EFFECTS OF A POWER PLANT DISCHARGE
INTO MONTEREY BAY
AT MOSS LANDING

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THESIS

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ABSTRACT

The effects of a power plant discharge into Monterey Bay at Moss Landing are investigated. Possible effects of increased temperatures upon the metabolic and behavioral patterns of biota are presented. These effects are usually very subtle, and depend upon the physical as well as the biological characteristics of an area. Temperature studies at Moss Landing indicate an exponential-like decay of temperature with increasing area surrounding the discharge. Due to changing physical conditions, the size and shape of the warm water "plume" are subject to appreciable variations. Heat budget calculations predict only a small amount of the heat discharged into the Bay escapes to the atmosphere, although turbulence near the discharge probably accounts for a much larger heat loss to the atmosphere than predicted by calculations.

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I. INTRODUCTION

The term "thermal pollution" is being used extensively by both the popular and scientific presses to describe the addition of hot water discharge from electric power plants to the ocean and fresh water environments. The mean temperature of the ocean is not affected by this heat, but local temperatures may be significantly affected with possible adverse effects on the ecology of the area in the vicinity of the outfall. Thus the term "thermal pollution" has arisen to denote this unnatural addition of heat to the environment. Whether the word "pollution" is appropriate is a subject of debate among scientists, and depends upon the particular area and how one defines the word "pollution."

The demand for electric power is expected to double from 1968 to 1980 [Adams, 1969]. More nuclear power plants will be built in response to the public outcry against air pollution. These nuclear plants are even less efficient than the fossil fuel plants because technological difficulties make it impractical to use high pressure superheated steam in a water-cooled reactor system which would allow more efficient operation and less wasted heat to be discharged into our waters [Baldwin, 1970]. The even increasing amount of heat added to our rivers, lakes, and bays makes it imperative that we understand its effect upon the local flora and fauna (particularly those which are vital links in the food chain) to avoid serious problems which could arise in the future. Detailed studies must be conducted at sites of proposed power plants to accurately determine physical, biological, chemical, geological, and meterological characteristics of areas affected by discharges. Supplied with this information, a competent ecologist can thus predict

the effects upon the local biota and conclude whether it is advisable to build an electric power plant. Strict governmental control is also needed to insure that power companies construct their plants at locations where they will be no damaging effects on the local biota or where the adverse effects are as minimal as possible.

II. EFFECTS OF TEMPERATURE

A. GENERAL EFFECTS

Temperature is considered the most important factor affecting the distribution of life in any aquatic environment. A biological community or aggregation of species is formed when the physical parameters of the water match the tolerances of the species in the community [Wurtz, 1968]. Temperature exerts a profound influence on salinity, density, oxygen content, turbidity, pH, amount of suspended matter and dissolved solids, photosynthetic activity, organic decomposition and remineralization of nutrients, phytoplankton growth, and other physical parameters affecting the membership of a biological community [de Sylva, 1968]. An unnatural addition of heat to the environment could significantly alter the thermal regime and produce a series of changes in the physical characteristics of the water. Measurements in the vicinity of hot water discharges have shown a predominance of warmer water species and an accompanying decrease in the diversity of species present [Mount, 1968]. This decreased diversity represents a simplification of the ecosystem in response to the thermal stress placed on it [Mount, 1968]. This simplification results in a more efficient food chain, but produces a less adaptive system with a higher risk of failure since an individual species aquires greater importance in the food chain [Mount, 1968]. Noticeable effects such as outright fish kills in the area of a discharge rarely occur. Even if they do occur in a small area surrounding the discharge, such kills cannot be interpreted as evidence that the discharge has adversely affected the ecosystem. What one must discern are the more subtle effects such as changes in the reproductive cycles, growth, slow

decline and disappearance of valuable species, eventual disruption of the food chain leading to our valuable commercial resources, and undesirable shifts in the floral or faunal community [Hedgepeth, 1968].

Numerous experiments have been conducted to determine the physiological and behavioral responses of aquatic species to temperature. In interpreting the "lethal" temperature to an organism one must consider the abruptness of the temperature change and the exposure time. It is useless to subject a fish to elevated temperatures for several hours when its maximum exposure time (if it becomes trapped in the intake system of the power plant) is a matter of minutes [Adams, 1969]. Laboratory experiments are useful in determining an organism's response to temperature alone, but in the real world the organism does not respond in a simple, predictable way. Numerous other physical parameters such as salinity, oxygen concentration, and pH affect its response to a temperature stimulus [Strickland, 1968].

B. PHYSIOLOGICAL AND BEHAVIORAL EFFECTS

Clark (1969) has described the physiological and behavioral effects of an increase in temperature on living aquatic animals. Temperature influences the metabolism, activity, growth, and reproductive process. In mose cases activity, feeding, and oxygen consumption increase directly with temperature increases until "thermal shocks" or disequilibrium results. There are a few exceptions to this rule such as the brown trout, which undergoes a decrease in metabolic rate and activity in the temperature range from 49°-66°F, then shows the normal increase in activity as the temperature rises beyond 66°F. All organisms are subject to maximum temperatures above which they cannot exist. Death from exposure to rapidly fluctuating temperatures or to prolonged

exposures at lethal temperature has been attributed to numerous physiological causes such as inactivation of enzymes, lack of sufficient oxygen to meet the increased demand, smooth-muscle peristalsis, and coagulation of protoplasm, but scientists are still unsure of the exact cause.

Clark (1969) has pointed out that perhaps the most important effect of temperature (in terms of alterations in the ecosystem) is its effect upon growth and development. Higher temperatures usually produce a species of larger size than its cold-water counterpart, but such is not always the case. Karl Mobuis, a German Zoologist, noted that molluscs and shellfish living in cold water grew slower, but attained a larger adult size than the warm water molluscus and shellfish. An increase in activity usually accompanies an increase in food consumption, and this acts to diminish the amount of energy available for growth. In most cases, however, warmer temperatures produced biota of larger size than did colder temperatures provided there is sufficient food supply to sustain the increased appetites and growth rates.

deSylva (1968) has noted that the effect of temperature on growth is most critical during the ovum and larval stages. Warmer temperatures are thought to induce and protract spawning. If spawning is induced when water conditions are unfavorable, the eggs may not develop properly due to the elevated temperatures or other physical factors. Also, some animals which spawn in warm water depend upon colder water for the development of their ova during certain stages. A hot water discharge could prevent the seasonal or diurnal fluctuations necessary for proper ovum development. It is thought that natural fluctuations may even be required by some animals such as intertidal species, which are subject to side variations between air and sea temperatures. The egg can also experience a problem osmoregulation due to increased salinity from the

discharge, and the lighter, warmer water can cause pelagic eggs to sink to levels of insufficient oxygen and light, which are necessary for growth. Bacteria also become more active, and decompose organic matter faster in warmer water thus presenting an added problem to the ova. The organism also experiences difficulty in its larval stages. Increased temperature and salinity cause a decrease in oxygen solubility. Less oxygen in the water is dangerous to most aquatic life. More oxygen is required when biota become more active due to the warmer temperatures. Larvae require more oxygen to avoid predators, which also become more aggressive at higher water temperatures. Oxygen is also useful in neutralizing the effects of sewage and chemical pollutants. If the hot water discharge is less dense than the sewage, it will float on top of the sewage and prevent its access to oxygen. The toxic effect of chemical pollutants on aquatic life seems to increase at elevated temperatures thus making both the adult and the larvae more susceptible to chemical poisoning.

C. OTHER EFFECTS OF HIGH TEMPERATURES

deSylva (1968) has also recorded additional effects of a temperature increase. The activity of the gribble and shipworm often increases in warmer water. Warm water also attracts sharks, jellyfish, stingrays and other undesirable species to swimming areas. Growth of algae is accelerated in warmer water thus clogging estuaries and impairing the filtering mechanisms of shellfish and oysters.

According to deSylva (1968), benefits are also possible from a hot water discharge. In many cases sport fishing has improved in the area of a discharge especially in winter months. Benthic organisms are attracted to the area during colder periods, and growth is accelerated

during colder months if there is sufficient light and a supply of nutrients present. By pumping the discharge into the water near the bottom, nutrients could be brought to the surface by the rising warm water and thereby foster a greater phytoplankton population and increase photosynthesis and oxygen production. This hot water could also be used for shellfish farming under controlled conditions, to melt ice in polar waters, and to warm waters for more pleasant swimming.

Clearly, the overall effects are very difficult to assess. Whether a discharge is harmful or beneficial depends on the particular area. Evaluation of the effects requires a detailed study of the physical as well as the biological aspects of an area and a constant monitoring of any changes detected in the ecosystem and environment.

III. BACKGROUND[1]

A. POWER PLANT OPERATION

The largest fossil-fuel power plant in the United States (2113 megawatts) is located at Moss Landing, California [Adams, 1969]. Sea water is used as a coolant in the power plant condenser system, and is discharged into Monterey Bay as a velocity of 3 ft/sec, at a temperature 15°F (8.3°C) to 20°F (11°C) above its intake temperature. Discharge units 6 and 7 are located in the Bay twenty feet below mean water level on the southern side of Elkhorn Slough. The position of the discharge is 36° 48.3'N and 121° 47.4'W. Unit 6 is 640 feet offshore at mean water level (mean lower low water) and 800 feet offshore when the tide is eight feet above mean water level. When both units are operating at full capacity, the plant can produce 1500 megawatts of electrical power.

B. PHYSICAL ENVIRONMENT

The topography of the area is characterized by the Pajaro River to the North, the Salinas River to the South, and Elkhorn Slough, all of which serve as sources of winter runoff thereby decreasing the salinity of nearshore water. This runoff carries a great amount of silt into Monterey Bay affecting sediment characteristics and reducing water transparency. The Monterey Bay Submarine Canyon, largest of its kind on the Pacific coast of the United States, heads offshore at Moss Landing exerting an appreciable influence upon circulation and sediment transport in the area.

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[1] The background information in Part III is from PG&E Progress Report Number 2 (1968).

The water temperatures are characterized by three seasons: 1. Davidson Current (November-February), 2. Upwelling (March-August), and the 3. Oceanic or California Current (September-November). During the Davidson Period, offshore surface water flows northward and toward shore producing a stable, warm, well-mixed upper layer. Salinities are low due to the high river runoff in the latter part of this period. When the wind shifts to the North, surface water is transported offshore causing cold bottom water to "upwell" to the surface. Due to increased evaporation, salinities are usually high during upwelling. September initiates the Oceanic Period, during which warm, highly saline offshore water replaces cold water, which sinks nearshore and is transported southward by the California Current. In late August and in September, due to increased solar radiation, sea surface temperatures are maximum, averaging 58°F (14.4°C). The surface temperatures are lowest in March and April, averaging 52°F (11.1°C). Warm water from Elkhorn Slough moving in and out of the Bay due to tidal forces causes marked diurnal fluctuations in the surface temperatures.

The tides at Moss Landing are "mixed." Two sets of highs and lows are observed each day, but there are large inequalities between successive highs and lows (Figure 2). Highest tides are approximately eight feet above mean water level with an average or diurnal range (mean higher high to mean lower low) of about six feet.

Winds, density currents, and tides affect circulation in the discharge area. Although tidal currents are apparently weak, measurements have shown that the tidal cycle does affect circulation somewhat. Gatje and Pizinger (1965) and Caster (1969) have measured currents along the bottom of the Canyon with components flowing counter to the tidal

movement (up canyon flow on ebb tide and down canyon flow on flood tide). These currents are limited to a thin region above the bottom so their effect upon the thermal structure is probably negligible. Pacific Gas and Electric Company (PG&E) dye studies have indicated a movement southward and toward shore of the surface water in the discharge area during ebb tide and northward and away from shore during flood tide. The presence of the Canyon makes the circulation very complicated and difficult to predict in a small region. PG&E current studies show that the dominant large scale circulation in Monterey Bay is a counterclockwise movement of surface water. Wave action apparently does not produce seasonal circulation changes because the dominant swell is from the northwest and west all year round.

C. BIOLOGICAL CHARACTERISTICS

Before the construction of Units 6 and 7, PG&E conducted surveys of the benthic life in the area of the proposed discharge. Surveys of 10 June 1966, 24 October 1966, and 1 July 1967 showed that the biota of the shallow bottom consisted primarily of polychaetes, crustacea (shrimp, pill bugs, and sand fleas), molluscs (snails and clams), and echinoderms (sand dollars and sea stars). No plant species were found on the bottom due to an absence of a suitable substrate caused by the shifting sands along the bottom. Plants were found only as drifting debris. The surveys showed that fluctuations occurred in the amount of a particular species, but the type of species present at a particular station remained virtually constant. In general changes in the species type at a particular station from one sample date to the next were less pronounced than the differences in species type between stations. This finding seems to indicate that the benthos is not exposed to marked

fluctuations in the physical environment, but distinct faunal areas apparently do exist.

The distribution of macrobenthos is influenced primarily by sediment particle size, water depth, amount of detritus, and factors such as temperature, oxygen supply, and food supply. Particle size is determined by depth, location, and currents. Detrital content is affected by currents and the distance from a source such as a river or slough. The large polychaete abundance at inshore stations may be a result of the large amount of detritus and sand size particles. Crustaceans are more abundant at deeper water stations, and may prefer a substrate of smaller sediment particle size (fine sand and sandy silt). The dominant species, however, are usually adapted to a variety of conditions and are often cosmopolitan.

IV. PHYSICAL EFFECTS OF DISCHARGE

A. AMOUNT OF HEAT

From October 6, 1970 to October 8, 1970, PG&E conducted a series of measurements in the area of discharge Units 6 and 7. Units 6 and 7 were operating at maximum capacity (1500 megawatts) throughout the course of the survey in order that the maximum effects upon the temperature structure in the area could be determined. 1280 cubic feet of water heated 21.75°F (12°C) above its intake temperature was discharged per second into the Bay, resulting in a heat addition of 435 million calories per second to the Bay.

B. RESULTS OF MEASUREMENTS

From 1300 to 1700 on October 6, bathythermograph (BT), salinity, and dissolved oxygen measurements were made by PG&E at twenty stations representing distances of 300 feet to 5400 feet seaward of the discharge (Figure 3). The salinities measured were virtually the same at all stations(33.5 to 33.6 parts per thousand at the surface), but the dissolved oxygen concentration at the stations closest to the discharge (Stations 1-4) were lower than those at the other stations. Oxygen concentrations in the surface layers at Stations 1-4 varied between 5 and 6 parts per million, while the concentrations at Stations 17-20 (farthest from discharge) varied between 7 and 9 parts per million in the surface layers. Since oxygen is less soluble in warmer water, one would expect the concentrations to be smaller near the discharge where the warmest water is present.

Temperature measurements made by PG&E on October 6 consisted of mechanical BT measurements at Stations 1-20 (Figure 3) and an infrared radiation (IR) study of the discharge area using an airborne radiation thermometer and a "thermal mapper" system [Doyle, 1969] to plot the shape of the hot water "plume." Figures 4-7 show the results of the IR surveys of October 6 and December 6, 1970. The ambient surface water temperature on October 6 was 56.5°F, and the maximum temperature detected by the IR survey was 67°F. Four hundred twenty three thousand square feet of surface water had temperatures of 57°F to 59°F, while 111 thousand square feet of surface water had temperatures of 59°F to 67°F. The December 6 IR survey indicated higher surface temperatures and larger areas influenced by the discharge than the October 6 survey. The ambient surface water temperature was 55°F, and the maximum temperature detected by the IR survey was 78°F. 8.9 million square feet of surface water (18 times larger than the area influenced by the same temperatures on October 6) had temperatures of 57°F to 60°F, while 284 thousand square feet of surface water (twice the area influenced by temperatures of 60°F to 67°F on October 6) had temperatures of 60°F to 78°F. The pronounced differences between the two surveys can perhaps be explained by examining the BT data of October 6,1970.

At Stations 1-4, 100 yards from the discharge, temperatures of 60°F to 62°F were measured as deep as 15 feet, and temperatures of 57°F to 59°F were detected as deep as 25 feet. At Stations 17-20, 1800 yards from the discharge, temperatures of 57°F to 59°F were measured 10 feet below the surface (Figures 8 and 9). The BT data indicate that most of the heat from the discharge remained beneath the surface, resulting in a large "block" of warmed water concentrated near the discharge.

The absence of currents to disperse the heat could perhaps explain the comparatively low surface temperatures observed on October 6. Unfortunately, no BT data is available for December 6. It seems highly unlikely, however, that the higher surface temperatures and larger areas influenced observed on December 6 were due to a progressive warming up of the water. If progressive warming of the water were occurring such a drastic change in surface temperatures could not occur in such short time (October 6 - December 6). A possible explanation for the discrepancy between the two surveys is that warm, subsurface water rose to the surface and spread out due to local currents, thereby increasing the influenced area. This process would result in a shallower thermocline since more of the warm water has reached the surface. More BT, IR, and current measurements should be taken in the area to determine what physical processes affect the distribution of heat in the water column.

At 0850 on October 7, a surface current drogue was launched by PG&E at the discharge site and tracked by ship's radar until 0945 on October 8. The drogue was equipped with a thermistor to measure surface water temperatures along its path. Figure 10 shows the surface temperatures recorded by the drogue, and Figure 11 indicates the position of the drogue at various times. The temperature decayed rapidly from 70°F to 60°F, and then became more constant as the ambient temperature was approached. Figures 10 and 11 indicate that the temperature decayed from 70°F to 60°F in 5 minutes time or a distance of approximately 40 yards from the discharge. The drogue traversed 3200 yards in three hours time before the ambient temperature was reached. The undulations in the temperature decay curve of Figure 10 indicate

the presence of small patches of water slightly warmer than ambient at distances of five miles or more from the discharge.

The BT, IR, and drogue studies indicate that the "thermal plume" consists of a small area of high temperatures (60°F to 70°F or more) and large temperature gradients surrounded by a much larger region of lower temperatures (57°F to 60°F) and small temperature gradients (Figure 7). Numerical models such as Baldwin's (1970) predict this exponential-like decay of temperature with area. Baldwin's model assumes steady-state currents, and predicts that the inner area of high temperatures is composed of stable, circular isotherms while the outer area of lower, constant temperature consists of elliptically-shaped isotherms which become elongated in the direction of the dominant current, assumed to be steady-state. According to his model, currents are the most important influence on the heat dispersion. Obviously, the assumption of steady currents vastly oversimplifies what is really occurring in nature, but numerical models nevertheless are valuable tools for estimating how much surface area will be affected by a discharge. Circulation at Moss Landing is particularly complicated due to the influence of the Canyon so one would expect the outer area of the "plume" to change in shape and areal extent in response to fluctuating local currents. Detailed current studies in the discharge area under various wind and wave conditions would provide the empirical data necessary to more accurately predict how the heat will be dispersed.

C. HEAT BUDGET CALCULATIONS

It is important to know the net heat flux across the air-sea interface to determine what percentage of the discharge heat is escaping to the atmosphere. Using the IR studies (Figures 4,5, and 6) and

the meteorological data available for October 6 and December 6, one can estimate the amount of heat loss to the atmosphere through radiation, evaporation, and sensible heat transfer. The transfer of heat across the air-sea interface is referred to as the heat budget and can be expressed by the following:

$$Q = Q_s + Q_c - Q_b - Q_e - Q_r - Q_h \quad \text{[James, 1966]}$$

where Q = net gain or loss of heat of the water surface.
Q_s = heat gain due to solar insolation.
Q_c = heat gain due to condensation.
Q_b = effective back radiation to atmosphere.
Q_e = heat loss due to evaporation.
Q_h = heat conduction across interface.
Q_r = reflected solar radiation.

On October 6 the winds were from the west and northwest at 5-15 knots. The air temperatures ranged from 53°F to 57°F, and the dew point temperatures varied from 47°F to 52°F. The sky was virtually clear with a cloud coverage of 30 percent above 20,000 feet. Using average values to facilitate the calculations, one can consider a 10 knot wind, a 55°F air temperature, and a 49°F dew point temperature as representative of the overall meteorological conditions on October 6. It is further assumed that the effective solar insolation ($Q_s - Q_r$) balances the amount of heat released to the atmosphere from water surfaces at ambient temperature (56.5°F). This assumption allows one to neglect seasonal heating and cooling of the water surface. Letting Q_a represent the amount of heat released to the atmosphere, the following relation holds:

$$Q_a = Q_b + Q_e + Q_h$$

Assuming the heat lost to the atmosphere from the ambient surfaces is balanced by the effective solar insolation, then the difference in the values of Q_a (ΔQ_a) between surfaces at temperatures (T_w) above ambient

and the ambient surface is a measure of how much of the heat from the discharge is released to the atmosphere.

Tables I, II, and III show the results of the heat budget calculations for October 6 using James' (1966) nomographs. Only 5.02×10^5 calories per second or about 0.1 percent of the discharged heat was being lost to the atmosphere over the entire "plume" area on October 6.

On December 6 the ambient surface water temperature was 55°F, the sky was virtually clear (10 percent cloud coverage above 20,000 feet), and the average winds were 10 knots. Air and dew point temperatures averaged 57°F and 48°F respectively. The heat budget calculations for December 6, Tables IV, V, and VI, indicate that 1.05×10^7 cal/sec, 2.5 percent of the rate at which heat is being discharged into the Bay, was released to the atmosphere over the entire "plume" area. The heat budget calculations suggest rather strongly that the area influenced by the warm water is increasing since such small values for the amount of heat lost to the atmosphere were obtained. The water in the vicinity of the discharge is very turbulent due to the rapid discharge of hot water from the plant into the Bay. The "boiling" surface water near the discharge could increase the heat loss to the atmosphere by one or two orders of magnitude above that predicted by the heat budget calculations through turbulent heat transfer to the atmosphere. Direct measurements of turbulent fluxes of heat and moisture across the air-sea interface would be helpful in determining how important turbulence is in transferring heat to the atmosphere.

If one assumes Monterey Bay to be enclosed by insulated boundaries, one can calculate roughly what length of time would be required for the discharge to produce a 1°C rise in the mean temperature of the Bay.

Assuming the plant always operates at its maximum load, 4.35 x 10^8 cal/sec, and that no heat escapes to the atmosphere, the total heat absorbed by the Bay in one year is 1.2 x 10^{16} calories. Monterey Bay is approximately 200 square miles in area with an average depth of 200 feet, excluding the Canyon region. Thus the volume of the Bay is about 4.2 x 10^{16} cubic centimeters, a total mass of approximately 4.3 x 10^{16} grams. Assuming the discharged heat is uniformly distribued throughout the Bay, the mean temperature of the Bay would be raised 1°C after 3.6 years. The assumptions used to arrive at this figure are of course unrealistic, since Monterey Bay is not enclosed by insulated boundaries. Some of the heat escapes to the atmosphere, some may be transferred by conduction to the land, and some is carried away from the discharge by advection and diffusion and dispersed in the vast ocean environment outside the confines of the Bay.

Because much of the discharged heat escapes from the Bay, it would seem highly unlikely that any noticable increase in the mean temperature of the Bay could occur in the foreseeable future. Temperatures in the immediate vicinity of the discharge are significantly affected, however. Although the IR surveys indicated that the area of surface water influenced by the discharge is very small compared to the area of Monterey Bay, the heat budget calculations suggest that this area is increasing steadily, although local currents and wave action may cause periodic fluctuations in the area of the "plume." According to the heat budget calculations, the "plume" would have to increase its surface area by 100 times its present area in order to reach an equilibrium condition (rate of heat discharged into the Bay equals the rate of heat lost to the atmosphere). The discharge region should be monitored regularly to

determine whether the "plume" area is growing and the importance of turbulence, advection, diffusion, and wave action in the dispersal of heat. As the warm water area increases in size, more heat will be lost to the atmosphere, and more will disperse into the ocean by diffusion and mixing processes. Thus an equilibrium condition would be approached. A numerical model could be developed to predict when this equilibrium condition could be expected and the size of the "plume" area at equilibrium. Detailed information concerning physical processes such as advection, diffusion, and mixing is needed for such a model to be useful in predicting how the heat will be dispersed. Knowing the total surface area affected by a power plant discharge at equilibrium enables one to predict how many power plants per unit length of coast can operate at one time without significantly affecting temperatures on a large scale along the coast.

PG&E used the Moss Landing IR data to predict how the heated effluent would be dispersed from a similar discharge located at Davenport, Santa Cruz County, California.[2] In its report concerning the studies conducted at Davenport, PG&E states that the rapid reduction of the temperature gradients near an offshore, submerged discharge, such as that at Moss Landing, is due to the initial mechanical (jet) mixing of the discharge water with the receiving water at the discharge point. Subsequently, after dilution of the effluent, the turbulence of the receiving water becomes the dominant factor in the mixing process. For shoreline discharges PG&E measurements indicate that the initial temperatures are not reduced as rapidly as near offshore discharges because the effect of the initial mechanical mixing is inhibited.

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[2] The information in this paragraph is from PG&E Report on Investigations of the Marine Environment at Davenport.

PG&E measurements of "plumes" at operating power plants with submerged, offshore discharges indicate that 80-90 percent of the heat transferred to the atmosphere occurs at surface temperature increases of 1°F above ambient or less. The fact that the thermal discharge is spread over a large area at a low level of temperature increase (2°F and less) above ambient makes it difficult to determine the true ambient temperature at the discharge. Since currents can shift the "plume" up and down the coast, water within a 1-2 mile radius of the plant could experience a temperature increase of 1-2°F. Measuring the ambient temperature outside the "plume" influence would not yield the true ambient temperature at the discharge.

TABLE I

T_w F°	Q_b cal/cm^2/hr	Q_e cal/cm^2/hr	Q_h cal/cm^2/hr
56.5	6.5	6.5	1.0
58.0	6.7	8.2	2.0
60.0	6.9	9.5	3.3
62.0	7.1	11.0	4.4
64.0	7.3	13.5	5.5
66.0	7.5	16.0	6.2

TABLE II

T_w F°	Q_a cal/cm^2/hr	ΔQ_a cal/cm^2/hr
56.5	14.0	0.0
58.0	16.9	2.9
60.0	19.7	5.7
62.0	22.5	8.5
64.0	26.3	12.3
66.0	29.7	15.7

TABLE III

T_w F°	ΔQ_a cal/cm²/hr	AREA cm² X 10^8	ΔQ_a X AREA cal/hr X 10^9
58.0	2.9	3.93	1.14
60.0	5.7	0.87	0.50
62.0	8.5	0.10	0.08
64.0	12.3	0.06	0.07
66.0	15.7	0.02	0.03

TABLE IV

T_w F°	Q_b cal/cm²/hr	Q_e cal/cm²/hr	Q_h cal/cm²/hr
55	6.8	8.5	-1.0
57.5	7.0	10.5	0.5
59	7.1	11.5	1.0
61	7.2	13.5	2.3
63	7.3	15.5	3.4
65	7.4	18.0	4.6
67	7.6	22.0	5.7
69	7.8	24.4	7.0
71	8.0	27.6	8.0
73	8.2	30.0	8.9
75	8.4	32.4	9.8
77	8.6	36.5	10.7

TABLE V

T_w F°	Q_a cal/cm^2/hr	ΔQ_a cal/cm^2/hr
55	14.3	0.0
57.5	18.0	3.7
59	19.6	5.3
61	23.0	8.7
63	26.2	11.9
65	30.0	15.7
67	35.3	21.0
69	39.2	24.9
71	43.6	29.3
73	47.1	32.8
75	50.6	36.3
77	55.8	41.5

TABLE VI

T_W F°	ΔQ_a cal/cm^2/hr	AREA cm^2 X 10^8	ΔQ_a X AREA cal/hr X 10^9
57.5	3.7	56.3	20.8
59	5.3	26.4	14.0
61	8.7	1.7	1.5
63	11.9	0.5	0.6
65	15.7	0.2	0.3
67	21.0	0.13	0.3
69	24.9	0.08	0.2
71	29.3	0.01	0.04
73	32.8	0.01	0.04
75	36.3	0.01	0.04
77	41.5	0.02	0.09

V. BIOLOGICAL EFFECTS OF DISCHARGE

Because organisms respond in a complicated fashion to temperature changes, the task of determining the effect of a power plant discharge upon the local biota is very difficult. Fluctuations in the population of a particular species at a given station due to natural effects must be separated from changes resulting from the power plant discharge alone. A detailed biological sampling program should be undertaken in the proposed discharge area before the plant begins operation. Such sampling would provide a means for determining changes in the biological life due to natural processes alone. These changes could later be separated from the observed changes to arrive at an accurate prediction of the effect on the local biota due to the discharge only.

Unfortunately, there has been an insufficient amount of biological data collected at Moss Landing in the area of Units 6 and 7. PG&E conducted three benthic surveys before Units 6 and 7 began operation, but these surveys were separated by several months, and gave no indication of the variations in the amount of a particular species between successive samples at one station. If only one sample is taken at a station, an accurate representation of the species populations cannot be determined because the benthos may be clustered in a small area rather than equally distributed throughout the area of the sampling station. Multiple sampling at various points within a station area indicates what variability one can expect between samples due to the non-uniform distribution of the benthos.

The Moss Landing Marine Laboratory has been sampling the biota of the discharge area since 1968, but the sampling has not been extensive

enough to pinpoint the exact effects of the discharge upon the biological community. Essinger is now preparing a report for PG&E on the results of a benthic survey conducted in November 1969 in the discharge area. The report (not yet completed) states that ten samples were taken at each station, yet no mention of the variability among samples was made. The benthic survey showed a marked decline of polychaetes with time at stations close to the discharge and a gradual appearance of nematodes. Without knowing the variability among samples, one cannot conclude the polychaetes are gradually disappearing in the discharge area. A problem also arises in separating the effects of natural causes upon the distribution of benthic life. Samples at stations not influenced by the discharge showed variation in the species populations and distribution indicating that natural factors do produce changes in the benthic community. If future surveys substantiate the fact that the discharge is causing the decline of polychaetes, one can conclude that the ecosystem has indeed been damanged because polychaetes are important as a source of food for numerous organisms.

Houk conducted a survey of the Pismo clam population in the shallow waters near the discharge. His results showed a definite absence of Pismo clams in the shallow waters directly behind the discharge. This fact might possibly indicate that the hot water emanating from the discharge acts as a barrier preventing the temperature-sensitive clam larvae from passing into the shallow water along the beach. Since Pismo clams are an important commercial resource, their disappearance would be damaging economically as well as ecologically. More sampling data is needed before a conclusion can be reached.

No surveys of the planktonic and nektonic life have yet been conducted in the vicinity of Units 6 and 7. Nektonic organisms should

be capable of swimming away from the heated areas, but planktonic organisms (including nektonic and benthic larvae) are not capable of swimming away from heated areas. Benthic larvae drift along with the currents until they become adults and settle in one place. Since adult benthic organisms are virtually sedentary, the distribution of benthic life in an area depends upon the larvae's drifting from place to place and settling down. Larvae are more sensitive to temperature than the adult of the species so the presence of a hot water discharge could present a barrier to the drifting larvae resulting in the depletion of a benthic species in the discharge area [deSylva, 1968]. The effects upon planktonic life due to a discharge are very difficult to assess, but plankton surveys should be conducted in order to better understand the effects of a hot water discharge upon this form of life which is so vital to the food chain.

PG&E summarized the results of its biological investigations at nine power plant offshore discharge sites along the California coast in its report on the studies conducted at Davenport, California. The results indicate that a replacement benthic community is developed in areas where the temperature is 10°F above ambient. When temperatures are 2-10°F above ambient, a transitional community is developed composed of warm and cold water forms. Few; if any, effects are found where temperatures are less than 2°F above ambient. Investigations have shown that replacement communities are typically "dense, luxurious" communities composed of warm-tolerant species. Transitional communities are composed of warm-tolerant forms plus many species which can tolerate intermediate temperatures. The bull kelp population decreases when exposed to temperatures greater than 4°F above ambient. Power plant

discharges will not have a significant effect upon the plankton population because of the large number of warm-tolerant forms, the rapid turnover time, and the continual recruitment from other areas of the plankton. PG&E surveys also indicate that the discharges should not have a significant effect upon water quality parameters, such as dissolved oxygen, based on abundant evidence at discharge sites. Studies by PG&E around power plant discharges on the California coast indicate that certain sport fish, such as striped bass, are attracted to these warm water discharge areas.

VI. CONCLUSIONS AND RECOMMENDATIONS

Unfortunately, there is insufficient biological data available to make a competent prediction of the effects of this discharge at Moss Landing. The results of Houk's Pismo clam survey certainly merit further consideration and research. More benthic surveys should also be conducted to investigate the cause of this apparent decline in the polychaete population in nearshore waters.

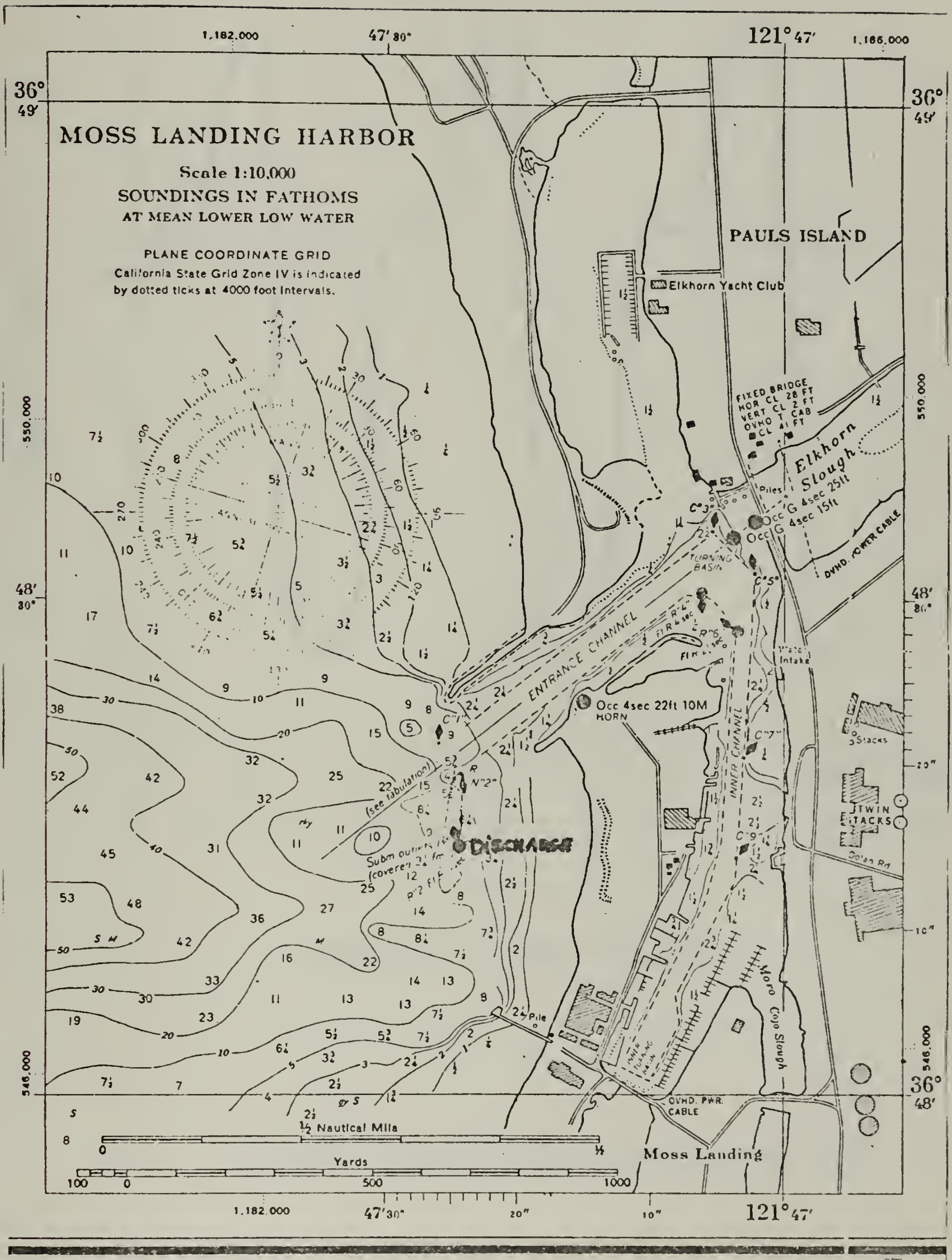
The effects of a hot water discharge upon an ocean environment are much more difficult to detect than the effects upon a closed system such as a river, lake, or estuary. Power plant discharges are capable of producing very pronounced temperature changes in small lakes and ponds, but the heat from a discharge is rapidly dissipated in the vast ocean environment. The ever-increasing demand for electric power will result in more and more heat being dissipated into streams, lakes, bays, and estuaries. Naturally, the area affected by a discharge is proportionately much greater in a lake than in an ocean, but one cannot conclude that it is less damaging ecologically to discharge heat into the ocean rather than smaller bodies of water. The species present in a discharge area and the susceptibility to temperature changes of the species (particularly those vital to the ecosystem) must be determined before one can begin to predict what the effects of the dischargeed heat will be upon a particular environment.

The key to predicting the effects of a discharge upon an ecosystem lies in understanding the physical oceanographic characteristics of an area [Strickland, 1968]. The more complicated hydrodynamic behavior of

an ocean water mass makes it much more difficult to determine the physical characteristics of the ocean environment than the estuarine environment where circulation is much more predictable [Krenkel and Parker, 1968]. Water temperature fluctuations should be determined in as much detail as possible in order that an accurate representation of the thermal regime be used when assessing the effects upon biota [Hedgepeth, 1968]. There is also a need for a more efficient biological monitoring system of a discharge area. Chemical and physical parameters can be determined much faster than biological parameters [Wurtz, 1968]. Further research is also needed to better understand such problems as plankton physiology, effects of passing through a power plant condenser on benthic and nektonic organisms, and the effects due to temperature increases on behavioral patterns such as acclimation, feeding habits, reproduction, metabolism, horizontal and vertical plankton migrations, and predator-prey relationships [deSylva, 1968].

The need for electric power must be satisfied so compromises must be made between progress and conservation of the environment. What must be determined is how to best dispose of this excess heat with minimal damage to an ecosystem. Sites for future power plants must be chosen so that the ecosystem of the area is affected as little as possible. Power plant discharges such as the one at Moss Landing affect a comparatively small area of water in the ocean so one cannot possibly conclude that the entire ecosystem of an ocean will suffer adverse effects. The ecology of a small area, however, may be significantly affected, but only an extensive biological and physical survey of an area will uncover these effects. Even if adverse effects are discovered in one area, one cannot conclude that such effects will occur in other areas

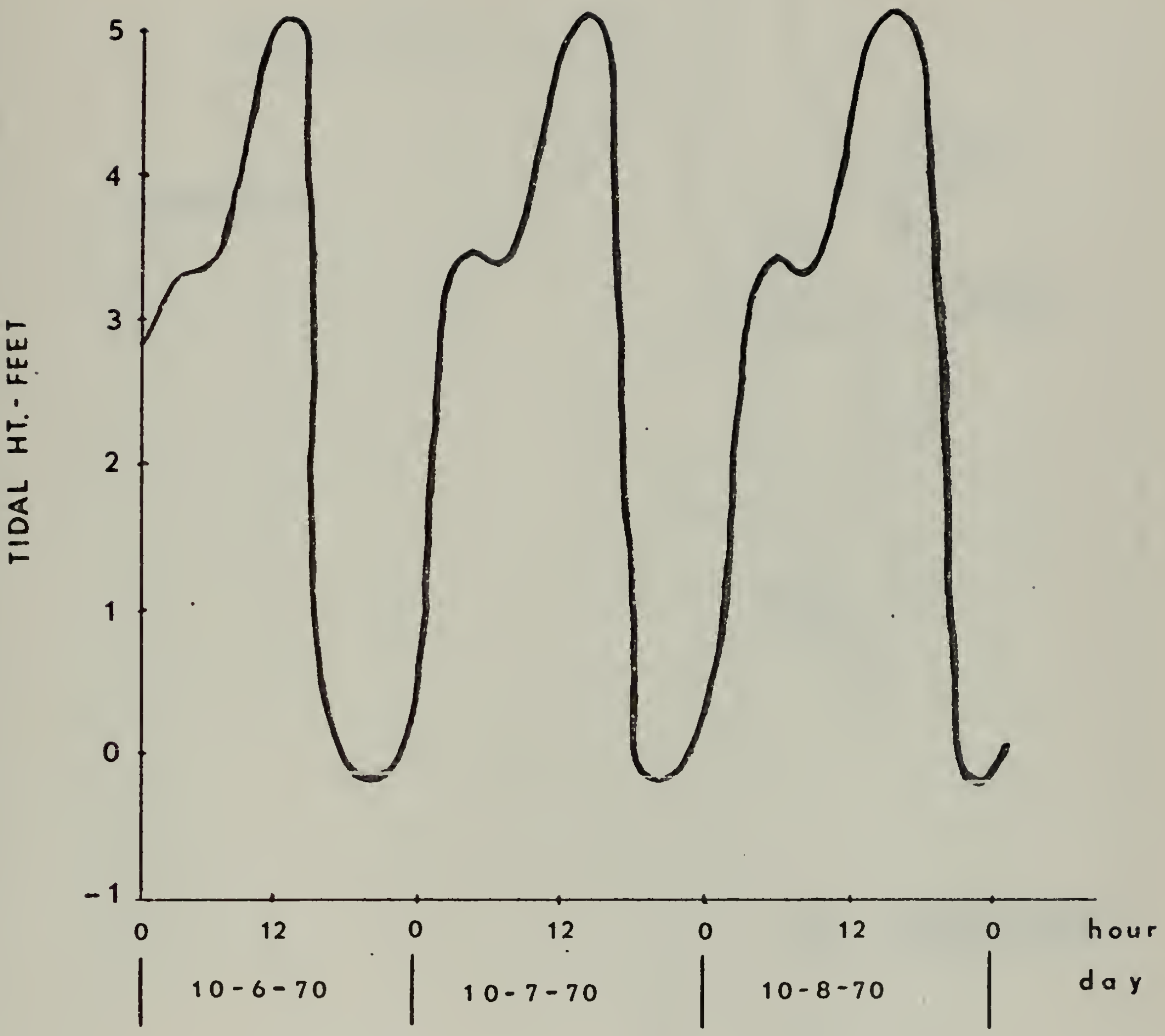
where the physical and biological characteristics are different. The increasing demand for power may necessitate artificial measures such as artificial lakes, cooling towers, etc. to dissipate this excess heat [Clark, 1969]. Future research will provide much needed information on this problem of "thermal pollution."



MOSS LANDING HARBOR **figure 1**

Tabulated from surveys by the Corps of Engineers - report of Sept 1968 and surveys of July 1968

FIGURE 1 - from C.&G.S. 5403



PREDICTED TIDE - FIGURE 2

FIGURE 2 - from PG & E Moss Landing survey data

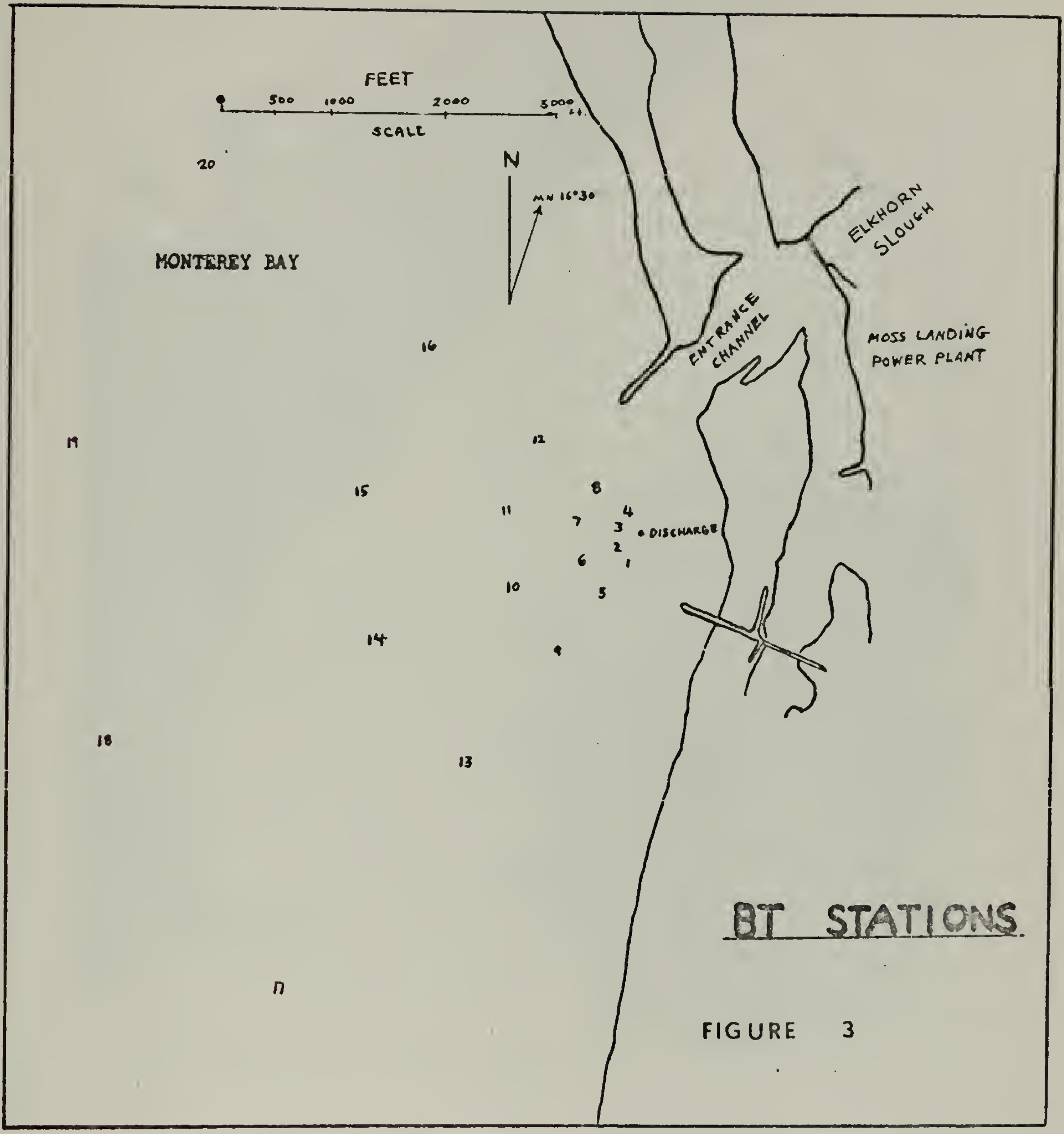
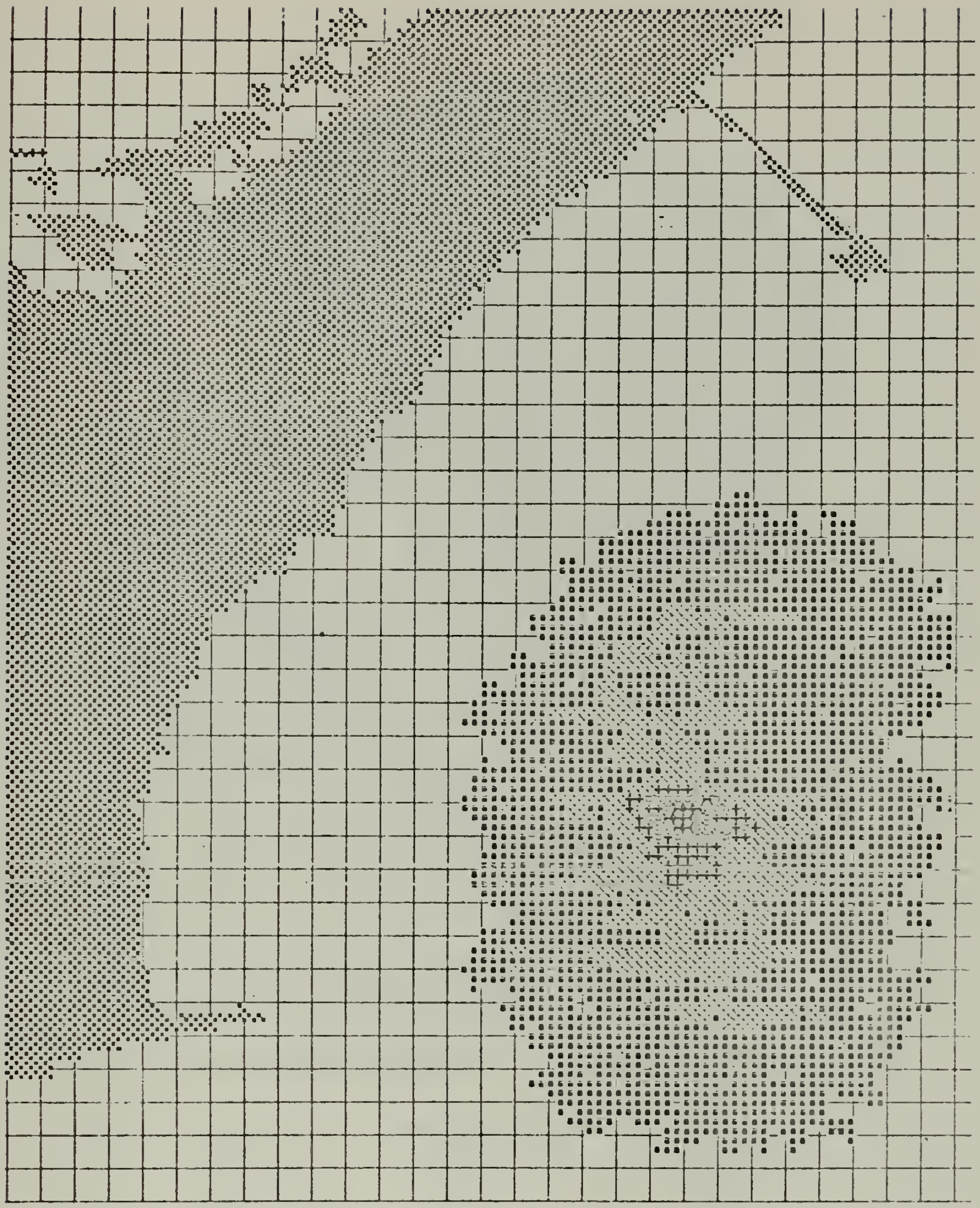


FIGURE 3 - from PG & E Moss Landing survey data



LEVELS ⁙ 1 ▨ 2 ▦ 3 ▩ 4 ▓ 5

Moss Landing IR Survey, 10-6-70
conducted by PG & E

LEVEL	TEMP. RANGE (DEG. F)	NUMBER OF AREA ELEMENTS	AREA (SQ.FT.)
1	57.01 - 59.00	2078	13660
2	59.00 - 61.00	459	93491
3	61.00 - 63.00	50	10183
4	63.00 - 65.00	30	6110
5	65.00 - 67.00	9	1832

AREA OF ONE ELEMENT (SQ. FT.) = 203.69

TIME OF PASS = 1420

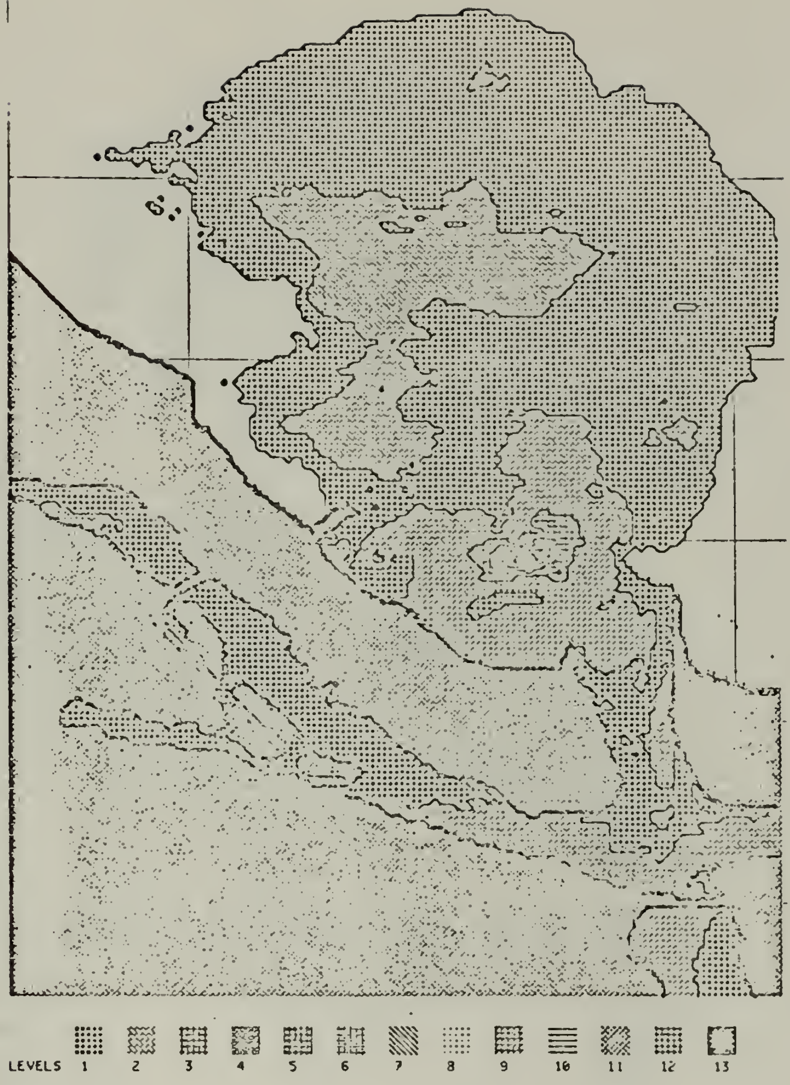
ALTITUDE (FEET) 1000

HEADING (DEG. FROM NORTH) 320

SPEED (MPH) 105

DISTANCE SCALE (100 FEET BETWEEN MARKS) I I

FIGURE 4



LEVEL	TEMP. (DEG. F)	NUMBER OF AREA ELEMENTS	AREA (SQ.FT.)
1	56.93 - 58.00	6836	7133400
2	58.00 - 60.00	3234	3374600
3	60.00 - 62.00	92	96002
4	62.00 - 64.00	27	28174
5	64.00 - 66.00	17	17739
6	66.00 - 68.01	4	4173
7	68.01 - 69.99	1	1042
8	69.99 - 72.00	1	1042
9	72.00 - 74.00	0	0
10	74.00 - 76.00	1	1042
11	76.00 - 78.00	0	0
12	78.00 - 80.00	0	0
13	80.00 - 82.00	0	0

AREA OF ONE ELEMENT (SQ. FT.) = 1043.51
TIME OF PASS = 1326
ALTITUDE (FEET) 2000
HEADING (DEG. FROM NORTH) 20
SPEED (MPH) 100
GRID SIZE IN FEET = 1000
MOSS LANDING IR TEST 12/6/70

FIGURE 5 Moss Landing IR Survey Analysis conducted by PG & E

```
LEVEL     TEMP. (DEG. F)          NUMBER OF AREA ELEMENTS          AREA (SQ.FT.)
1         56.99 - 58.00                4917                        6053900
2         58.00 - 60.00                2302                        2834320
3         60.00 - 62.00                147                         180991
4         62.00 - 64.00                43                          52942
5         64.00 - 66.00                18                          22161
6         66.00 - 68.01                11                          13542
7         68.01 - 69.99                7                           8617
8         69.99 - 72.00                1                           1230
9         72.00 - 74.00                1                           1230
10        74.00 - 76.00                1                           1230
11        76.00 - 78.00                2                           2461
12        78.00 - 80.00                0                           0
13        80.00 - 82.00                0                           0
AREA OF ONE ELEMENT (SQ. FT.) = 1231.24
TIME OF PASS = 1345
ALTITUDE (FEET) 3000
HEADING (DEG. FROM NORTH) 30
SPEED (MPH) 100
GRID SIZE IN FEET = 1000
MOSS LANDING IR TEST 12/6/70
```

Figure 6 Moss Landing IR Survey Analysis conducted by PG & E

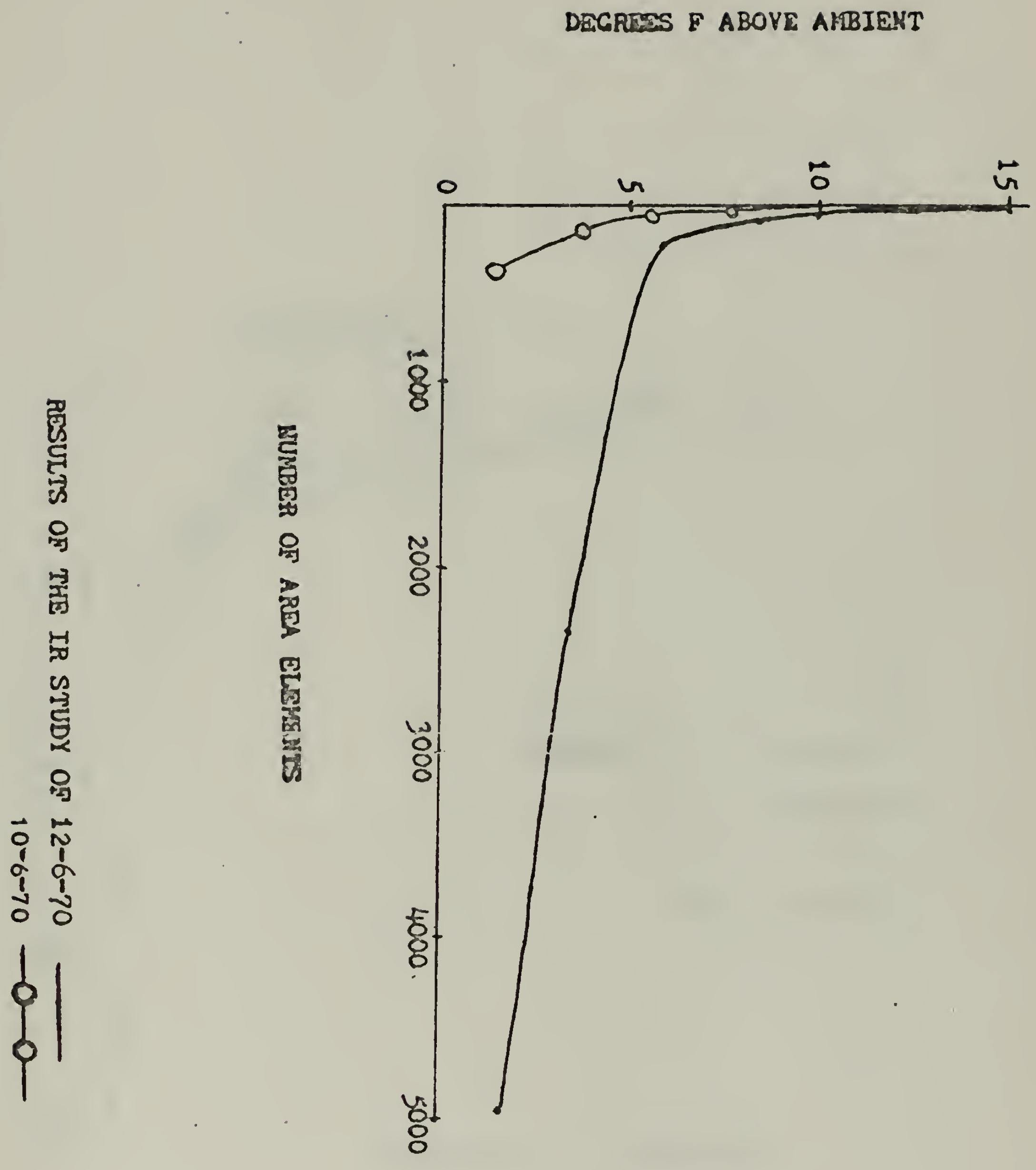

DEGREES F ABOVE AMBIENT
0
5
10
15
1000
2000
3000
4000
5000
NUMBER OF AREA ELEMENTS
RESULTS OF THE IR STUDY OF 12-6-70
10-6-70

FIGURE 7

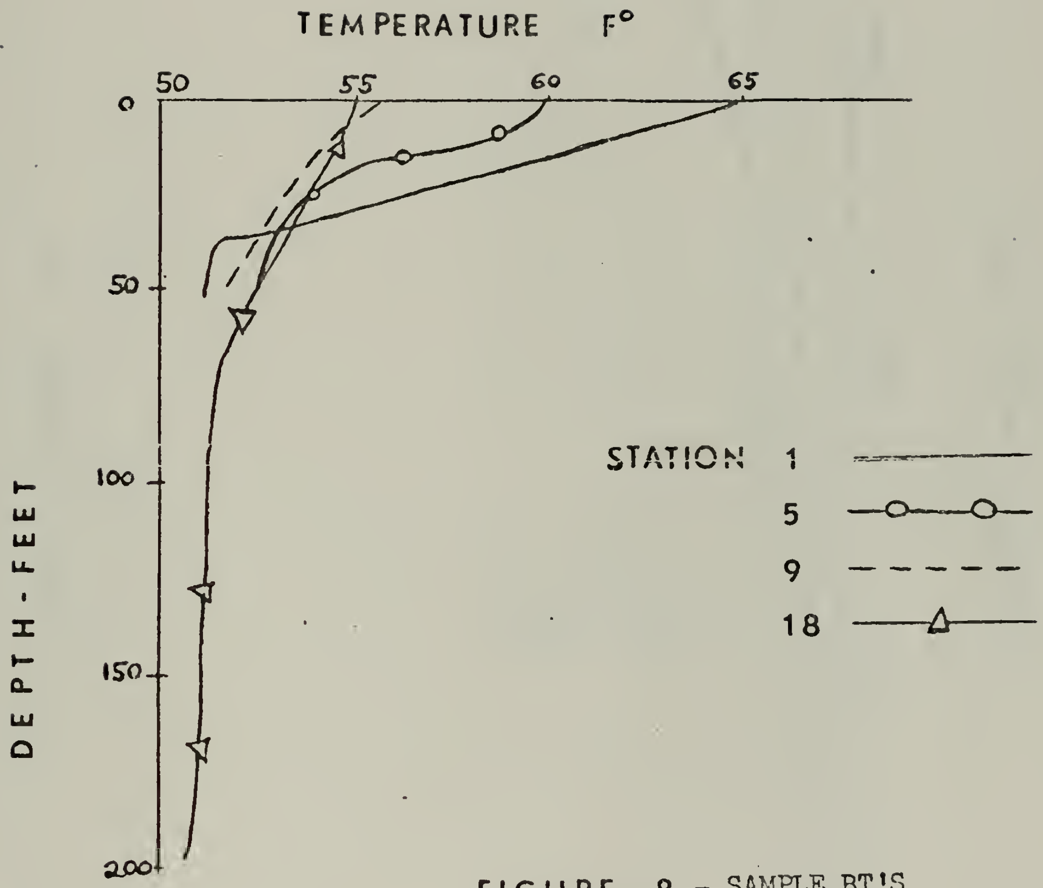
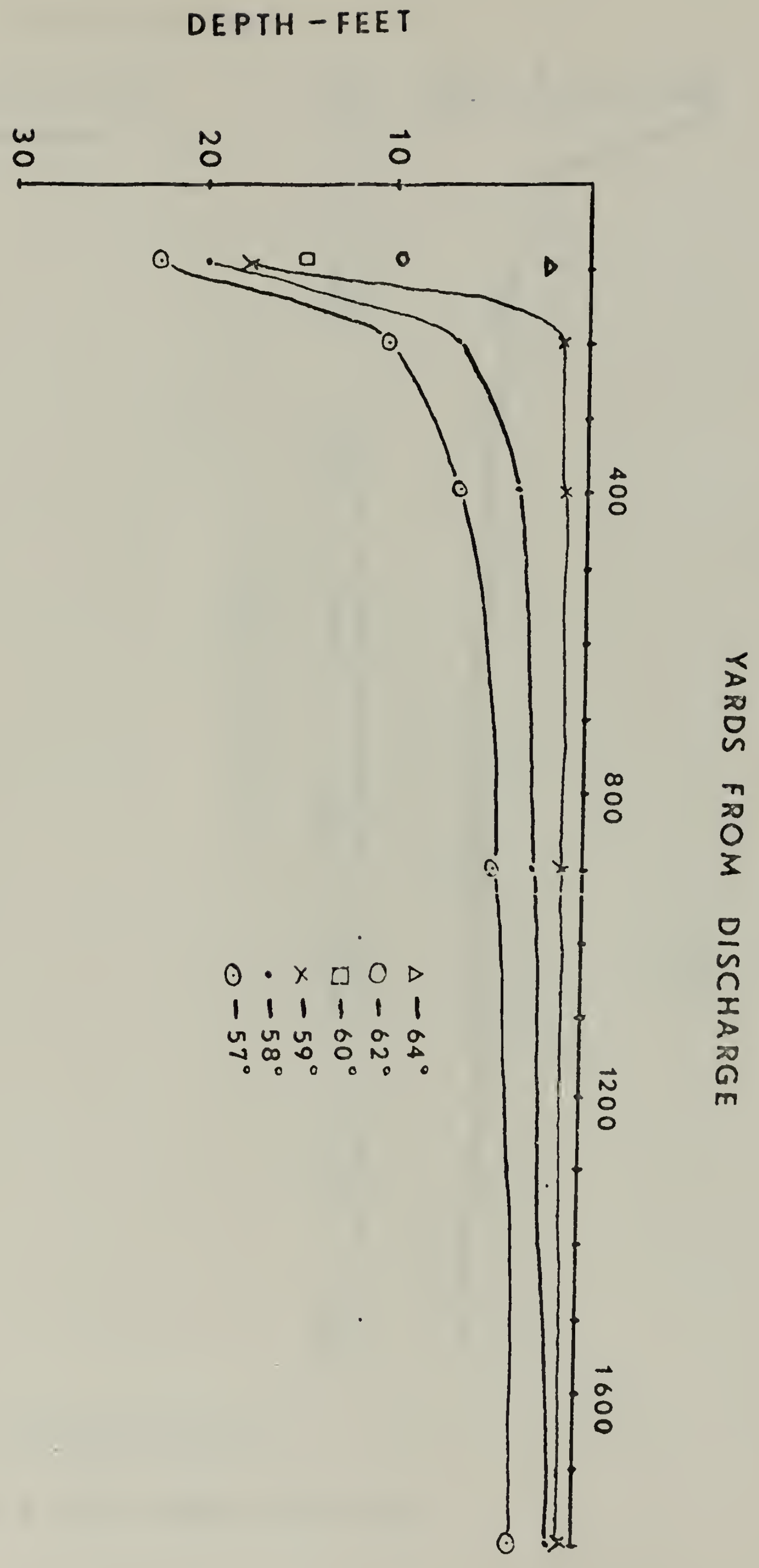


FIGURE 8 - SAMPLE BT'S

from PG & E Moss Landing BT data



BT RESULTS — FIGURE 9

FIGURE 9

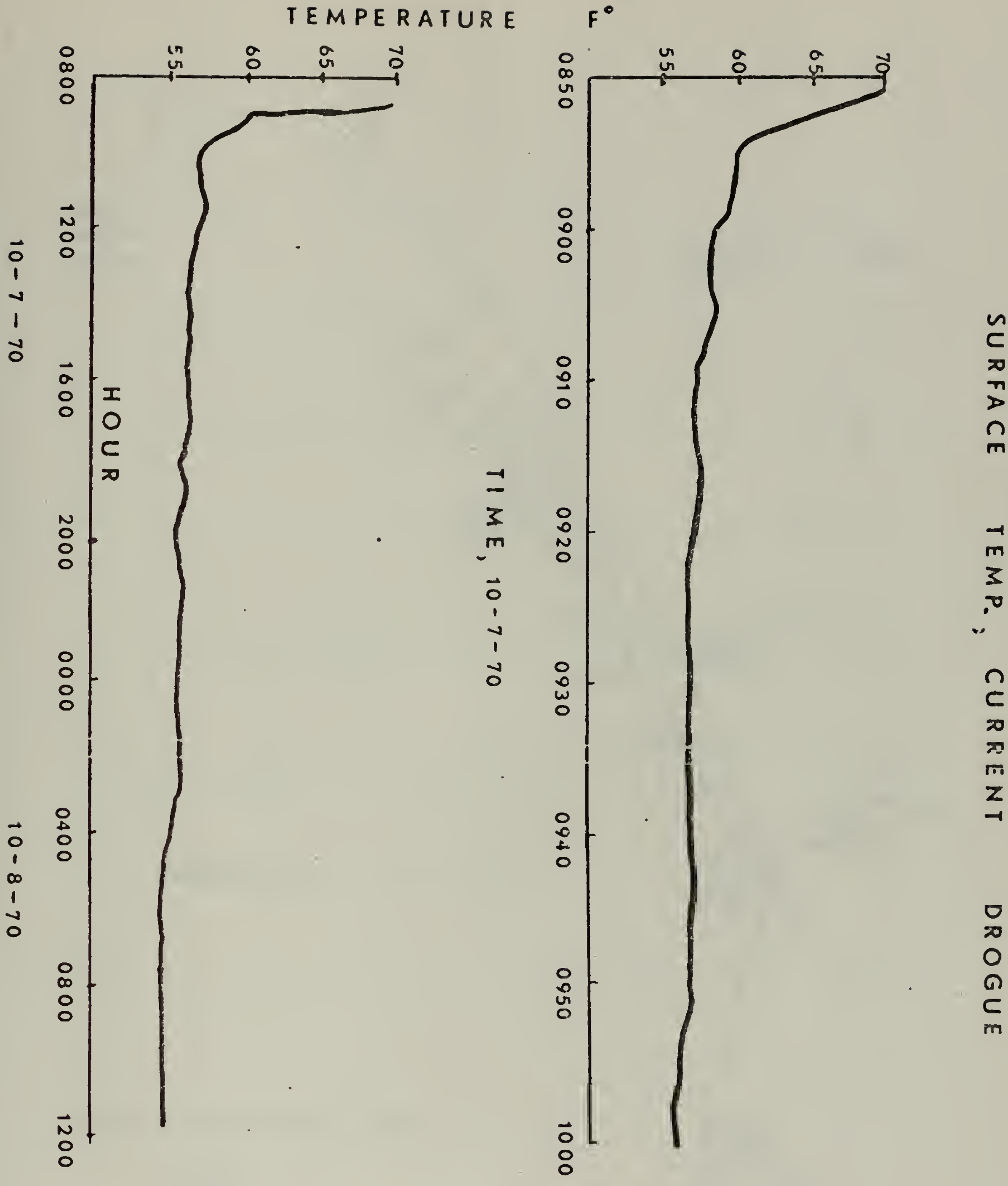
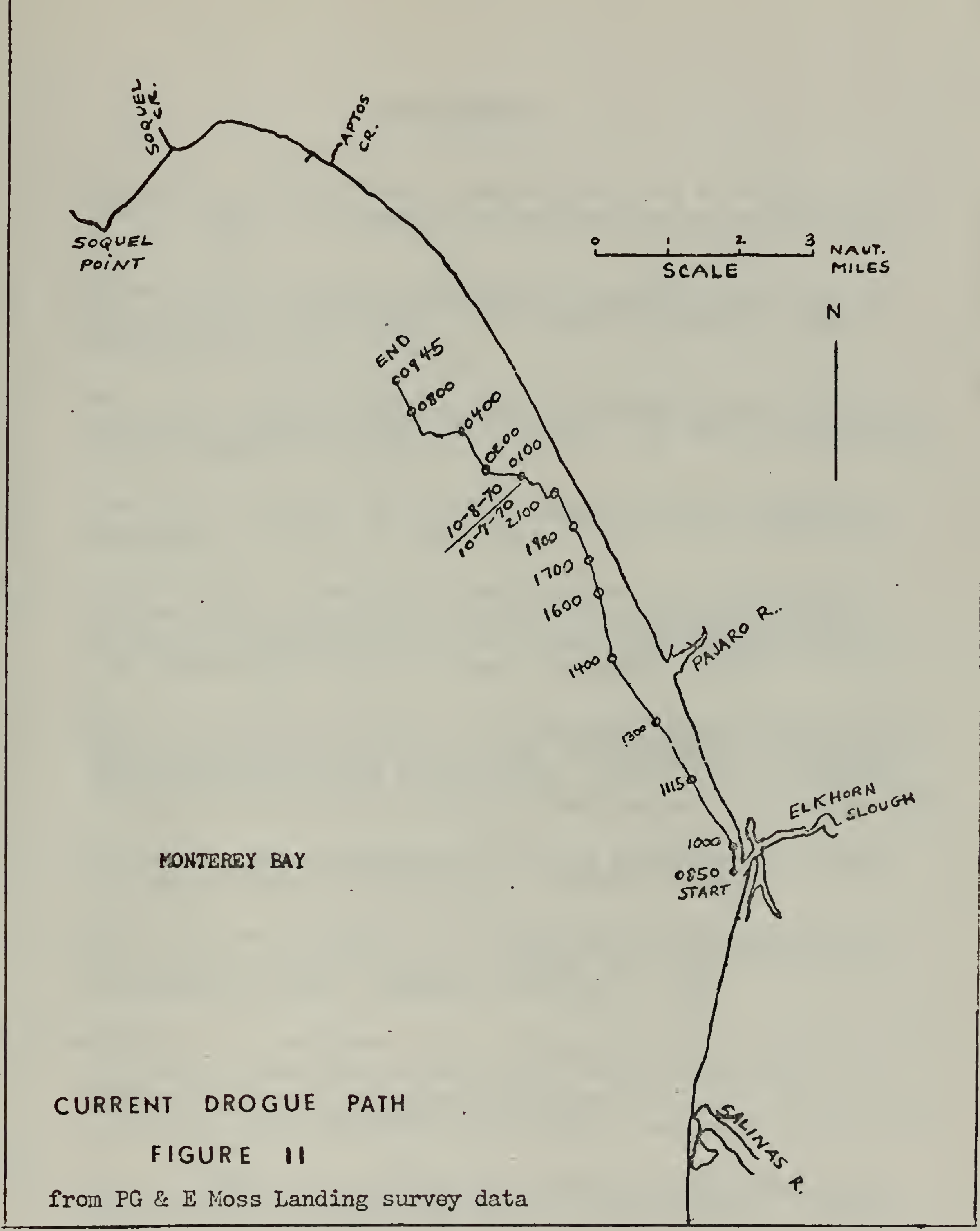


FIGURE 10

from PG & E Moss Landing survey data



CURRENT DROGUE PATH

FIGURE 11

from PG & E Moss Landing survey data

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13. ABSTRACT

The effects of a power plant discharge into Monterey Bay at Moss Landing are investigated. Possible effects of increased temperatures upon the metabolic and behavioral patterns of biota are presented. These effects are usually very subtle, and depend upon the physical as well as the biological characteristics of an area. Temperature with increasing area surrounding the discharge. Due to changing physical conditions, the size and shape of the warm water "plume" are subject to appreciable variations. Heat budget calculations predict only a small amount of the heat discharged into the Bay excapes to the atmosphere, although turbulence near the discharge probably accounts for a much larger heat loss to the atmosphere than predicted by calculations.

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