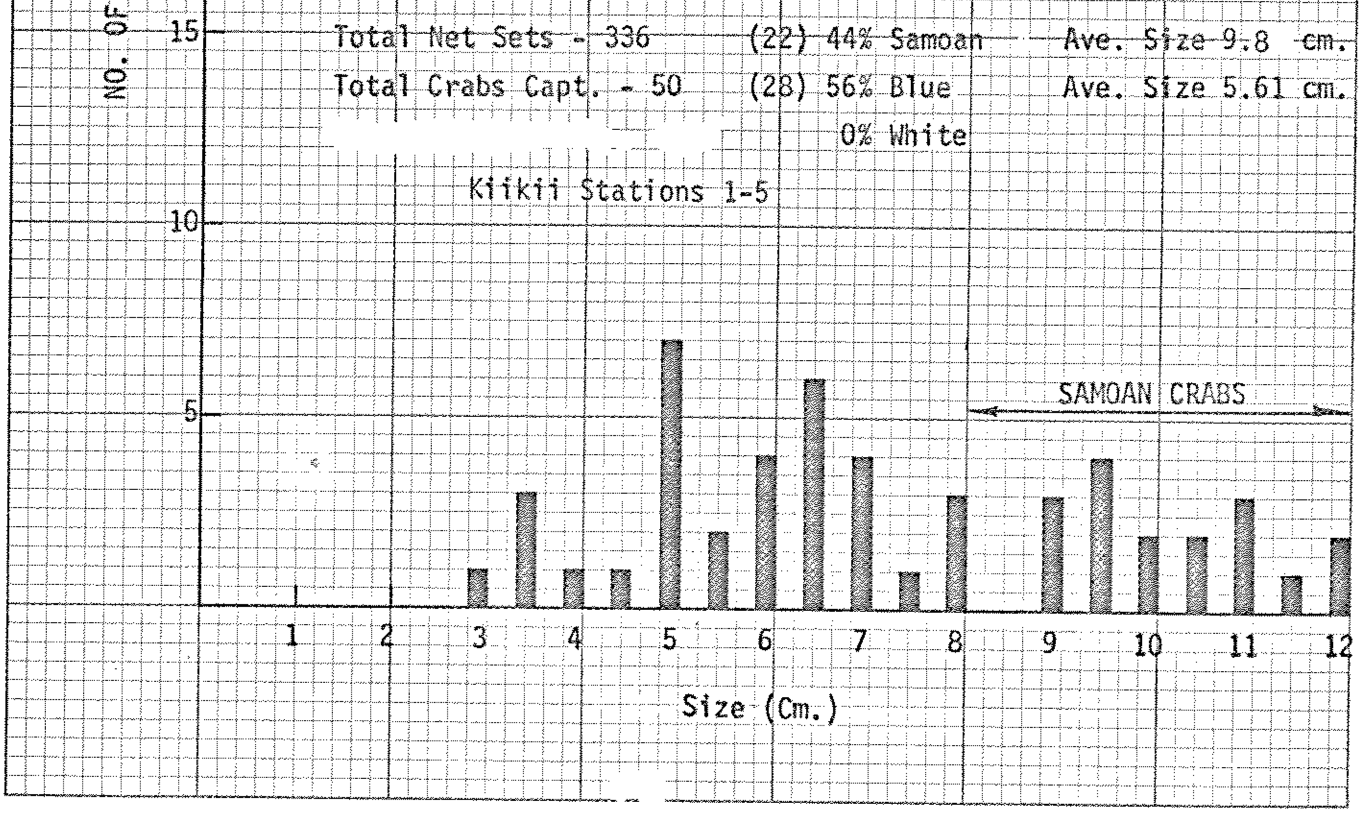
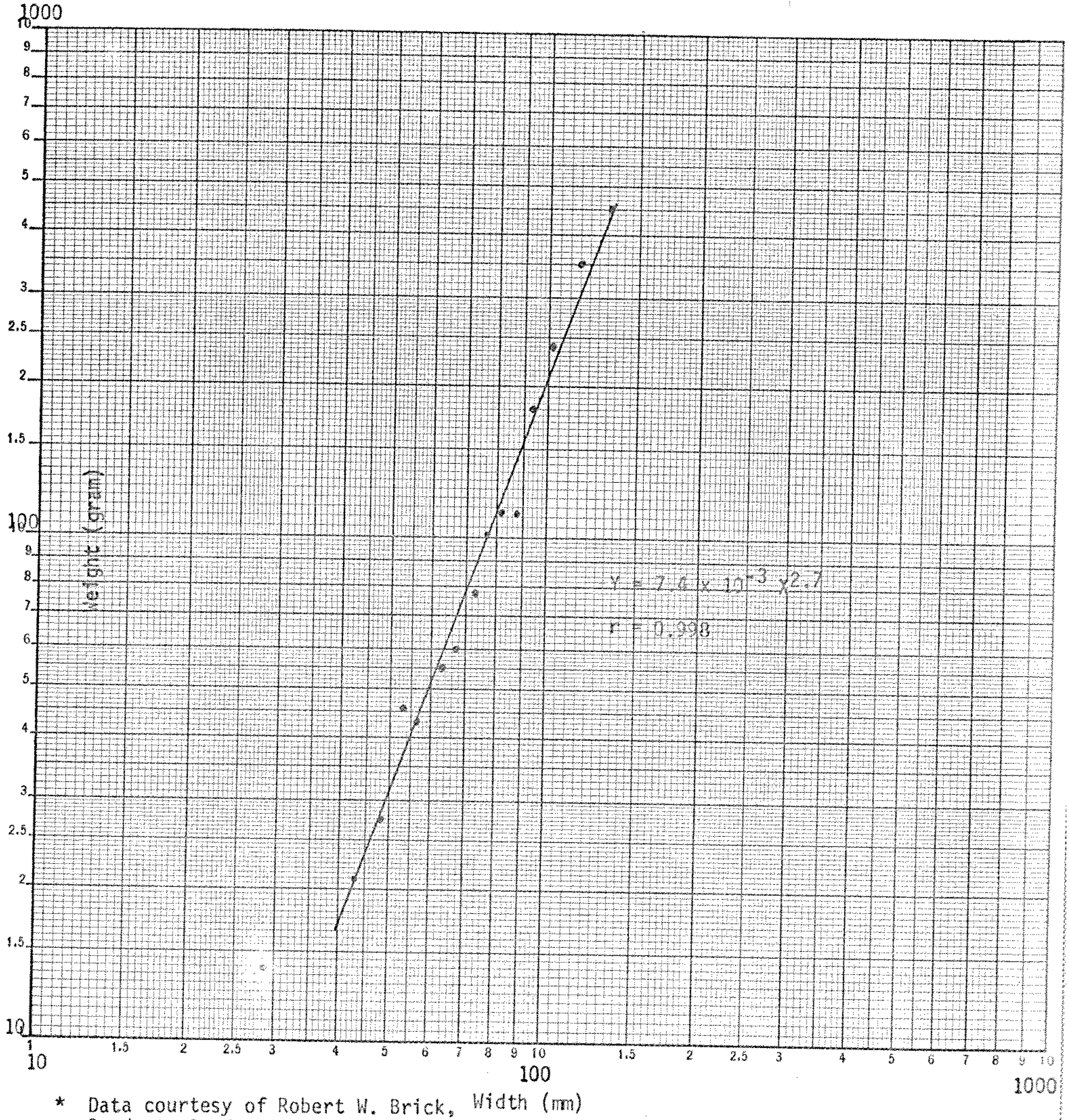


FIGURE C-3

AVERAGE WEIGHT-WIDTH RELATIONSHIP

SAMOAN CRAB*



* Data courtesy of Robert W. Brick, Graduate Student, Hawaii Institute of Marine Biology, University of Hawaii

TABLE C-3

SAMOAN CRAB BIOMASS AND WEIGHT PER UNIT EFFORT

Station	Size (cm)	No.	Wt (g)	Nets Set	g/unit effort
KIIKII					
1	11.0, 8.0, 10.0, 9.5, 7.0, 9.0, 9.5, 8.0, 10.0	9	1,482	72	20.6
2	10.5, 7.0, 9.0, 9.5, 10.5, 3.5	6	879	67	13.1
3	9.5, 9.0, 12.0, 11.0	4	925	58	15.9
4	11.0	1	270	65	4.1
5	12.0, 11.5	2	630	67	9.4
Total		22	4,181	329	Av.=12.7
PAUKAUILA					
6	12.0, 9.0, 9.5, 9.0, 9.0, 7.5, 9.0, 8.5, 10.0, 8.5	10	1,669	24	69.5
7	7.5, 8.5	2	224	18	12.4
8	7.0	1	77	18	4.3
9	7.0, 7.5	2	171	10	17.1
10	9.0, 8.5	2	280	15	18.7
Total		17	2,421	85	Av.=28.5
SUMMARY:					
Kiikii	9.8 av.		190 av.		12.7
Paukauila	8.8 av.		142 av.		28.5

crabs from Paukauila Stream show an increase in arithmetic average carapace width of 0.68 centimeters over those from Kiikii Stream. Based on the assumption that increased fishing pressure removes more Samoan crabs from Kiikii Stream, one would suspect that both the numbers and sizes of the crabs would be reduced. Such is not the case and although the numbers of crabs appear to be reduced, the sizes are not. These results suggest that the characteristics of Kiikii Stream allow for rapid growth of the Samoan crabs found there.

Kiikii Stream generally shows salinity values somewhat lower and temperatures higher than those found in Paukauila Stream as a result of discharge waters from the Waialua Sugar Mill. In certain cases an increase in water temperature above ambient of 10 to 12°F has a positive effect on the growth and breeding of many crustaceans. Generally growth rates of juvenile forms are increased, eggs develop and hatch more rapidly, larval forms settle from the plankton more rapidly, and breeding can occur more often. Increased temperature may be a stimulus for rapid growth in the Samoan crabs but does not appear to have the same effect on the blue claw crabs. More likely, a combination of factors including temperature, salinity, and substratum characteristics provide a more optimum habitat for the Samoan crab in Kiikii Stream as opposed to Paukauila Stream. The converse appears to be true for the blue claw and white crabs, with the more optimum habitat conditions occurring in Paukauila Stream.

Fish

Table C-4 shows the abundance and distribution of the various species of fishes sampled by gill, pocket, and opae netting. It is apparent that the greatest concentrations of aholehole, mullet, gobies, and tilapia are found in the upstream portions of Kiikii Stream.

Fishes such as the aholehole and mullet are very commonly observed in areas of decreased salinity but are also capable of surviving in normal sea water. The goby, Oxyurichthys, is an estuarine species and is found, throughout its life history, in waters of low salinity. Tilapia inhabit fresh waters as well as estuarine waters, but generally they do not enter normal sea water for any extended length of time. The remaining

TABLE C-4

DISTRIBUTION AND ABUNDANCE OF FISH

	Station Number	Types and Abundance														
		Kuhlia	*Mugil*	*Oxyurichthys*	*Sphyraena*	*Chanos*	*Gnatholepis*	*Tilapia*	*Strongylura*	*Eleotris*	*Saurida*	*Etrumeus*	*Stolephorus*	*Ctenogobius*	*Scomberoides*	*Ginathanodon*
Kiikii	1	183	50	240	1	1	6	27	ND	ND	ND	ND	ND	1	ND	ND
	2	3	4	101	4	ND	1	306	ND	ND	ND	ND	ND	ND	ND	ND
	3	ND	1	125	2	3	ND	1	ND	ND	ND	4	ND	1	ND	ND
	4	4	ND	4	4	ND	ND	ND	ND	1	ND	ND	ND	ND	ND	ND
	5	23	1	1	ND	1	ND	ND	1	ND	1	3	ND	ND	2	ND
Paukauila	6	ND	ND	15	3	5	ND	3	ND	ND	ND	ND	ND	4	1	ND
	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
	8	ND	1	ND	ND	ND	ND	3	ND	ND	ND	ND	ND	ND	ND	ND
	9	ND	1	ND	ND	ND	ND	2	ND	ND	ND	ND	8	ND	ND	ND
	10	ND	ND	ND	1	ND	ND	54	ND	ND	ND	ND	ND	ND	ND	ND

ND = None Detected

species of fishes sampled were not in concentrations equal to the fishes previously mentioned. These fishes (barracuda, awa, miki awa, nehu, etc.) may represent forms that only occasionally enter estuarine waters where feeding and/or reproductive processes are completed.

The salinity values in Kiikii Stream are consistently lower than those measured in Paukauila Stream. It appears that this characteristic has a greater influence on the abundance and distribution of fishes than does either the phytoplankton or the zooplankton densities. Although Paukauila Stream apparently has the higher concentrations of available energy (phytoplankton and zooplankton) it does not show the abundance or numbers of species of fishes found in the less saline waters of Kiikii Stream.

APPENDIX D

ALTERNATIVE PROCESSES

There are several methods available for the cooling or disposing of a thermal effluent. The existing method of direct discharge into the receiving water is the most economical and should be acceptable if there are no known detrimental effects on the receiving water. The Waialua Sugar Company has already tried to inject the condenser cooling water back into the ground, but the infiltration rates were found to be too low to make this method of disposal a viable alternative. Injection was therefore not considered further. Further, had such an alternative succeeded, the ecological impact of decreasing the discharge would be appreciable and less desirable. Several other alternatives were evaluated with respect to both the economical cost and the ecological effect on Kiikii Stream. These alternatives include; cooling towers, cooling ponds, spray ponds, and dilution prior to discharge.

COOLING TOWERS

A cooling tower is a tower filled with any of a number of materials in various configurations designed to maximize the exposure of the water to the air. The water is pumped to the top of the tower and allowed to trickle down and be cooled by evaporation. The air supply may be forced, induced, or natural draft and it may be cross- or counter-current. For the situation in question the most economical cooling tower installation was judged to be two towers using an induced cross-current draft of the centrifugal type. The capital cost for these towers was submitted by the American Equipment Co. to be $75,000. Installation cost is estimated at $30,000; a 10,000 gpm, 40' TDH, 125 HP pump at $12,000; and pump installation at $4,000 for a total capital cost of $121,000.

Annual costs are as follows:

Capital Cost	$121,000
Contingencies @ 20%	24,000
	$145,200

Amortization @ 8% for 20 years (.10185)	$14,800
Power for pump @ $0.010/Kw-hr. (220 operating days)	5,500
Operation and Maintenance	3,000
TOTAL COST FOR COOLING TOWERS	$23,300/year

The cooling tower effluent would be more saline and of course cooler than the present discharge. The exact effect that such a change in effluent characteristics would have on Kiikii Stream is difficult to predict. However, it is reasonable to believe that the slightly lower temperature would result in a lower metabolic rate of the present organisms and would probably result in a somewhat different balance among them with the possibility of the addition or elimination of some species. Since the existing situation is good for the beneficial uses of the stream, there should be no need to change the input since the results of such a change cannot be accurately predicted.

COOLING PONDS

Cooling ponds are essentially large holding ponds that allow cooling through evaporation. They may be mixed or flow-through. Using meteorological, temperature, and flow data in a flow-through pond, it was determined that a 50-acre pond was required. The calculation method used was that outlined by the Water Quality Office of the Environmental Protection Agency in their publication "A Survey of Alternate Methods for Cooling Condenser Discharge Water, Large-Scale Heat Rejection Equipment," Project No. 16130 DHS, July 1969.

The capital cost for a 50-acre cooling pond is due to the construction of a perimeter compacted berm 4 feet high, 8 feet wide at the top with side slopes of 3:1 and internal baffles. At $4/cu. yd. the cost of the perimeter berm is about $70,000. The cost of flow guides inside the pond to minimize short-circuiting and insure the flow-through (plug flow) character on which the design is based is estimated to be $160,000.

The annual costs would be the following:

Capital Cost	$230,000	
Contingencies @ 20%	46,000	
	$276,000	
Amortization @ 8% for 20 years		$28,000
Loss of Cane Profit @ $900/acre		45,000
TOTAL COST FOR COOLING POND		$73,000/year

The comments regarding the effects on Kiikii Stream as a result of the use of a cooling pond are the same as those noted above for the cooling tower effluent.

SPRAY POND

Using the design criteria of 20 gal/hour/sq. ft. for 70°F wet bulb temperature and 95°F condenser discharge temperature, a 1 acre (0.7 acres effective area) spray pond was decided upon. The cost for piping and appurtenances (quotations from local dealers) would be about $20,500. The pond construction and pipe installation is estimated to be $30,000. The pump (10,000 GPM @ 10' head, 75 HP) installed would be about $10,000.

The annual cost breakdown would be:

Capital Cost	$60,500	
Contingencies @ 20%	12,100	
	$72,600	
Amortization @ 8% for 20 years		$ 7,400
Power @ $0.010/Kw-hr. (220 operating days)		3,300
Operation and Maintenance		2,000
Profit Loss from Cane		900
TOTAL COST FOR SPRAY POND		$13,600/year

The same comments noted for the cooling tower effluent effects on Kiikii Stream apply here.

DILUTION

Another possibility for reducing the temperature of the condenser discharge 10°F would be to dilute the discharge by an equal volume of groundwater pumped from a well that would be constructed in the area where brackish cooling water is presently pumped. The capital cost of such an installation including a pump (10,000 GPM @ 40' head, 125 HP), a well (8' dia. by 20' depth), and a 2600-foot, 24-inch diameter pipeline is estimated to be $136,000.

The annual cost would be:

Capital Cost	$136,000	
Contingencies @ 20%	27,200	
	$163,200	
Amortization @ 8% for 20 years		$16,600
Power @ $0.010/Kw-hr.		5,500
Operation and Maintenance		500
TOTAL COST FOR DILUTION		$22,600/year

The effect on Kiikii Stream of diluting the present discharge by an equal volume of groundwater would be to significantly reduce both the salinity and residence time as well as to reduce the temperature. The resulting average theoretical residence time would be less than a half day and consequently the plankton population would be markedly reduced due to wash out. Since the plankton are a significant part of the basis of the Kiikii ecosystem, the effect would probably be general reduction of productivity in the entire system. The salinity reduction would generally shift the present salinity zones downstream and reduce the area of high and moderate salinity while increasing the low salinity regime. The increased flow may also reduce the existing salinity stratification and upset the present ecosystem configuration which is dependent on these conditions. The reduction in temperature would variously slow down the life process rates of the constituent species and thus alter their interrelationship. In summary, the dilution alternative would probably have a negative effect on the present desirable Kiikii ecosystem although it would more closely meet the 1.5°F temperature change criteria.

In consideration of all of the above alternatives, it is recommended that the present method of discharge be continued in order to maintain the existing ecosystems in Kiikii Stream.

APPENDIX E

FISHERMEN'S TESTIMONIES

To whom it may concern:

Dear Sir,

It has been brought to my attention that several people of an ecologically-minded group have voiced a complaint against the Waialua Sugar Company's practice of discharging hot water from its mill into the Kiikii Stream — alleging, I presume, the possibility or existence of thermal pollution. What the group states may be true; however, personal observation brings me to believe seemingly otherwise.

On many occasions throughout the past few years, members of my family and I have gone crabing, setting our crab nets from the Kiikii Bridge which is close to the point of complaint (aproximately thirty yards away). I assure you that the catches have been most satisfactory in number and size, yielding at times crabs of two to three pounds.

While crabing or just passing by I have often noticed the presence of river shrimps only inches away from the "hot water" discharge and varying types of fishes nearby in the area. Others will undoubtedly attest similar experiences and observations should an attempt be made to bear out the views.

Although I have no affiliation what so ever with the Waialua Sugar Company (Inc.), I wish no undue or needless hardships for it. Thus, I had hoped by writing this letter to bring out a possible second side to the "coin." If none are planned or underway, I suggest that a fact-finding committee of expertise in such matters make a comprehensive on-the-spot study of the problem, incorporating the finding of past investigations of which there are many involving thermal pollution. (If such be the case, I see no reason for the Waialua Sugar Company to foot the bill.) The results, no matter what side they may lean to, will help all and will be of great use should similar problems and disputes occur at a future date, at a different location.

Sincerely yours,

Mrs. Haruka Sakuoka

(Mrs.) Haruka Sakuoka

Note: Mrs. Sakuoka attended Waialua High School and is working at the Koga Superette in Haleiwa.

VOLUNTARY TESTIMONY BY ISAMU TAMURA

I was born in Waialua and, as far back as I can remember, I fished and crabbed in Kiikii Stream, except when I lived on the mainland. The last time I crabbed there was with Police Officer Richard Yoshizaki about a month ago when we caught 21 Samoan crabs, about 1½ times my fist size, in about two hours and then left because three other boats of crabbers crowded us.

Sixty-one Samoan crabs were the most I ever caught and that was about four years ago. But I crabbed for over five hours and nobody crowded us.

The spot where the warm mill water goes into Kiikii Stream is loaded with tilapia and more and more haole crabs, which we couldn't catch in Kiikii Stream about five years ago, are being caught now. And now-days because fishing and crabbing is so good, more people from Waialua and outside the district go there.

Signature [signature]
Isamu Tamura

July 10, 1972

Note: Mr. Tamura is a graduate of Waialua High School, an ex-serviceman, and is presently an independent businessman, operating the Tamura Barber Shop in Waialua.

I was born in 1932 at Kemoo Camp #4, better known as Old Mill Camp. The smoke stack from the old mill (1883) still stands there. The Poamoho stream flows by the camp and merges with the Kaukohahua stream and flows out to the ocean at Kaiaka Bay.

I grew up fishing, crabbing and scooping for opae in the river and it was pleasant because we practically had the whole river to ourselves. I enjoyed these activities until sometimes in the 1940's when my interest turned to other things. I thought at that time that the Samoan crab was becoming extinct.

I left Hawaii in 1953 for various reasons (U.S.AF, Eniwetok, Los Angeles etc.), and I returned to Kemoo Camp #4 in 1969. I noticed that the river had been widened and cleared of overhanging grass by the plantation. I went crabbing one day, not expecting to catch anything, and I got about 10 Samoan crabs. I also saw the water boiling with tilapia, a new fish introduced to Hawaii while I was away. Subsequently, my enthusiasm for crabbing has waned because there are so many people crabbing from the bridge and the river is lined with floats by people who go crabbing on motor boats.

There is a ditch about 15 yards upstream from the bridge. Warm mill water flows in the ditch and empties into the Kiikii stream. My brother-in-law, who is an expert fisherman, told me that it is a good place to throw net because the mullet likes the warm water. I have seen people fishing in the ditch for tilapia. Last year we were hooking papio from the bridge and when the word got around, the bridge was crowded shoulder to shoulder for several weeks. I have never known of papio coming that far upstream. I firmly believe that the warm water from the mill has no negative effect on the Kiikii stream. Judging from the number of people who like to fish there, I think it may have a positive effect.

Bruce Y. Shimada

Bruce Y. Shimada

July 11, 1972

Note: Mr. Shimada obtained his bachelor's degree from the University of Hawaii and his master's in library science from the University of Southern California. At present he is with the State library system.