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April 1968

Technical Progress Report No. 3

TEMPERATURE EFFECTS IN CLEAR LAKE AND GALVESTON BAY

Prepared for:

HOUSTON LIGHTING & POWER COMPANY
HOUSTON, TEXAS

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SwRI Project No. 21-1608

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SUMMARY AND CONCLUSIONS

The study of temperature effects in Clear Lake and Galveston Bay was initiated in 1964 when a series of temperature distribution studies were made in Clear Lake prior to the operation of the No. 3 generating unit at the Webster Station. The results of these studies were previously reported in Technical Progress Report No. 1 submitted in August of 1965.

In early 1965, the No. 3 unit started operation and increased generation capacity from 220 megawatts to approximately 570 megawatts. The cooling water canal system was changed with the addition of a new four-mile discharge canal entering Clear Lake from the south. A relative evaluation of the lake performance as a source of cooling water was made in July of 1965 with generation at approximately 525 megawatts and the entire coolant flow diverted through the new discharge canal. The presence and relative abundance of the various types of plankton at selected locations on Clear Creek and Clear Lake was also determined.

Temperature distribution studies were repeated in 1966 with power generation the same but the coolant flow was distributed between both discharge canals. The plankton sampling and analysis were also duplicated and a letter report was submitted on August 8, 1966. A temperature distribution study was also conducted at Bacliff, the point of discharge for the P. H. Robinson Station which at that time had a generation capacity of 450 megawatts.

The temperature distribution studies at Clear Lake were not repeated in the summer of 1967. However, a study of the dissolved oxygen balance in the cooling water system was made and Technical Progress Report No. 2 entitled "Oxygen Balance of the Webster Generating Station Cooling Water Canal System" was submitted in November of 1967. The plankton sampling and analysis were again duplicated.

Based upon the investigations conducted by Southwest Research Institute, the following conclusions and recommendations are made:

1. Under the present system configuration and generation capacity at Webster Station, it is improbable that the plant intake temperatures will be affected by short-circuiting of heated cooling water. The major influence on intake temperatures will be meteorological conditions.

2. The interrelation between the two discharges in Clear Lake under present conditions is relatively minor, and the two lobes of heated water are separated by an area of water only slightly higher than the ambient water temperature.

3. Thermal stratification in Clear Lake is insignificant except near the new canal outlet during mild wind conditions.

4. The area of water in Clear Lake which is at an elevated temperature does not vary significantly but does shift in position due to wind and tides.

5. From 15 to 25 percent of Clear Lake can be above normal lake temperatures. The normal temperatures in Clear Lake during July may be two to three degrees higher than Galveston Bay water temperatures.

6. At the new canal discharge to Clear Lake the area of heated water has been observed, under maximum values of plant loading, to reach from shore to shore with temperatures three degrees above the normal lake temperature. This condition might temporarily restrict migration routes of some marine organisms.

7. Additional expansion at Webster is not recommended under the current canal configuration. Expansion of generation capacity might be accommdated by relocation of heated water discharge points.

8. No significant differences in plankton distribution or relative numbers in Clear Lake have been observed over the 1965 to 1967 period.

9. The use of airborne temperature sensing equipment should be seriously considered for future temperature distribution studies of this type.

I INTRODUCTION

The study of temperature effects in Clear Lake and Galveston Bay began in 1964 for Houston Lighting & Power Company. Since then a series of field studies has been conducted to evaluate the thermal effects of the Webster Generating Station and the P. H. Robinson Generating Station upon their respective cooling water sources.

The Webster Generating Station is located southeast of Houston between the towns of Webster and League City. Until 1965 the station operated with two steam electric units with a net capacity of 110 megawatts each. Cooling water was taken by canal from Clear Creek and was discharged through a 3.8 mile long canal which enters Clear Lake from the west. In 1965 a third unit of 350 megawatts net capacity was installed. A new canal constructed to accommodate increased flows from Unit No. 3 is four miles long and enters the lake from the south.

Clear Lake is a shallow lake of approximately 1,500 acres. It has a channel with a maximum depth of 12 feet running from Galveston Bay to Clear Creek. The maximum depth of Clear Lake at mean low water is between three and four feet. The average range of tide is approximately one foot, and the tidal influence is observed well up Clear Creek. There are several small streams feeding Clear Lake from natural run-off as well as from large areas of irrigated rice land.

The P. H. Robinson Generating Station is on Highway 146 near Bacliff. The station began generation in May of 1966 with Unit No. 1 which has a capacity of 450 megawatts. Commercial operation of the 450-megawatt Unit No. 2 began in April 1967 and Unit No. 3 with a capacity of 565 megawatts is scheduled to start in late 1968. The station takes cooling water from Dickinson Bayou and discharges it to Galveston Bay between Bacliff and San Leon.

The map shown in Figure 1 illustrates the relationship of these locations to each other and also to the W. A. Parish Station for which similar studies are being conducted by Southwest Research Institute.[6]

This project was authorized and initiated in 1964 under SwRI Project No. 21-1608. Its purpose was to provide information on temperature distribution and related effects in Clear Lake and in Galveston Bay as a result of present and future operation of power plants at Webster and Bacliff. Such information is vital to long-range planning for future installation of generating capacity.

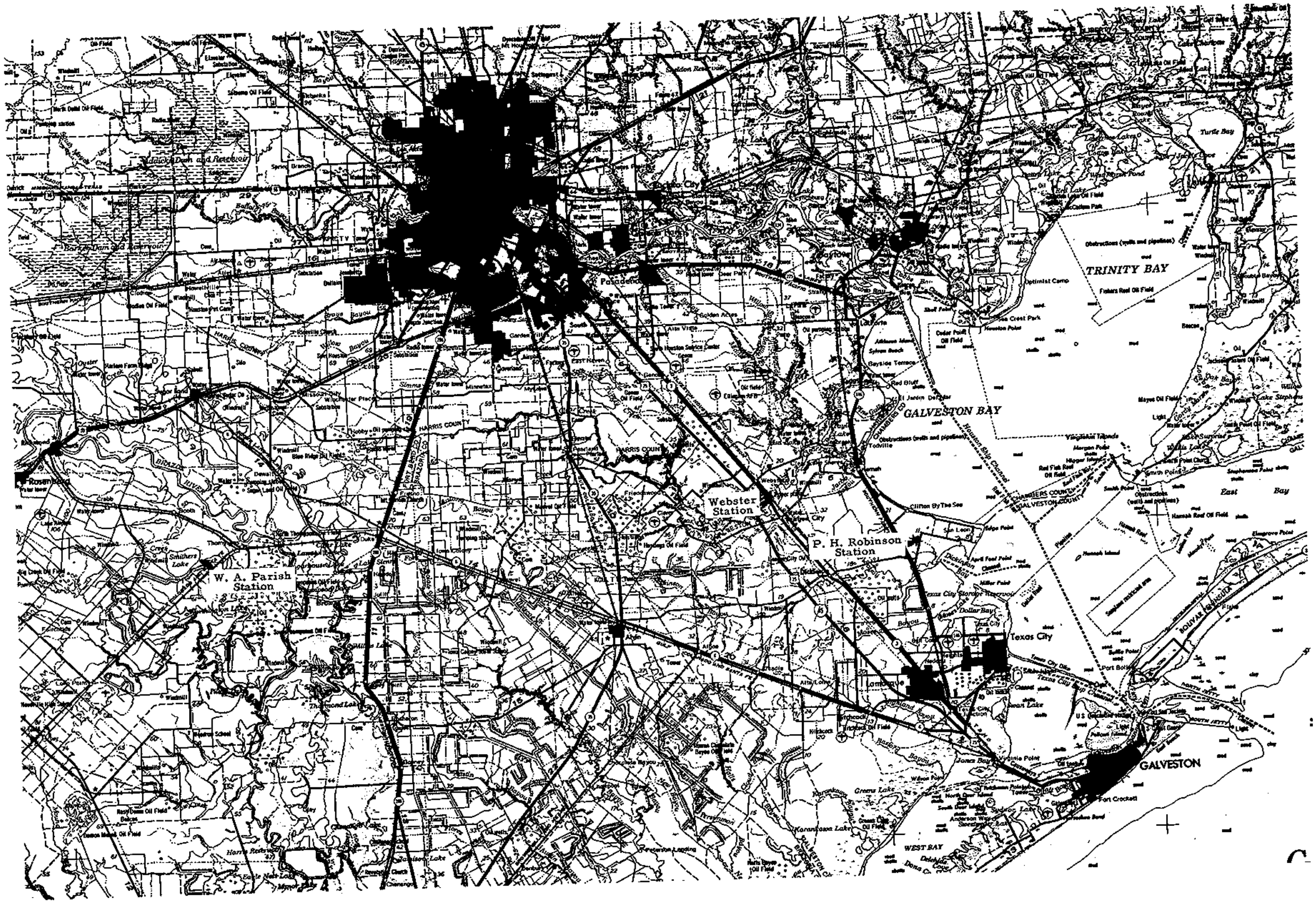


Figure 1

HOUSTON AREA MAP SHOWING PARISH, WEBSTER, AND ROBINSON STATIONS

The specific objectives of this investigation are as follows:

(1) Determine the ultimate cooling potential at the Webster and Bacliff sites within the limits of 110 degrees and 105 degrees F respective discharge water temperatures. These temperature limits have been set by the Water Pollution Control Board.

(2) Determine the temperature limits which do not adversely affect other uses of the bay system.

(3) Determine what interference might exist between the cooling systems of these two stations as a result of water circulation patterns.

(4) Provide sufficient physical and biological data to demonstrate what effect, if any, these cooling systems have on the marine life and pollution assimilation capacity of these waters.

As an extension of this project in 1967, an investigation of the dissolved oxygen balance in the Webster cooling canal system was conducted. Its objective was to provide a basis for evaluation of the role played by the Webster station in the overall oxygen balance of Clear Lake.

Some of the objectives of the studies have been met by submission of two previous reports. The temperature distribution studies at Clear Lake which were conducted in December 1964 and January 1965 have been reported in Technical Progress Report No. 1, entitled The Study of Temperature Effects in Clear Lake and Galveston Bay which was submitted in August 1965.[4] The studies involving the oxygen balance have been reported in Technical Progress Report No. 2, Oxygen Balance of the Webster Generating Station Cooling Water Canal System, which was submitted in November 1967.[5]

The remaining objectives excepting those involving future investigations will be satisfied in this document.

The project was conducted in the Houston office of Southwest Research Institute under the direction of Dr. H. C. McKee, Assistant Director, Department of Chemistry and Chemical Engineering; L. L. Hiser, Manager, Air and Water Pollution Research; Ralph E. Childers, Senior Research Engineer; Rudy Marek, Research Chemist; and Don Carter, Laboratory Assistant.

Participating in the studies for Houston Lighting & Power Company were F. E. King, Superintendent, Webster Station; D. A. Buell, Assistant Plant Superintendent, Webster Station; L. J. Bennett; and other members of the Webster Station staff whose assistance was greatly appreciated.

Administration of the project for Houston Lighting & Power Company was handled by H. G. Hiebeler, Engineering Consultant, and logistics coordination was provided by William Menger, Results Engineer.

II SCOPE AND METHODS

The scope of the field work was confined to summer month synoptic surveys in which the temperature distributions were determined. A compromise between extent of lake surface coverage and the time required for an individual survey was necessary. More accuracy in temperature profiles is theoretically possible by collection of larger quantities of field data provided that data collection is properly distributed over the entire lake area. The time required to complete a survey is proportional to the amount of data collected. Because of variation of water temperatures with time, it is essential to minimize the time required in order to avoid distortion of the temperature profiles. Therefore, synoptic studies were designed to include as much data as could be acquired in two to three hours time using the available transportation and measuring equipment.

Surveys were scheduled such that measurements were made under various weather and tide conditions — at night and during the day. During a survey all available weather data were recorded as well as selected plant operation data.

Water temperatures were measured at three or four depths using a multi-channel recorder and associated thermocouples. The thermocouples were mounted on a float which could be towed alongside a boat. Speeds up to five mph were possible with this equipment configuration except during runs made at low tide. The boat was piloted at a constant speed from one checkpoint to another while an essentially continuous temperature record for each depth was produced by the strip chart recorder on the boat. In this manner the data could later be located properly on a map of the lake. Methods of data reduction have undergone an evolution during the project and this evolution has led to more objective data processing and more meaningful results. In the methods an isotherm map was the usual result from which other data, such as average surface temperature, could be estimated.

On at least one occasion during the summer months water samples were collected at selected locations in Clear Lake and Clear Creek and subjected to microscopic analysis. The results of the microscopic analysis provided data on the types and abundance of zooplankton (animal kingdom) and phytoplankton (plant kingdom). Individual species, however, were not considered separately. A more detailed description of techniques used will be given in the respective section as the results are presented.

It is from these isotherm maps and biological data that the conclusions and recommendations of this report have been drawn. Much of the data evaluation technology was developed jointly with a parallel and simultaneous study of temperature distribution in Smithers Lake at the W. A. Parish Station under a separate project. The results of the Smithers Lake studies are presented in Technical Progress Report No. 1 under the title Temperature Distribution in Smithers Lake.[6] Theoretical relations between heat transfer at the water surface and meteorological variables and water surface temperatures have been presented by Edinger and Geyer as a part of Edison Electric Institute Research Project No. 49.[1] These theoretical considerations and continuing studies by Edison Electric Institute at Smithers Lake have provided valuable guidance in the evaluation of field data for this project.

III TEMPERATURE DISTRIBUTION IN CLEAR LAKE

Before 1965 the Webster Station had two steam electric generating units of 110 megawatts each and the cooling water was discharged through a 3.8 mile canal which entered Clear Lake at the west end. In December 1964 and January 1965 the temperature distribution in Clear Lake was determined and the results have been presented in Technical Progress Report No. 1, The Study of Temperature Effects in Clear Lake and Galveston Bay.[4]

Under the conditions existing at that time, approximately one-third of the lake was above the ambient water temperature. The lake appeared to be well mixed and wind and tide had little effect on the heated area but the location of this heated zone was greatly dependent on both wind and tide conditions. During the winter months, it was found that the heat dissipated in the discharge canal and was as much as one-third of the total heat load. The ambient lake temperature varied from 55 to 70 degrees and the condenser intake temperatures closely approximated the ambient temperature. The maximum condenser discharge temperature was 84 degrees with a corresponding canal outlet temperature of 78 degrees. The mean temperature of the heated area of the lake was from two to four degrees above the ambient lake temperature. These findings suggested that future work should be concentrated during summer months when maximum station loads and highest lake temperatures could be expected.

The 350-megawatt Unit No. 3 went into operation in 1965. A new canal, four miles long, discharged the heated cooling water into a small bay in the southern part of the lake. In normal operations the combined coolant flow from all three units was divided between the two discharge canals. The relationship of these canals to the lake is shown in Figure 2. There was some flexibility in this division of flow but accurate or variable division was not possible.

For the studies in the summer of 1965 only the new discharge canal was used and the old canal was blocked. The studies in 1966 were made with both canals in use. The results of these studies will be presented in the following subsections.

Temperature Distribution in 1965

During July of 1965 eight temperature distribution surveys were made. Four runs were made during the daytime at high tide conditions and four runs were made at night during low tide conditions.

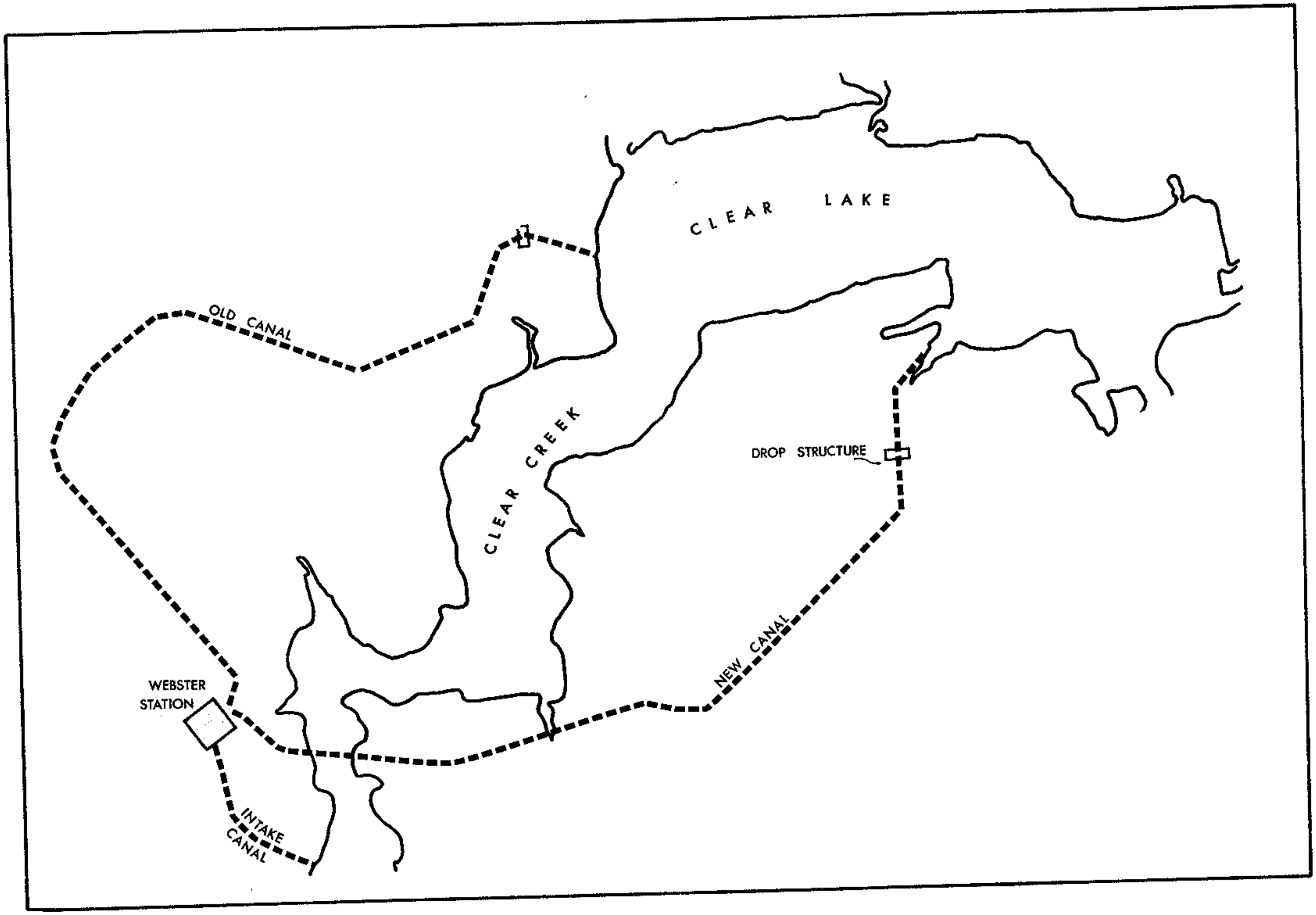


Figure 2

MAP OF WEBSTER GENERATING STATION CANAL

The cooling water flow was entirely through the new canal. Flow was limited by a siphon structure in the new canal and one circulating water pump on Unit No. 3 had to be shut down. The resulting flow was 314,000 gallons per minute (1,380 acre-feet per day) which represented approximately one-third of the lake contents per day. This approximation does not take into consideration the volume of Clear Creek.

The traverse pattern shown in Figure 3 was used with the same measuring equipment and techniques as for the previous studies. The first four traverses started at Beacon No. 17 (formerly Beacon No. 15) and extended outward as shown. The remaining traverses started at the canal outlet and extended in the directions indicated. This was the normal pattern used, however, some variation was necessary at low tide. The traverses were made proceeding clockwise at each point with the final traverse terminating at Beacon No. 13 (formerly Beacon No. 11) at the lake outlet. A constant boat speed of about five miles per hour was possible during high tide; however, the speed was necessarily reduced during low tide to reduce equipment damage in shallow water. The return trip to the starting point of the next traverse was made at the maximum safe speed over a route not disturbing the next traverse. Water temperatures were measured at depths of one-half foot, one foot, and two feet. The temperatures were measured by float-mounted thermocouples which were towed along beside the boat, and were recorded on the multi-channel recorder. The hand-held thermocouple was held at the maximum depth possible which was generally on the bottom or otherwise between three and four feet deep. The runs took two to three hours to complete depending upon wind and tide conditions.

Over the period from July 11 through July 16 all available meteorological data and plant operation data were recorded at hourly intervals. Much of the weather data is from the Weather Bureau at the Houston International Airport, about 15 miles from Clear Lake. These data are supplemented where appropriate with weather data from the Webster Station. These data are shown graphically in the following figures. The time and duration of each run is shown by the shaded bands in the figures. These graphs all have the same time axis so that the simultaneous inspection of variables is facilitated.

The wet-bulb and dry-bulb air temperatures are shown in Figure 4a. These data are from the Weather Bureau and the data were available at three-hour intervals. Hourly records normally taken at the Webster Station are consistent with these temperatures. There was no precipitation during this series of surveys.

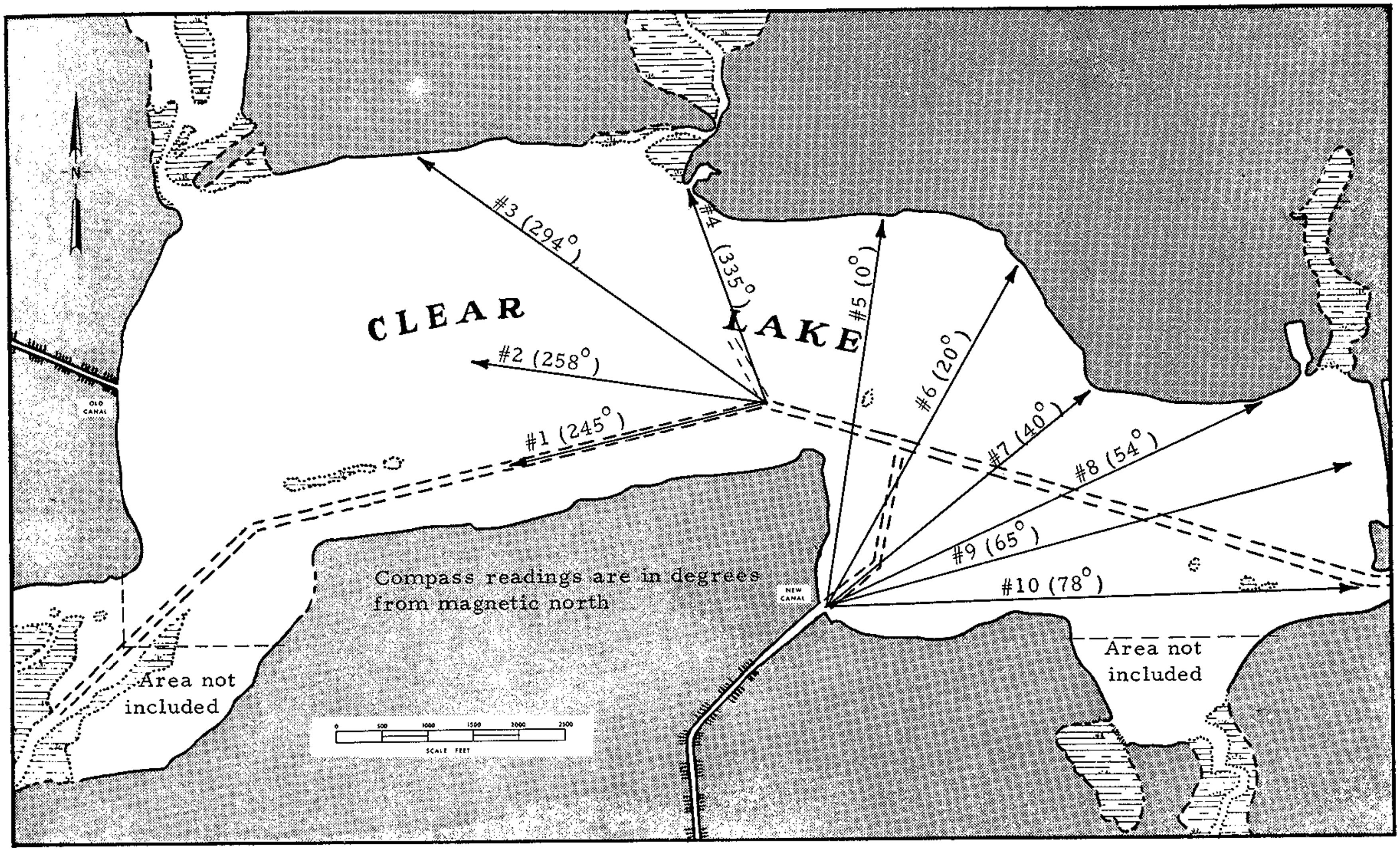


Figure 3

TRAVERSE PATTERN IN CLEAR LAKE
FOR 1965 SURVEYS

There was no wind instrumentation available at the Webster Station; therefore, the wind velocity and direction data shown in Figures 4b and 4c are from the Weather Bureau. The wind direction is recorded in degrees from north.

The tide elevation at the Webster Station intake is shown in Figure 4d. This series of field studies was scheduled to be done during a period during which had a single high and single low tide daily. It can be seen from Figure 4d that there were no mixed tides during this period.

The intake and discharge temperature shown in Figure 4e are taken from the Daily Condenser and Station Auxiliary Report for Webster Station Unit No. 2. The intake temperature of Unit No. 2 was often slightly higher than that for the other units. Since the operation of each unit is affected by absolute rather than average temperatures, the unit with what appears to be the "worst case" is illustrated. Since no study of the intake canal was made it is unexplained why temperature differences should exist since the intakes are adjacent.

The gross generation of Figure 4f is taken from the Consolidated Load Report for the Webster Station. The net generation is approximately five percent less. The gross load in megawatts is the total of all three units. The station was purposely operating at near maximum loads on Units Nos. 1 and 2 while the new Unit No. 3 was held at 85 percent of capacity since it was still in test status. The station was released from constant loading on July 18 after the completion of these studies.

The temperature data from the strip chart recorder used for field studies were transferred to a map of the lake, a rather laborious process when done manually. Since the boat traveled at a constant speed, the distance between reference points on the strip chart is proportional to the distance between the corresponding points on the map. With suitable reference points reasonably accurate data transfer is possible.

After the temperature data for each depth had been properly located on the maps, contour lines could be drawn. This process, requiring considerable experience and a fair amount of imagination, is also time-consuming and laborious. Ordinarily, lines of constant temperature would be drawn and the result called an isotherm map. The process here was only slightly different. Areas of equal temperature are separated by the lines since temperature data have been transferred to the map as nearest whole degrees Fahrenheit.

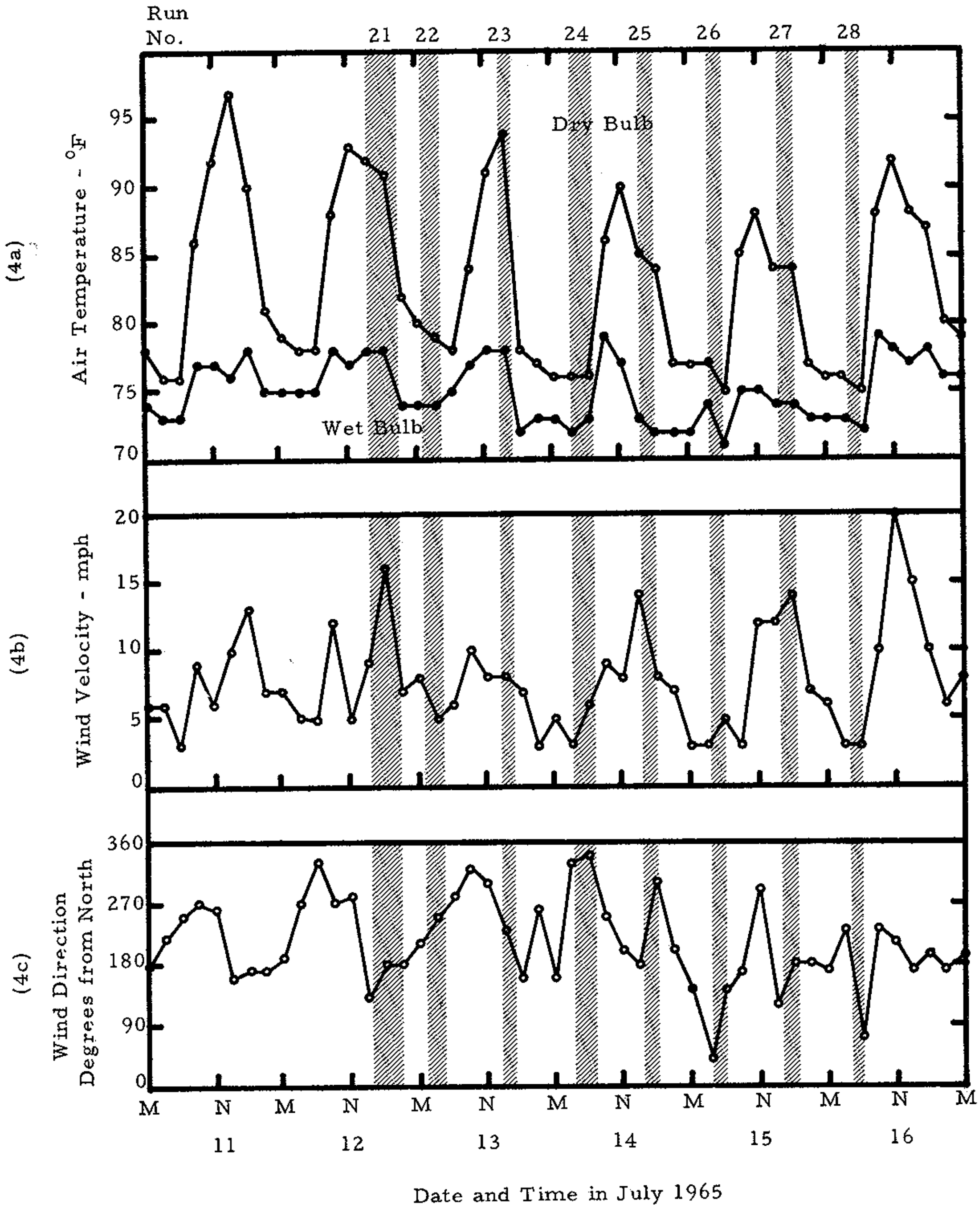


Figure 4a, b, c

METEOROLOGICAL DATA FOR 1965 SURVEY

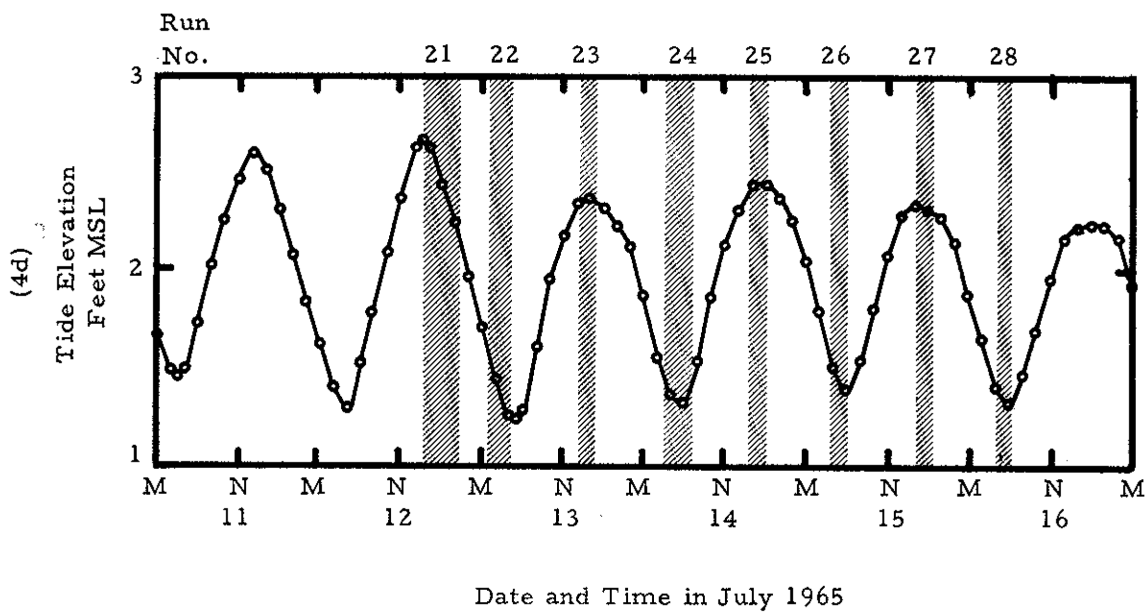


Figure 4d

TIDE ELEVATION FOR 1965 SURVEY

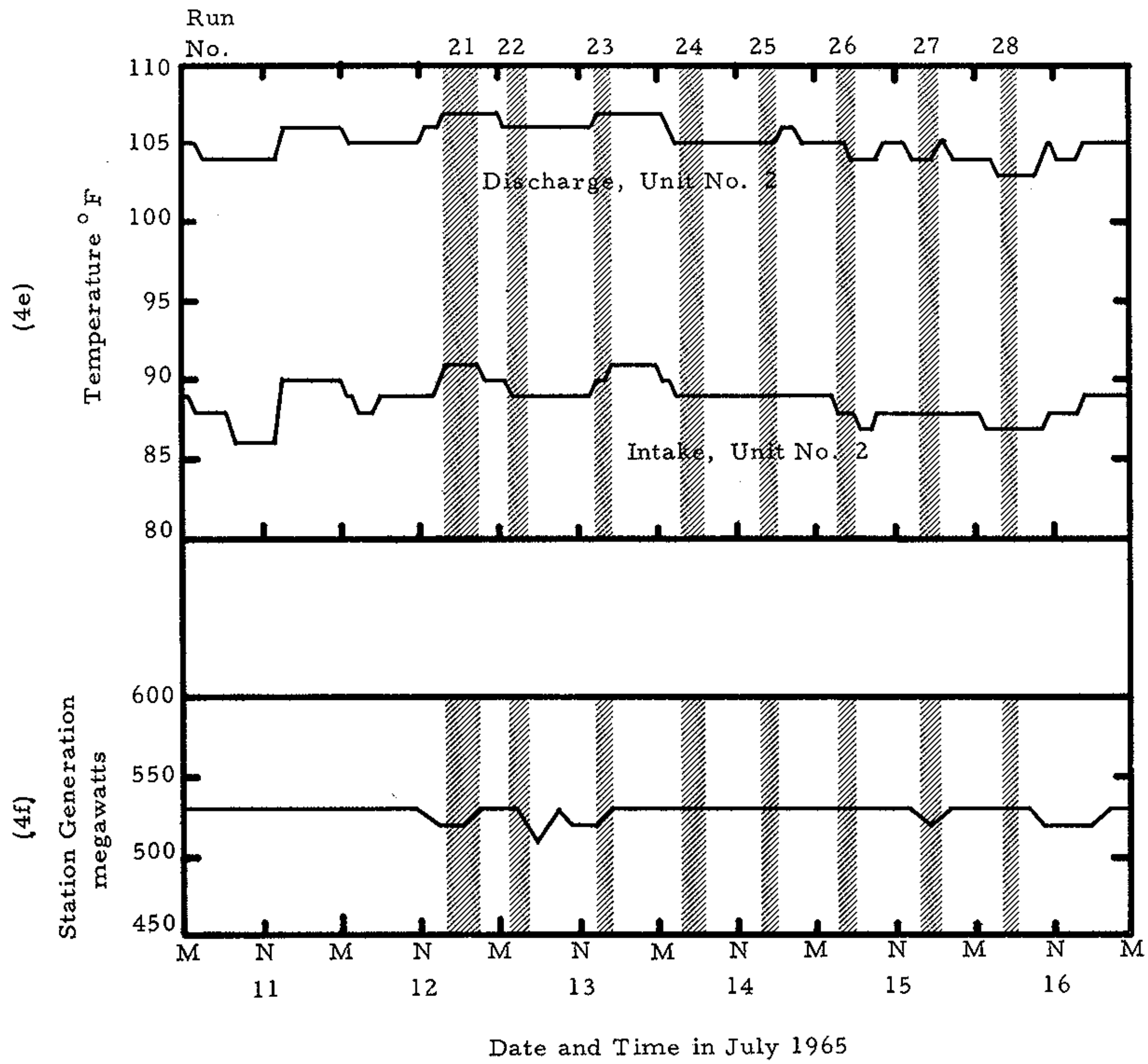


Figure 4e, f

GENERATION STATION DATA FOR 1965 SURVEY

Inspection of the resulting isotherm maps revealed that there was a great deal of similarity between runs made at the same tide conditions. The wind effects are smaller and more subtle for the range of wind conditions observed during these studies. Consequently, a single survey was selected to illustrate the temperature distribution at high tide conditions. Although there was some thermal stratification near the canal outlet, the area where there was stratification was small. Therefore, all depths are illustrated by a single isotherm map for the daytime runs at high tide conditions.

The runs at low tide conditions were similar and a single run is presented. However, at low tide the thermally stratified area became more significant and consequently an isotherm map for each depth was required to completely illustrate the results.

The results of these two typical surveys are presented in the following text of this report.

Temperature Distribution at High Tide. The results of a typical temperature distribution survey at high tide conditions are shown by Run No. 25 made on July 14, 1965. The isotherm map resulting from this survey is shown in Figure 5. This run was made at high slack-tide as shown in Figure 4d and verified by notation that slack-tide existed at the end of the run in the channel between Clear Lake and Galveston Bay. The tide elevation was 2.4 feet MSL. This run was started at 3:37 p.m. and took just two hours to complete. Since there was no significant thermal stratification the temperature distribution represents all depths excepting the deeper water in the channel.

The total generation of the station had been held essentially constant at 530 megawatts since July 11. The Unit No. 2 condenser intake temperature varied from 89 to 91 degrees during the preceding three days. A corresponding variation of 105 to 107 degrees in condenser discharge temperature was noted over the same period.

The survey was made after the daily maximum air temperature and while the relative humidity was minimum at 56 percent. Daily maximum air temperatures in excess of 90 degrees which was observed on this date are common and most of the other daytime runs of this series were made during higher air temperatures.

The winds according to field survey notes were southwest to south-southwest, producing four to six-inch ripples on the lake surface. The Weather Bureau data indicated a shift from south to west during the

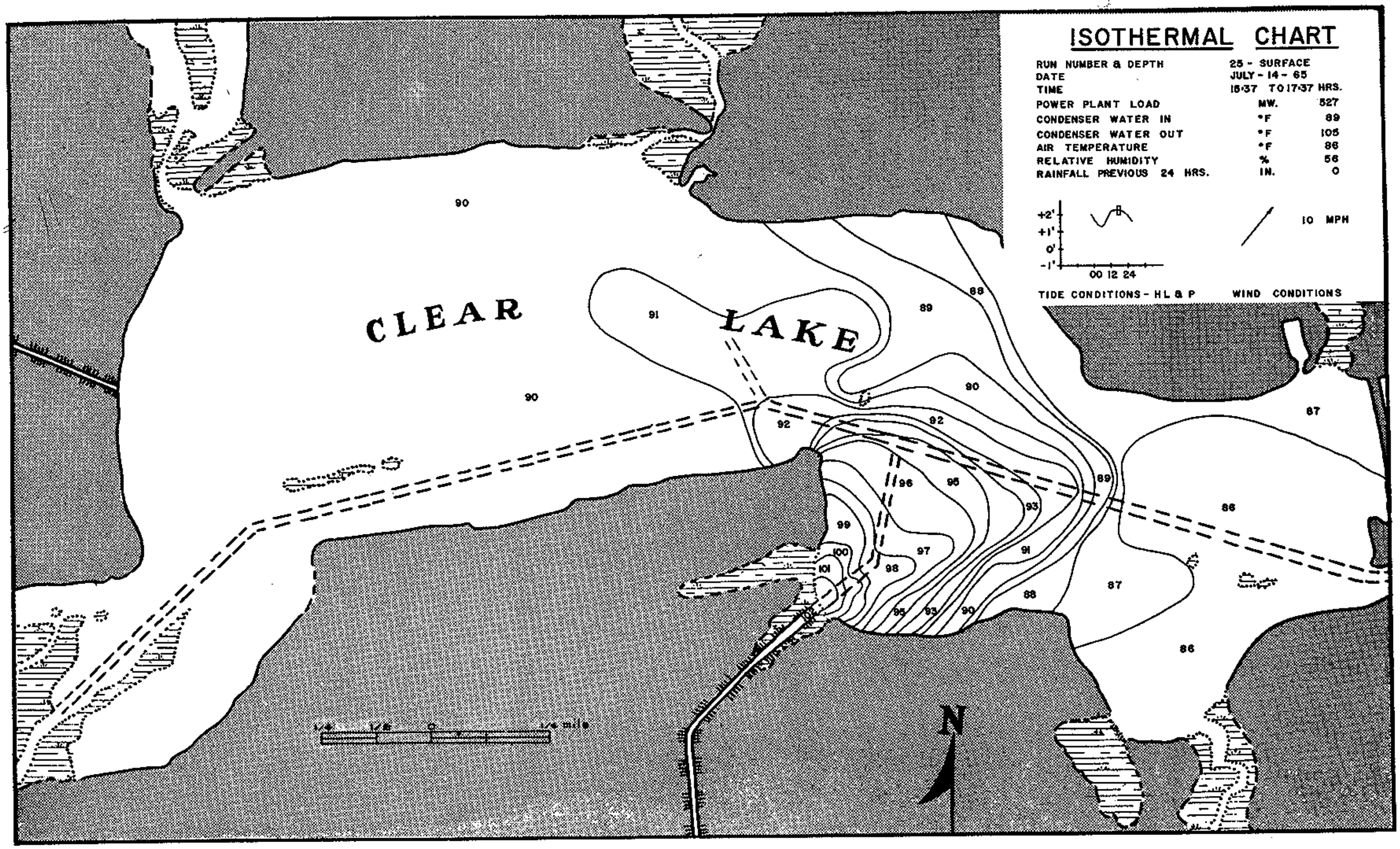


Figure 5

ISOTHERM MAP - RUN NO. 25 - SURFACE

interval of the run. The recorded velocities at the Weather Bureau, whose anemometer is 20 feet above ground, was from eight to 14 miles per hour during the run and ranged from three to 14 miles per hour from the southwest in the 24 hours preceding the run.

It is virtually impossible to accurately compute the average lake temperature or to define the area that is above the ambient lake temperature. This is due to large undefined areas of 90 degrees in the western portion of the lake. Although the lowest temperature in the lake at the east end is 86 degrees which represents essentially ambient water temperatures in Galveston Bay, the intake temperature records at the Webster Station imply that the ambient temperature of Clear Lake may be more near 89 degrees.

By making two assumptions some comparative data can be generated. First, assume a total lake area (excluding Clear Creek) of 1,150 acres. Later studies verify this value and warrant its use for comparative purposes. Second, assume that the undefined area in the western end of the lake is equally divided between 89 and 90 degrees. With these assumptions the data in Table I can be computed. The closed temperature areas are measured with a planimeter and the areas of 89 and 90 degrees in the western section are derived by difference.

Table I

AREA TEMPERATURE DATA FOR RUN NO. 25

Temperature (degrees F)	Area (acres)	Percent of Total Area[b]	Cumulative Total (percent)
99 or more	13	1	1
98	8	1	2
97	13	1	3
96	20	2	5
95	15	1	6
94	13	1	7
93	11	1	8
92	26	2	10
91	62	6	16
90	356[a]	31	47
89	368[a]	32	79
88	15	1	80
87	80	7	87
86	150	13	100

[a] Estimated

[b] Basis of 1,150 acres

Source: Southwest Research Institute

The resulting weighted average temperature of the lake is thus 90 degrees and it is to be noted that only 16 percent of the area is 91 degrees or more. Approximately 21 percent of the area is at a temperature of 86 to 88 degrees which is representative of Galveston Bay water temperatures. The remaining 63 percent of the area is at or near the ambient or normal temperature for the shallow waters of Clear Lake.

Temperature Distribution at Low Tide. Run No. 28 which was made on July 16 between 4:08 a.m. and 6:22 a.m. was typical of the temperature distribution at low tide conditions. The duration of the run spanned the low slack-tide condition. The tide elevation was 1.3 feet MSL which was 0.9 feet lower than for the high tide run. The resulting isotherm maps are shown in Figures 6a, 6b, and 6c. Since a fairly large area of thermal stratification existed an isotherm map for each measured depth is presented.

The total generation of the station had been held constant at approximately 530 megawatts since July 11. The condenser intake temperatures for Unit No. 2 ranged from 87 to 89 degrees over the preceding two days with the lower temperatures having been observed during the very early morning hours. The corresponding condenser discharge temperatures ranged from 103 to 105 degrees over the same period.

The survey was made during the daily minimum air temperature of 75 degrees and while the relative humidity was high at 86 percent. The daily maximum during this series of surveys was from 88 to 97 degrees and the daily minimum ranged from 75 to 78 degrees.

The Weather Bureau records showed that winds were southerly at three miles per hour and according to field notes, the wind six feet above the lake surface, was in the south-southwest at about two miles per hour. As a result the lake surface was complete calm, a condition which was not conducive to mixing and therefore permitted the stratification to occur.

Assuming an area of 1,150 acres and also assuming that the western end of the lake is all at 84 degrees, the data in Table II were generated.

The estimated average lake temperature can be computed from the data in Table II, assuming that each depth represents one foot of water. The average surface temperature is 87 degrees, the average at one foot is 86 degrees, and the average at two feet is 85 degrees. The weighted average is thus 86 degrees and represents almost the entire lake contents at low tide conditions.

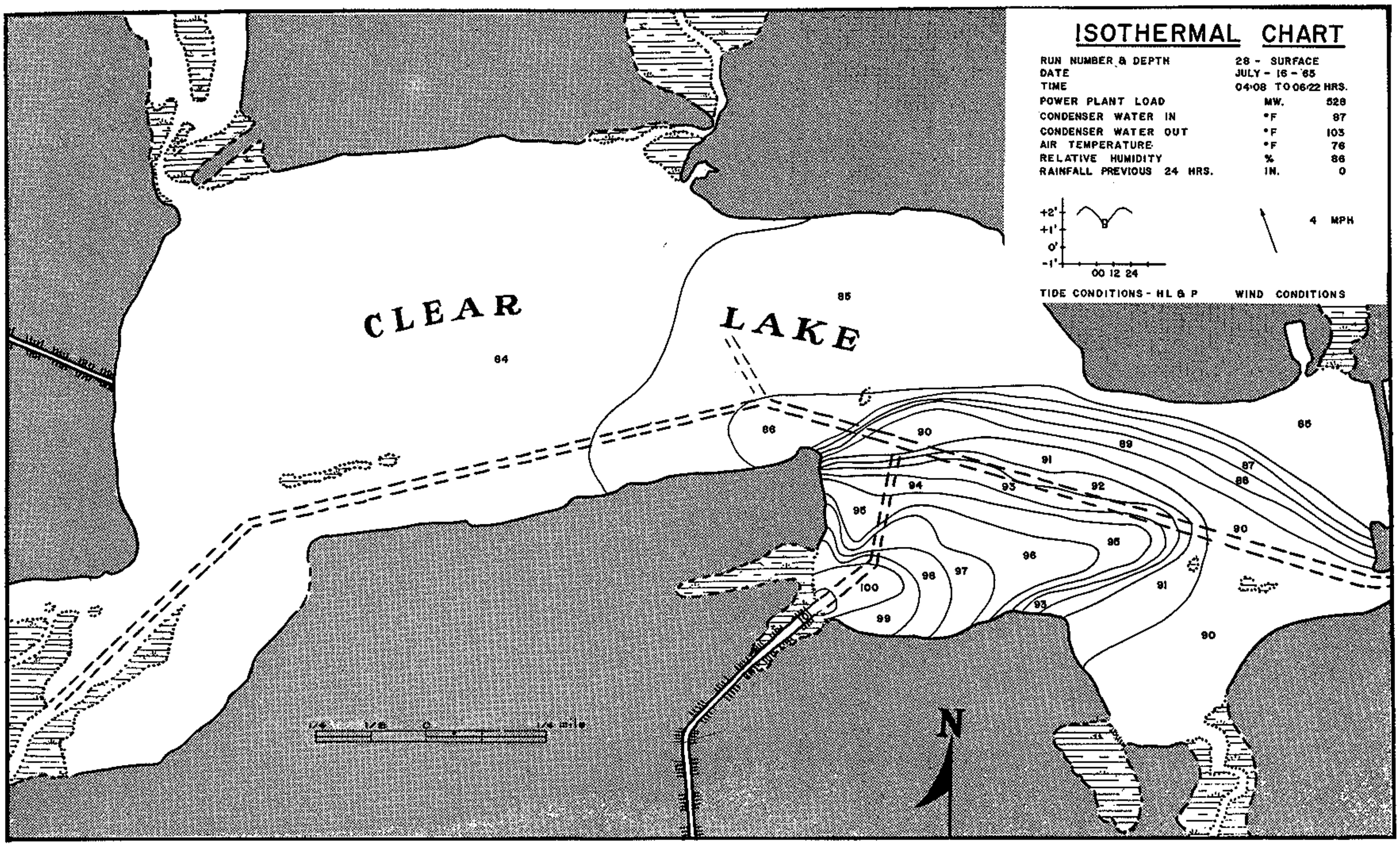


Figure 6a

ISOTHERM MAP - RUN NO. 28 - SURFACE

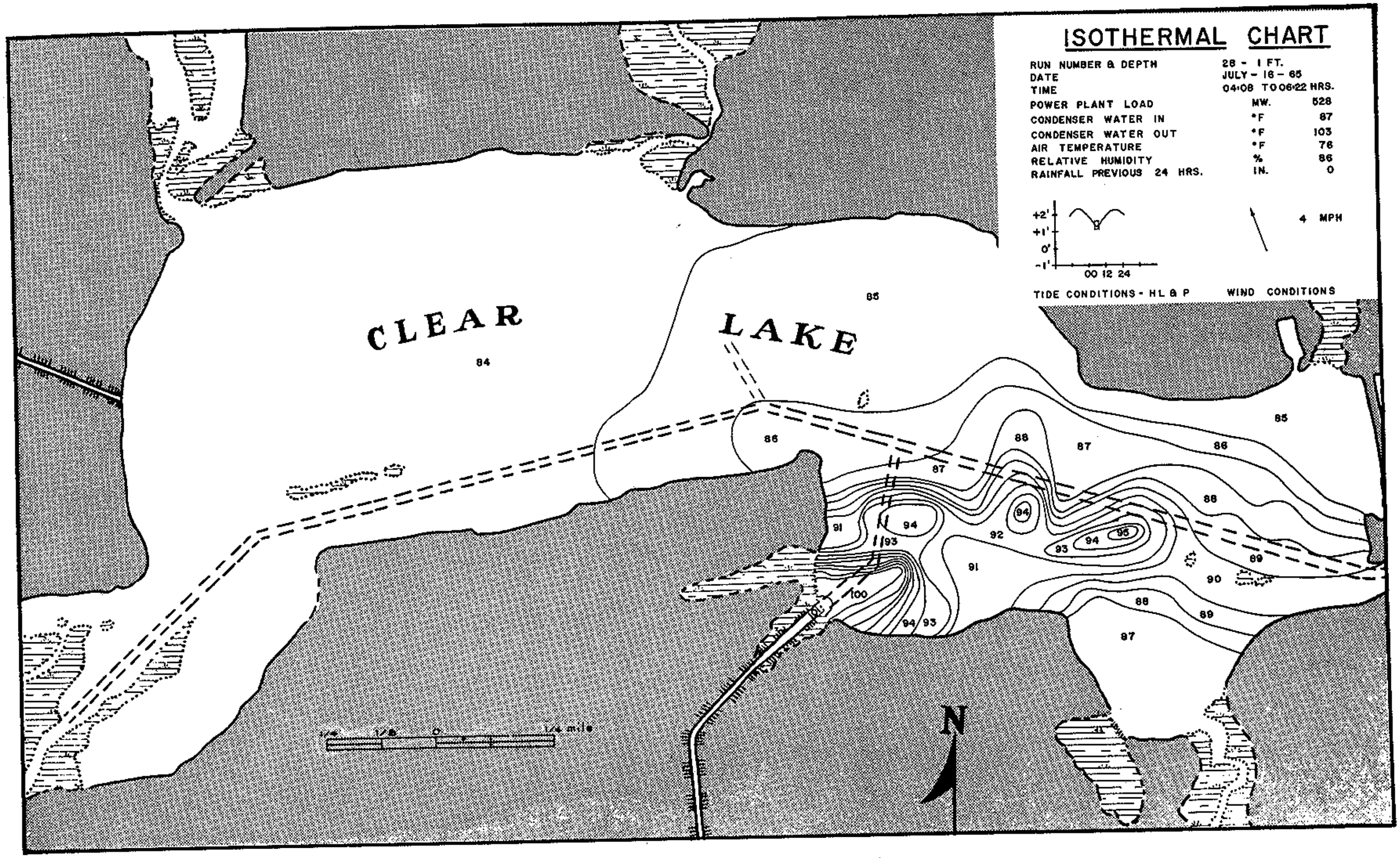


Figure 6b

ISOTHERM MAP - RUN NO. 28 - ONE FOOT

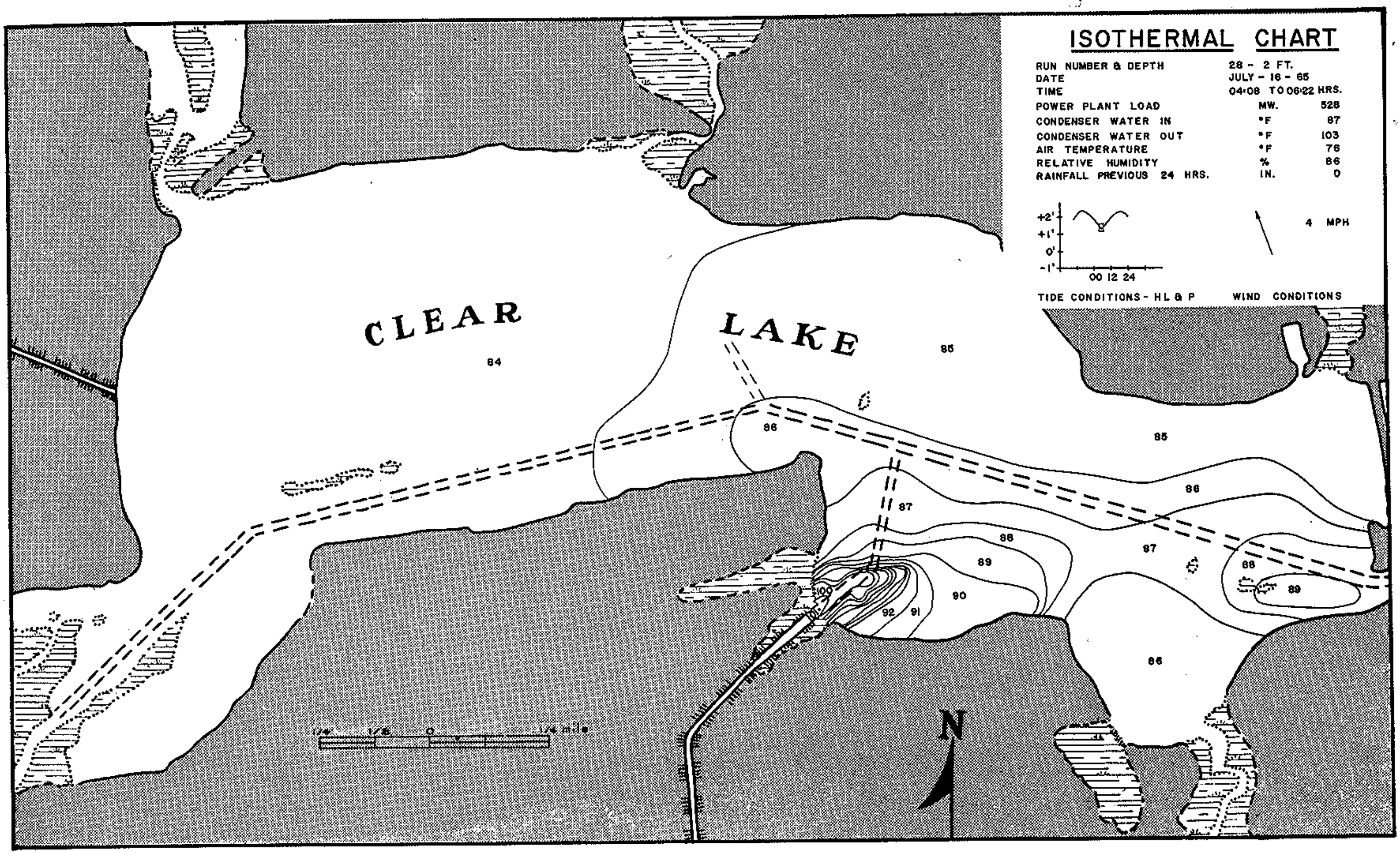


Figure 6c

ISOTHERM MAP - RUN NO. 28 - TWO FEET

Table II

AREA TEMPERATURE DATA FOR RUN NO. 28
AT SURFACE AND VARIOUS DEPTHS

Depth	Temperature (degree F)	Area (acres)[a]	Percent of Total Area	Cumulative Total (percent)
Surface	97-101°	43	4 %	4 %
	94-96	61	5	9
	91-93	67	6	15
	90	103	9	24
	86-89	78	7	31
	85	242	21	52
	84	556	48	100
One foot	97-101	13	1	1
	94-96	15	1	2
	91-93	66	6	8
	90	35	3	11
	86-89	190	17	28
	85	236	20	48
	84	595	52	100
Two feet	97-101	6	-	-
	94-96	3	-	1
	91-93	11	1	2
	90	16	1	3
	86-89	230	20	23
	85	300	26	49
	84	584	51	100

[a] Estimated

[b] Basis of 1, 150 acres

Source: Southwest Research Institute

Approximately ten percent of the lake volume and 15 percent of the lake surface is 91 degrees or more. Nineteen percent of the lake volume and 16 percent of the lake surface is between 86 degrees and 90 degrees. The remaining 71 percent of the volume and 69 percent of the area is at or near the ambient or normal nighttime temperature for the shallow waters of Clear Lake.

Comparison of 1965 Results. There is not a great difference in the area of the lake that is at a temperature above the ambient water temperature. Roughly, two-thirds of the lake area or lake volume is at or near the ambient water temperature for the weather conditions existing for either the high tide or the low tide conditions. The location of the area above ambient temperature is affected by tide conditions and wind as can be seen by comparing Figures 5 and 6a. The area moves with the tidal flow in the east-west direction and its north-south position is determined by the wind direction. Southerly winds will carry the heated area nearly to the northern shore. Northerly winds which are not as common would be expected to make the heated area follow the southern shores.

During high tides, Galveston Bay water occupies a relatively large area in the east end of the lake. This area may represent from 13 to 20 percent of the lake area and volume. This water which is considered to be normal Galveston Bay temperatures is three or four degrees lower than the apparent ambient water temperature in Clear Lake. The difference is explained by the shallowness of Clear Lake compared to Galveston Bay.

The elevation difference between high tide and low tide is about one foot and therefore, the high tide volume is approximately one-third more than the volume at low tide. The difference in the heat content of the lake between high and low tide is estimated at 220 billion Btu and of this amount 170 billion Btu is accounted for by an estimate of advected heat in tidal flow. The remaining 50 billion Btu is from other sources including the power plant.

The estimated daily heat discharged from the power plant was 60 billion Btu and approximately 50 billion Btu of this heat is discharged to the lake with the remainder being dissipated in the canal. Thus, between the high and low tide conditions the net heat from the power plant to the lake would be 25 billion Btu. Therefore, the remaining 25 billion Btu net change in heat content is the result of evaporation and radiation. Between low tide and high tide, the radiation is large and 25 billion Btu is accumulated, while between high tide and low tide a net amount of 25 billion Btu is dissipated from the lake.

These results will be compared with the previous results and 1966 results in a later section of this report.

Temperature Distribution in 1966

During late July of 1966 three temperature distribution surveys were made. Two runs were made during the daytime at high tide conditions and one run was made during the night at low tide conditions.

The cooling water flow was divided between the old canal and the new canal. The proportion of cooling water flow in each canal was not determined. The cooling water flow rate at the time of the surveys was 351,000 gallons per minute (1,540 acre-feet per day) which is about one-third of the lake contents per day. This approximation does not include the volume of Clear Creek.

The traverse pattern for the field temperature measurements had to be revised to include both canal discharge points. In order to get sufficient area coverage of the lake in a reasonable time, the pattern shown in Figure 7 was developed. The actual area of the lake which was considered is also shown. The same transportation and measuring equipment that had been previously described was used, and the technique was identical. The runs took about two hours to complete.

The meteorological data and plant operational data were recorded as described in the previous studies and covered the period from July 25 through July 28. Similar to previous field surveys, the meteorological data are from the Weather Bureau at the Houston International Airport which records data at three-hour intervals. These data are shown graphically in the following figures. The time of each run is shown by the dashed lines in the figures, thus simultaneous inspection of variables is convenient.

Wet-bulb and dry-bulb air temperatures are shown in Figure 8a and these are normal temperatures for this time of the year. There was no precipitation during this series of surveys.

The wind velocity and direction data from the Weather Bureau are shown in Figures 8b and 8c. The velocity and direction both were somewhat variable during the surveys.

Some additional data, shortwave solar radiation data, were then available from a new pyrheliometer installed at the W. A. Parish Station of Houston Lighting & Power Company where similar studies were being

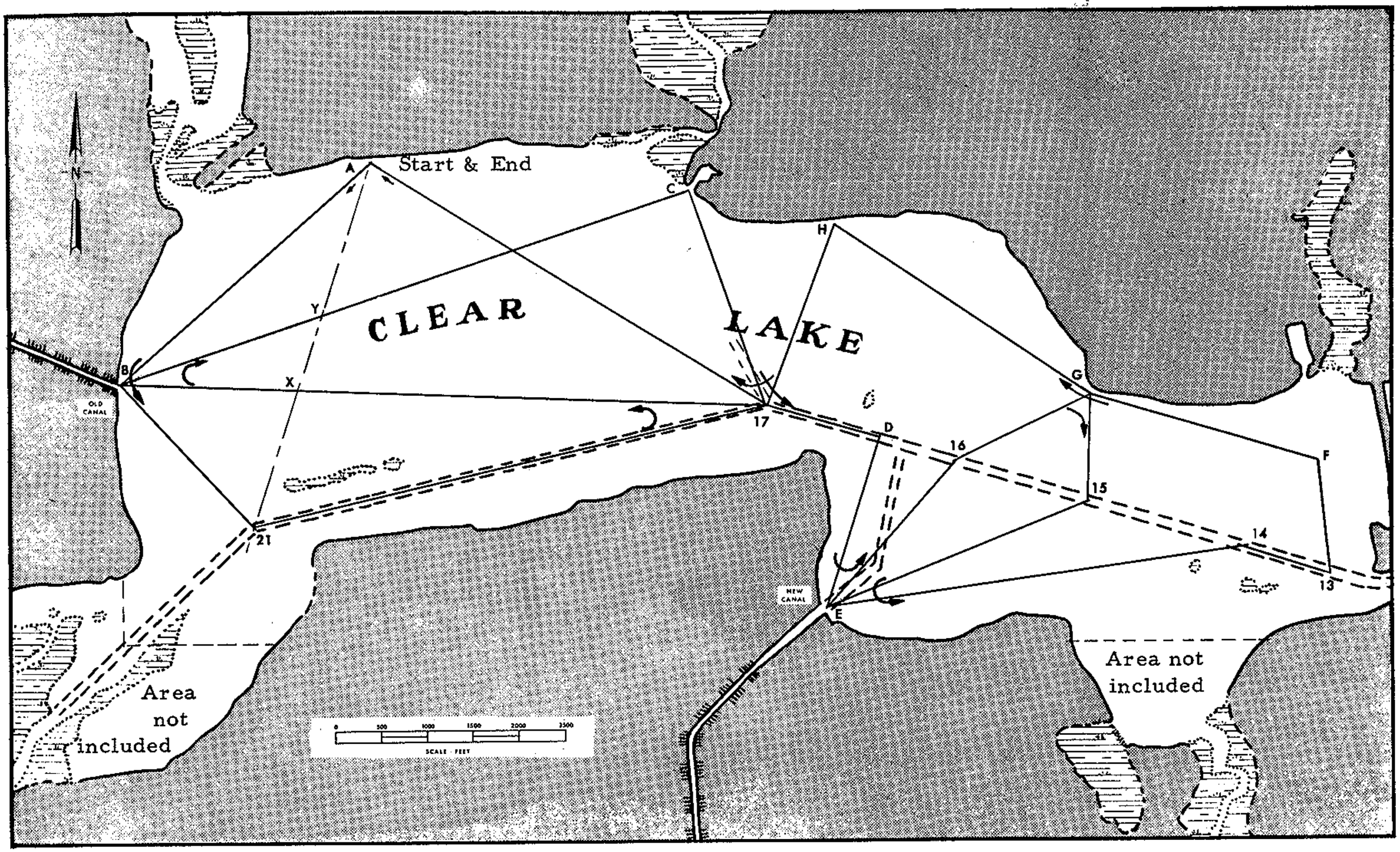


Figure 7

TRAVERSE PATTERN IN CLEAR LAKE
FOR 1966 SURVEYS

made. The W. A. Parish Station is 35 miles from Clear Lake. To convert the data which are recorded in calories per square centimeter per minute to Btu per square foot per day, multiply the observed value from Figure 8d by 5,300. The instrument records instantaneous values which normally show a great deal of fluctuation and spikes. The smoothed data are shown in Figure 8d since the values tabulated at four-hour intervals have been visually averaged. The maximum values of about 1.5 calories per square centimeter per minute (7,950 Btu per square foot per day) are the approximate maximum values possible for the latitude of the site and the time of the year. Cloudiness was at a minimum during the period and Weather Bureau records indicate a relatively high percent of possible sunshine during the period.

The tide elevation at the tide gauge at the intake of the Webster Station is shown in Figure 8e. The series of surveys was scheduled during a time when there were no mixed tides and therefore there was but a single high and single low per day. Inspection of Figure 8e reveals no mixed tides during the period.

The condenser intake and discharge temperatures shown in Figure 8f are taken from the Daily Condenser and Station Auxiliary Report for Webster Station Unit No. 2. The temperatures at the intake of Unit No. 2 were sometimes higher than the other units. The worst case presentation is justified since the operation of an individual unit is affected by absolute temperatures rather than average temperatures. The differences in the unit intake temperatures were not studied.

The gross generation of the station is shown in Figure 8g and is taken from the Consolidated Load Report for the station. The gross load is the sum of each of the operating units and recorded in megawatts at hourly intervals. The units were operating under constant load during this series of surveys.

Data Reduction. Some new techniques had been developed for data reduction but essentially the same methods of data analysis were used. The methods of data reduction will be covered in this subsection while the results and their significance will be presented in a following subsection.

There are some problems in data reduction which are unique to this type of survey. The usual data reduction process is to reduce a reasonably large quantity of data to a few simple parameters for comparison. In this particular study this is not the most desirable method. Since a compromise had been made between survey time and lake area coverage, a quantity of data resulted that was fairly large but was still

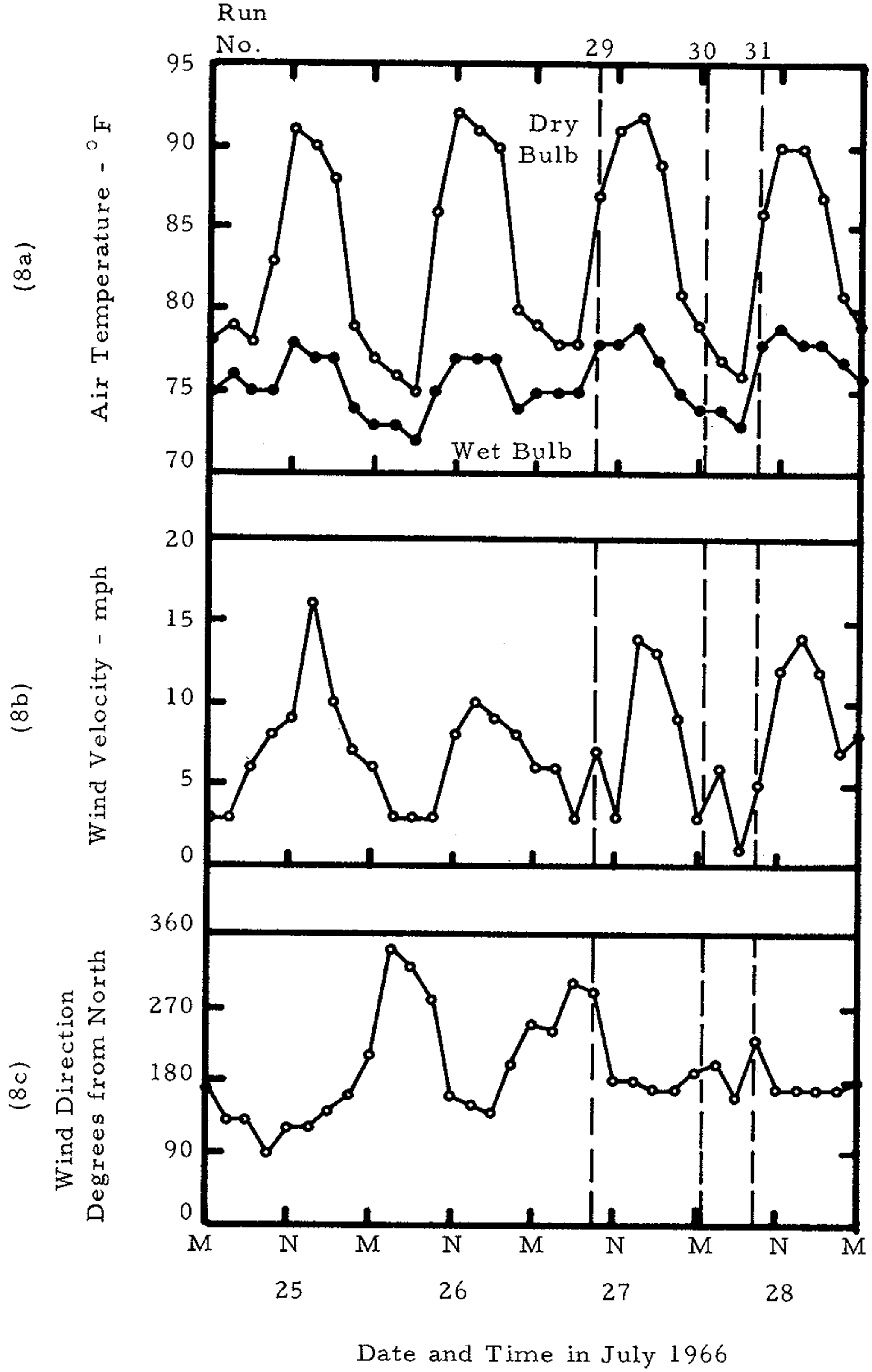


Figure 8a, b, c

METEOROLOGICAL DATA FOR 1966 SURVEY

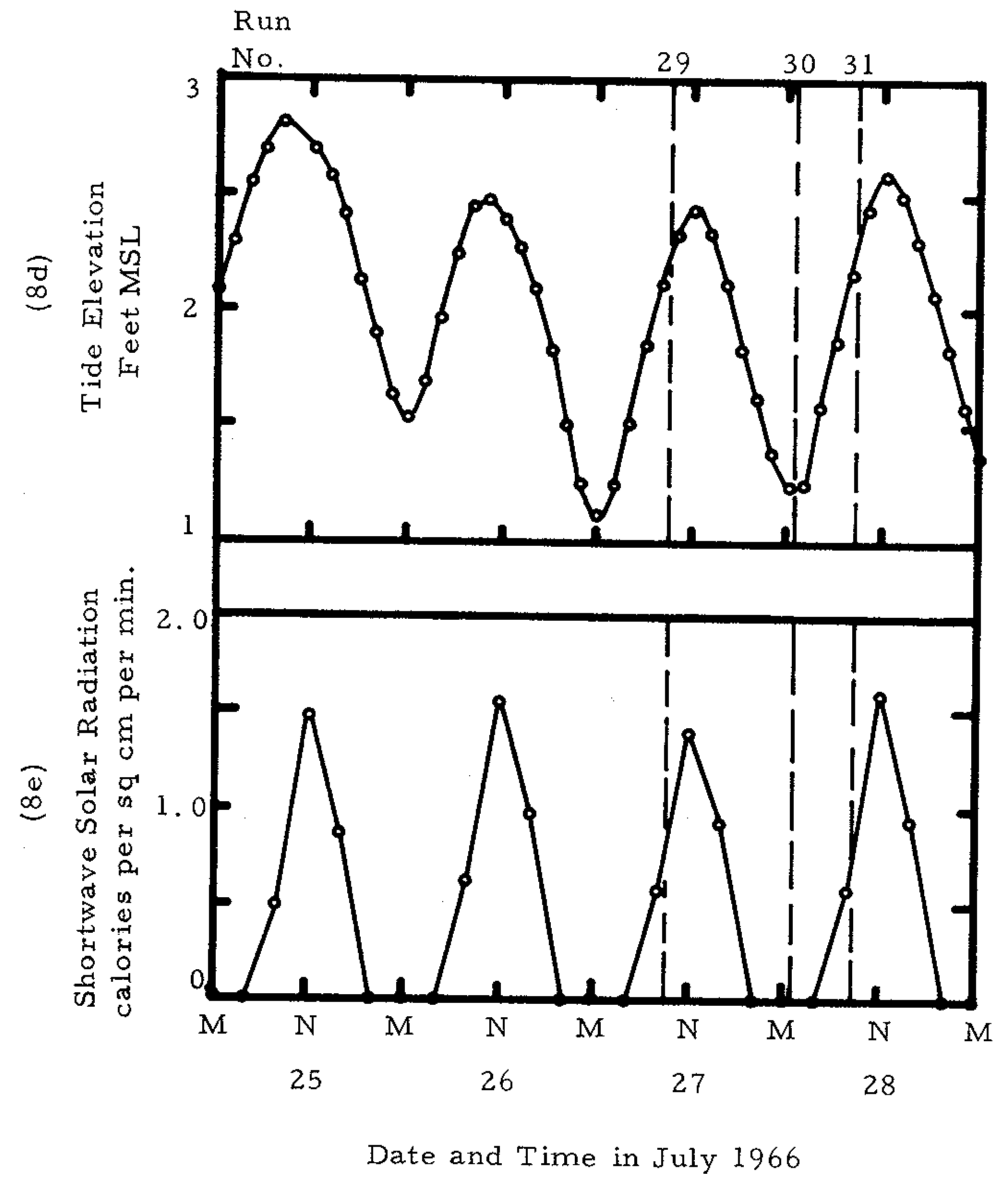


Figure 8d, e

TIDE ELEVATION AND SOLAR RADIATION
FOR 1966 SURVEY

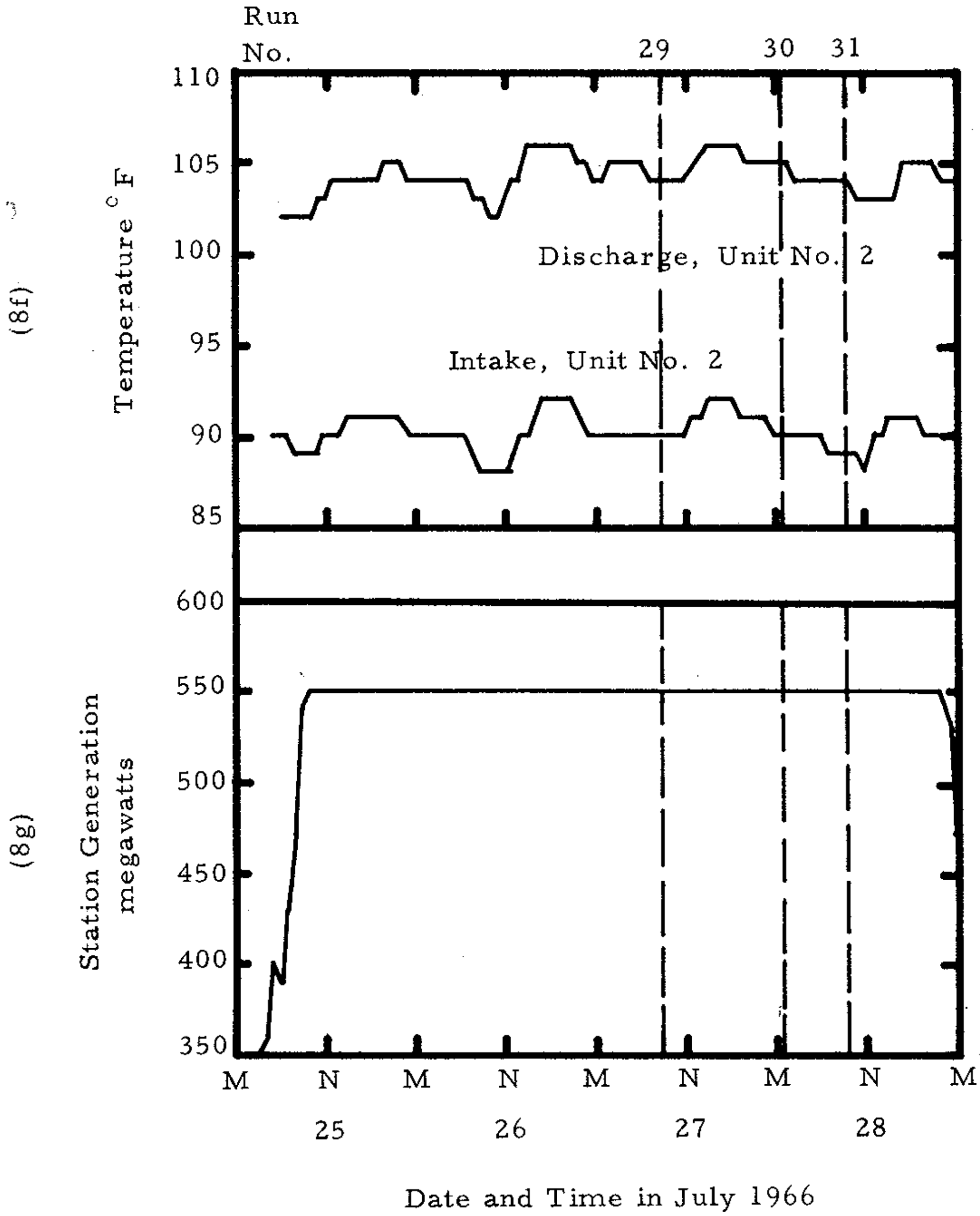


Figure 8f, g

GENERATION STATION DATA FOR 1966 SURVEY

an inadequate amount to reduce directly. The nature of the problem required a different sequence of data processing. First, the raw data had to be expanded by interpolation between data points and even by extrapolation outside of data points. Then this extremely large quantity of data was reduced to the required meaningful parameters for comparison. The only adequate means of handling this quantity of data was to use electronic data processing. Since computer use was mandatory, it was fully exploited in a sequence of separate operations of great flexibility. The raw data were in punched card form and all intermediate data were kept on magnetic tapes. This sequence is described in the following paragraphs.

One of the major items of information from the 1965 studies was that rapid changes in temperature distribution were occurring. Even over two hours of survey time these changes were inferred and became even more evident upon inspection of the 1966 field data. Because of intersecting traverses in the revised traverse pattern for the surveys, time-temperature data were available at the intersections. The permanent lake temperature recorders provided supplementary data but the survey data was the preferred source because of better accuracy in both time and temperature. The time accuracy of the recorders is very poor. Because of these changing conditions the data processing technique must provide an instantaneous look or a truly synoptic set of data. The rate of temperature change data at fixed locations on the lake was the key. A necessary assumption was that the temperature-time relationship was linear over the short time of a survey. This was shown to be adequate over the two-hour to three-hour periods with respect to the approximating techniques that follow.

Through the use of a specifically tailored computer program the X and Y coordinates of a point on the lake and its corresponding rate of temperature change was computed and made available to a surface fitting routine. A surface fitting program which uses orthogonal polynomials to represent the surface or Z coordinates would be ideal. Such programs were available for uniformly gridded data but not for random data. However, a very satisfactory substitute computer program using nonorthogonal polynomials and accepting randomly distributed data was available. The use of this program for a third-order polynomial was tested but the resulting surface proved too undulating for good results. The order was reduced to second and data fit was good. A second-order polynomial for this specific case is a formula for computing the rate of temperature change from X and Y coordinates on the lake and it has six terms in X and Y with no term having the sum of the powers of X and Y greater than two. A positive rate is increasing temperature and negative is decreasing. The program evaluated the coefficients of this polynomial by a least squares technique and tested the fit. The degree of fit varied from 0.5 to nearly 1.0 where 1.0 represents a perfect fit. Only in one case was a value of slightly less than 0.6 observed and most were between 0.7 and 0.9. This program was used to generate X-Y-rate of temperature change data for each depth for each of the three runs. An evaluation of the resulting surface for each level was made by computing the rates for a rectangular grid of points and printing out the values for inspection. Inspection of these data, which were essentially maps, indicated where temperature was increasing and where it was decreasing and at what rates. Over the entire lake these values ranged from decreases of about three degrees per hour to increases of about three degrees per hour.

Because of the proportionality of the distance between reference points on a map of the lake to the distance between corresponding reference marks on the strip chart record of temperature, it was quite simple to convert the strip chart data to digital form. The actual number of data points selected between any two reference marks was a function of the variability of the temperature in that area. In general the intent was to provide data points on the order of 1,000 feet or less apart. The constant speed of the boat on a traverse and the records of time at the beginning and at the end of each traverse segment provided the ability to ascribe a time to each data point by the same proportionality as that for distance. Thus, a complete set of X-Y-time-temperature datum points was generated for each depth of each run. Since the time was known for a datum point and the rate of temperature change at that point could be computed from X and Y using the polynomial previously evaluated, each datum point could be translated either forward or backward in time to an arbitrary reference time. The reference time selected for a given survey was approximately the mid-point of the run and no attempt was ever made to translate to a reference time more than two hours from the time of observation. Any attempt to translate longer times would undoubtedly produce errors. The final result of this segment of data processing was a complete set, for all runs and all depths, of X-Y-temperature data points all of which are at the same instant.

At this point there existed a possibility that anomalies might exist and a check had to be provided. A simple method was the printout shown in Figure 9 which permits an excellent visual check. This illustration is correctly scaled and also demonstrates the traverse path used. It was necessary to use a single character to represent temperature and although this was no sacrifice in spotting anomalies it does decrease readability for absolute values. The simple alphabetic characters represent the temperature in increments of one degree starting with 85 degrees represented by

RUN 29 CLEAR LAKE 1966 PROBE 1

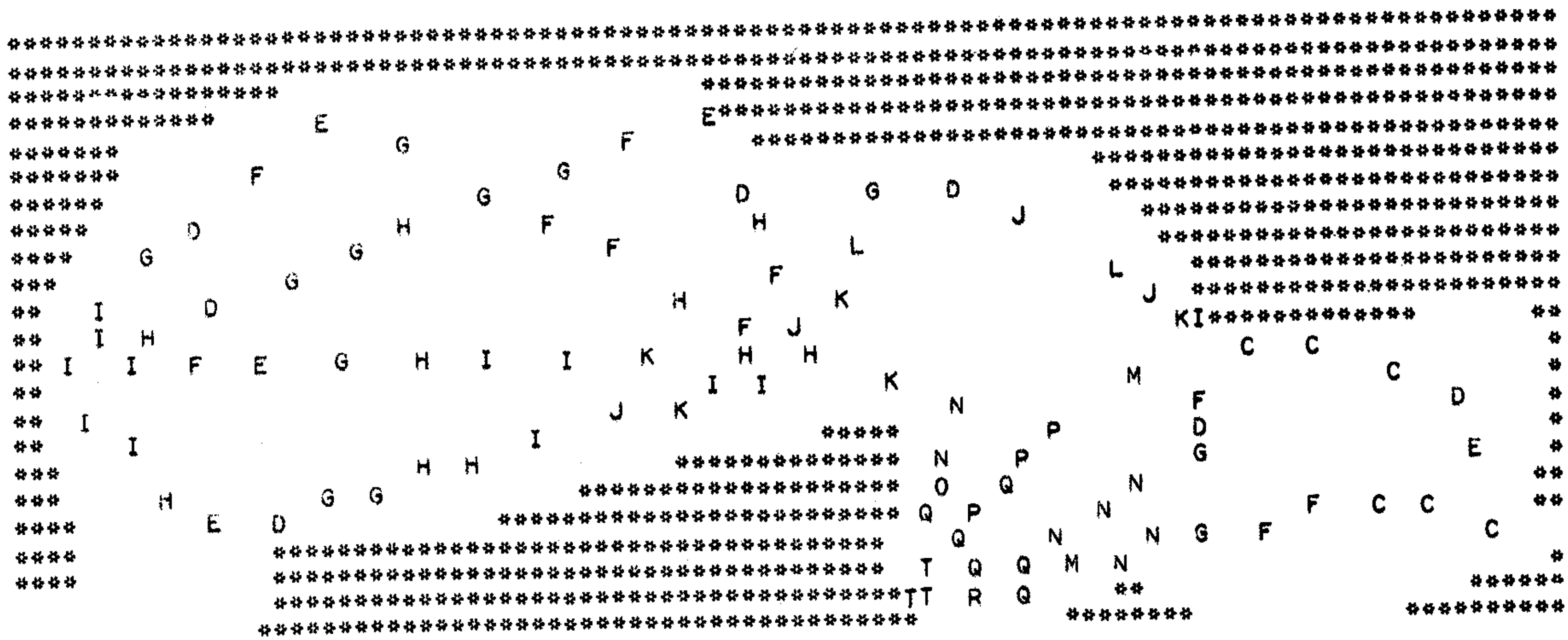


Figure 9

SAMPLE COMPUTER PRINTOUT OF
CORRECTED TEMPERATURE MAP

an A and 110 degrees represented by a Z. A temperature under 85 degrees would be indicated by a minus (-) and a temperature of over 110 degrees would be signified by a plus (+). There were no anomalies and data processing could continue.

The next problem was to interpolate and extrapolate. Computer programs to accept randomly distributed data and generate gridded data are available; however, they will not extrapolate outward. It was therefore assumed that the temperature at any point on the rectangular grid that was not lake surface was to be represented by the lowest temperature in the random data. Each depth of each run was a separate problem in the processing sequence thus far, so that the assumption was believed to be justified and later proved to be satisfactory. A simple but specific program inspected the data for each problem, found the lowest temperature value and set all points on the grid outside the lake to that temperature. The grid size was also established at this time. The proper grid size is a function of accuracy required and the computer running time and cost desired. The grid size for this series was 750 feet between mesh points requiring a rectangular grid of eight vertical and 20 horizontal grid points. The output of this program was on magnetic tape in a format correct for the gridding routine.

The gridding program, a program from Control Data Corporation called POLYGRID, accepted the random data for each problem and generated a uniform grid of the size specified with a temperature at each mesh point. The output of this program, also on magnetic tape, was then available for the next processing step.

Up to this point each depth of each run was a separate problem. The next step evaluated the average temperature for each of these problems. This was a simple process of summing up the temperatures at each mesh point that represented water and dividing by the number of mesh points added. Then, combining all depths for a run, the average temperature and the relative heat content for the top four feet of water in the lake was computed. In computing the average temperature, the grid interval was reduced to 150 feet between mesh points horizontally and 250 feet between vertical mesh points. The new mesh points added were set equal to the closest mesh point of the larger mesh grid. This improved accuracy but may not have been required. The surface temperature was assumed to apply to the first eight inches of water. The one-foot depth temperature was assumed to be representative of the next eight inches and the two-foot depth temperature was assumed to indicate the next eighteen inches of water. Thus, the upper three feet of water was represented and the average temperature of this layer computed. In addition, the heat content of this layer relative to 32 degrees F was computed. The results of this portion was printed out in the tabular form shown by the example in Figure 10.

The remaining problem was to have something to look at representing the temperature distribution. Two alternates existed. The data output from program POLYGRID was in the form which could be processed by a contouring routine called GRIDCON, also a program of Control Data Corporation. The output of program GRIDCON is a magnetic tape which can drive an automatic plotter and thereby draw contour lines and produce isotherm maps such as previously constructed manually. Because of the large number of maps required and since not all of them might be useful, the alternate appeared more attractive.

The alternate was to provide an illustrative digital output as a part of the same program providing the average temperatures. An example of this is shown in Figure 11. This type of output was extremely useful because it was provided in proper scale and therefore is essentially a map with annotated temperatures. These charts could be inspected and those for which contours were desired could be isolated and processed for automatic contour plotting. These charts, however, proved so useful that no automatic plotting was done. It was relatively simple to sketch in isotherms, as will be seen in the next subsections.

Not all of the isotherm maps are to be presented in this report, but the average temperature and heat content data are available for all and most will be discussed in the appropriate subsections following.

<u>Temperature Distribution at High Tide.</u> The results of a temperature distribution survey at high tide for this series is shown by the isotherm maps in Figures 12a, 12b, and 12c. This survey was Run No. 29 which was conducted at high tide on July 27, 1966. The high slack-tide was just after the end of the run and the tide elevation was 1.8 feet MSL. The run began at 8:07 a.m. and was complete at 9:53 a.m. The isotherm maps have been constructed for 9:00 a.m. There was significant thermal stratification and therefore an isotherm map is presented for each depth.

The gross generation of the station shown in Figure 8g was constant at 550 megawatts during the series. The Unit No. 2 condenser intake temperature range was from 88 to 92 degrees and the corresponding temperature range for the condenser discharge was from 102 to 106 degrees. The cooling water flow rate was 351,000 gallons per minute (1,540 acre-feet per day).

CLEAR LAKE 1966 RUN NUMBER 30

LAYER	THICKNESS	VOLUME	AVE TEMP	HEAT CONTENT
1	0.75	864	90.39	5.044013+004
2	0.75	864	89.79	4.992511+004
3	1.50	1728	89.91	1.000556+005
ALL	3.00	3456	90.00	2.004208+005

HEAT CONTENT IS IN UNITS OF HEAT REQUIRED TO
RAISE THE TEMPERATURE OF ONE ACRE-FOOT OF WATER
BY ONE DEGREE F. - 2.718 MILLION BTU

Figure 10

SAMPLE COMPUTER PRINTOUT OF AVERAGE TEMPERATURE AND RELATIVE HEAT CONTENT CALCULATIONS

CLEAR LAKE 1966 RUN NUMBER 31 PROBE NUMBER 1

		89.	92.	92.	91.	90.	91.	92.	91.									
	88.	88.	91.	91.	92.	92.	92.	92.	92.	92.	93.	92.	91.					
	89.	89.	90.	90.	91.	92.	92.	91.	91.	93.	94.	94.	92.	89.				
	92.	90.	89.	90.	91.	92.	92.	91.	91.	91.	93.	95.	94.	90.	89.	88.	89.	88.
	91.	91.	90.	90.	91.	91.	90.	89.			95.	98.	97.	93.	88.	88.	88.	88.
	88.	89.	89.								101.	100.	100.	96.	89.	88.	88.	88.
87.	87.	87.										87.			87.	87.	87.	

Figure 11

SAMPLE COMPUTER PRINTOUT OF GRIDDED
TEMPERATURE DATA

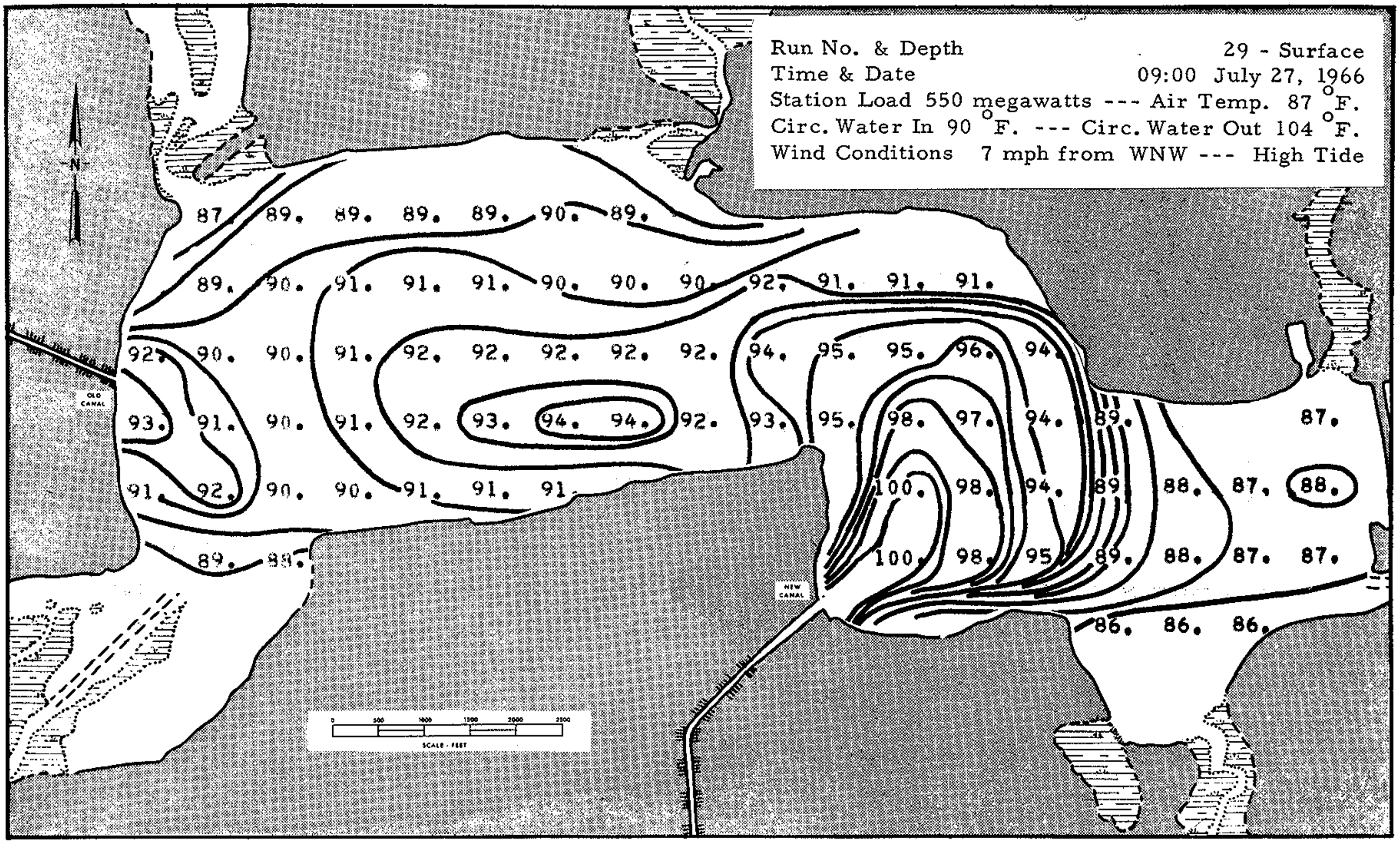


Figure 12a

ISOTHERM MAP - RUN NO. 29 - SURFACE

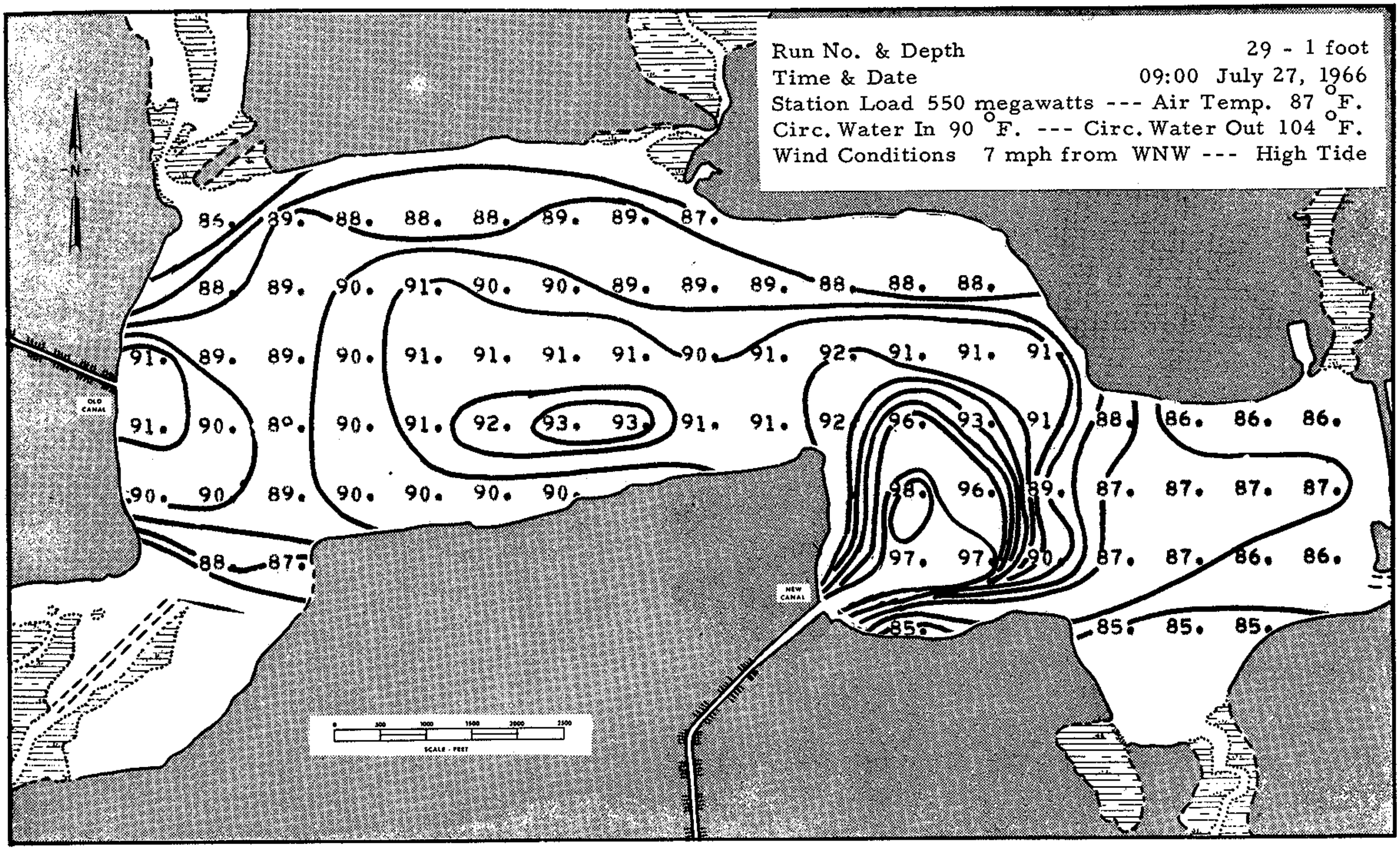


Figure 12b

ISOTHERM MAP - RUN NO. 29 - ONE FOOT

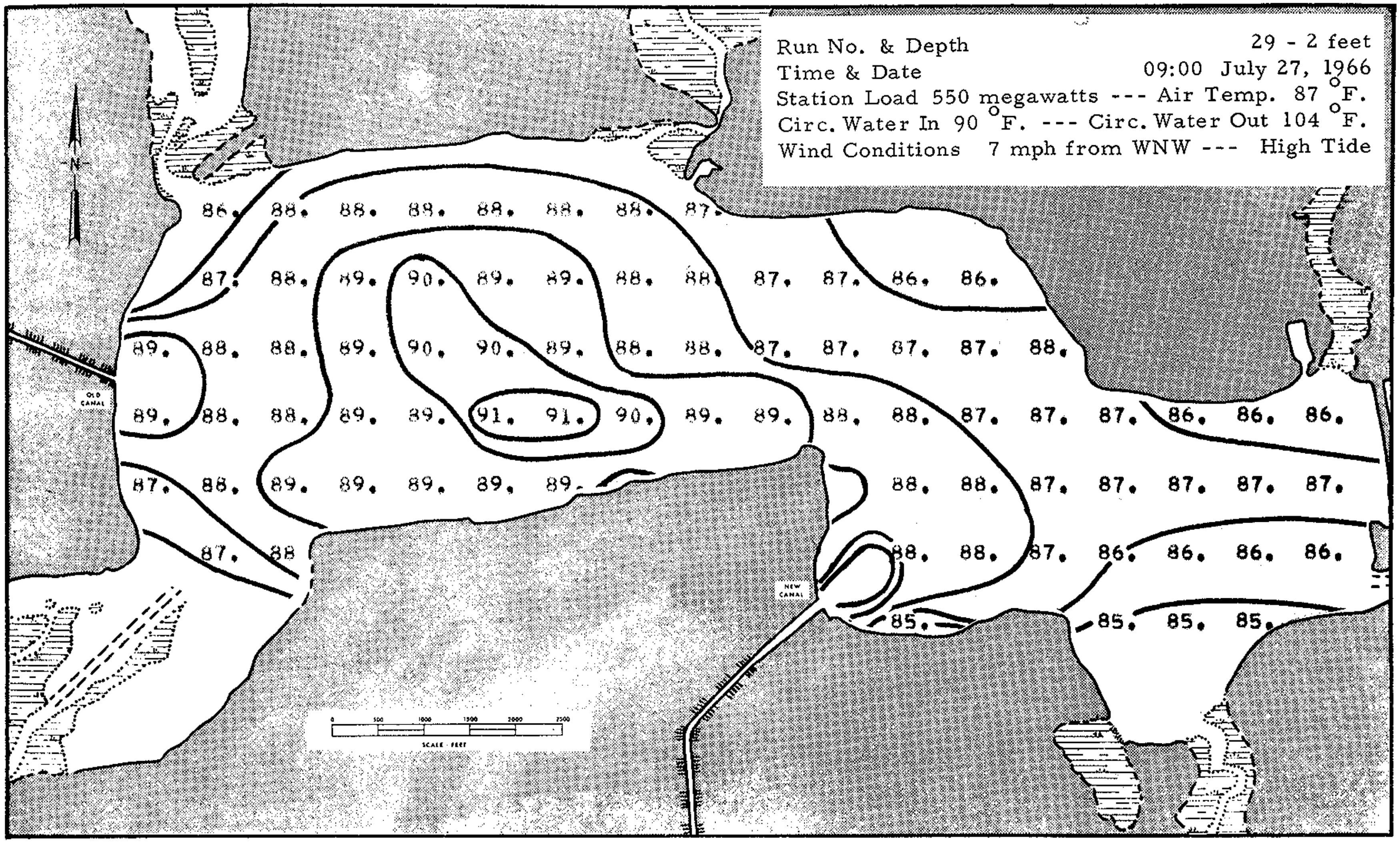


Figure 12c

ISOTHERM MAP - RUN NO. 29 - TWO FEET

This survey at high tide conditions was made in the early forenoon and the air temperature of 87 degrees was not near the daily maximum of 92 degrees. The relative humidity was fairly high at 70 percent. The cloud cover was 20 to 50 percent, according to field notes.

The winds were westerly from three to seven miles per hour as shown in the Weather Bureau data in Figures 8b and 8c. The wind conditions six feet above the lake surface were very slight with velocities of zero to one mile per hour and were from the west northwest. As a result the lake surface was exceptionally calm with an almost glassy smooth surface. This condition is primarily responsible for the thermal stratification that was in existence.

The average temperature of each layer and the relative heat content is shown in Table III and the degree of stratification can be observed. It is questionable whether the precision is as great as that implied in this table.

Table III

AVERAGE TEMPERATURE AND RELATIVE HEAT CONTENT OF THE UPPER THREE FEET OF CLEAR LAKE FOR RUN NO. 29

Layer	Thickness (feet)	Volume (acre-feet)	Average Temperature (° F)	Relative Heat[a] Content (billion Btu)
1	0.75	864	90.7°	138
2	0.75	864	89.2	134
3	1.50	1,728	87.5	261
All	Upper 3	3,456	88.7	533

[a] Heat content above 32 degrees F base temperature

Source: Southwest Research Institute

The area of the lake determined from this data processing method is 1,150 acres and the actual section of the lake studied is illustrated in Figure 7. The area excludes Clear Creek and some of the small bays.

The distribution of temperature at the time of this survey is shown in Table IV. Because there was stratification, the percent of area and percent of volume figures are not identical and both are shown.

Table IV

TEMPERATURE DISTRIBUTION IN CLEAR LAKE
FOR HIGH TIDE CONDITIONS - RUN NO. 29

Temperature (degree F)	Percent of Surface Area: Percent	Percent of Surface Area: Cum. total	Percent of Volume[a]: Percent	Percent of Volume[a]: Cum. total
101°	1%	1%	-	-
100	1	2	-	1%
99	1	3	-	1
98	3	6	2%	3
97	1	7	1	4
96	1	8	1	5
95	6	14	2	7
94	7	21	2	9
93	3	24	3	12
92	12	36	5	17
91	15	51	12	29
90	13	64	11	40
89	12	76	15	55
88	8	84	16	71
87	8	92	14	85
86	8	100	10	95
85	-	-	5	100

[a] Basis: Upper three feet of water in 1,150 acres
Source: Southwest Research Institute

From inspection of the Webster Station intake temperatures as well as from the analysis of the data from the Clear Lake Temperature recorders maintained by Houston Lighting & Power Company, the normal average bulk temperature for Clear Lake at this season varied from 88 to 91 degrees. The normal average bulk temperature in Galveston Bay from similar temperature recorders was from 86 to 87 degrees at that same time. Thus, temperatures of 92 and over which represented 17 percent of the lake volume were the effect of the heated water discharge. Similarly, 54 percent of the lake volume was in the normal lake temperature range while 29 percent approximated the normal Galveston Bay temperatures. Because of stratification the surface area temperature distribution was somewhat more in the higher temperature ranges.

The surface layer of heated water from the new canal outlet extended completely to the north shore with a temperature of 94 degrees close to the north shore. Subsurface temperatures north of the channel, however, were more normal because of the stratification that existed. Inspection of the subsurface isotherm map in Figure 12c indicates that the incoming tide flowed under the heated water since the temperatures at two feet and below were representative of Galveston Bay water temperatures.

The area of heated water at the old canal outlet was rather small and the two lobes of heated water from the canals were separated. This separation was by a rather narrow area of water with a temperature at the high end of the normal lake temperature range. This was more or less true for each depth as can be seen in Figure 12. In addition, substantially higher temperatures were observed at the new canal outlet than at the old canal outlet.

The relative heat content of the lake which is shown in Table III will be discussed in more detail as comparisons are made with the low tide temperature distribution results which follow.

<u>Temperature Distribution at Low Tide.</u> The results which follow are from the low tide survey, Run No. 30, which was made between 11:28 p.m. on July 27 and 1:48 a.m. on July 28, 1966. The isotherm map shown in Figure 13 was constructed for 12:30 a.m. on July 27. The thermal stratification was insignificant and therefore only one isotherm map is required. The tide elevation was 0.8 feet MSL which was one foot lower than the preceding run at high tide made 15 hours previously.

The gross generation was still constant at 550 megawatts and the Unit No. 2 condenser intake and discharge temperatures were 90 degrees and 105 degrees, respectively. The cooling water flow rate was unchanged at 351,000 gallons per minute (1,540 acre-feet per day).

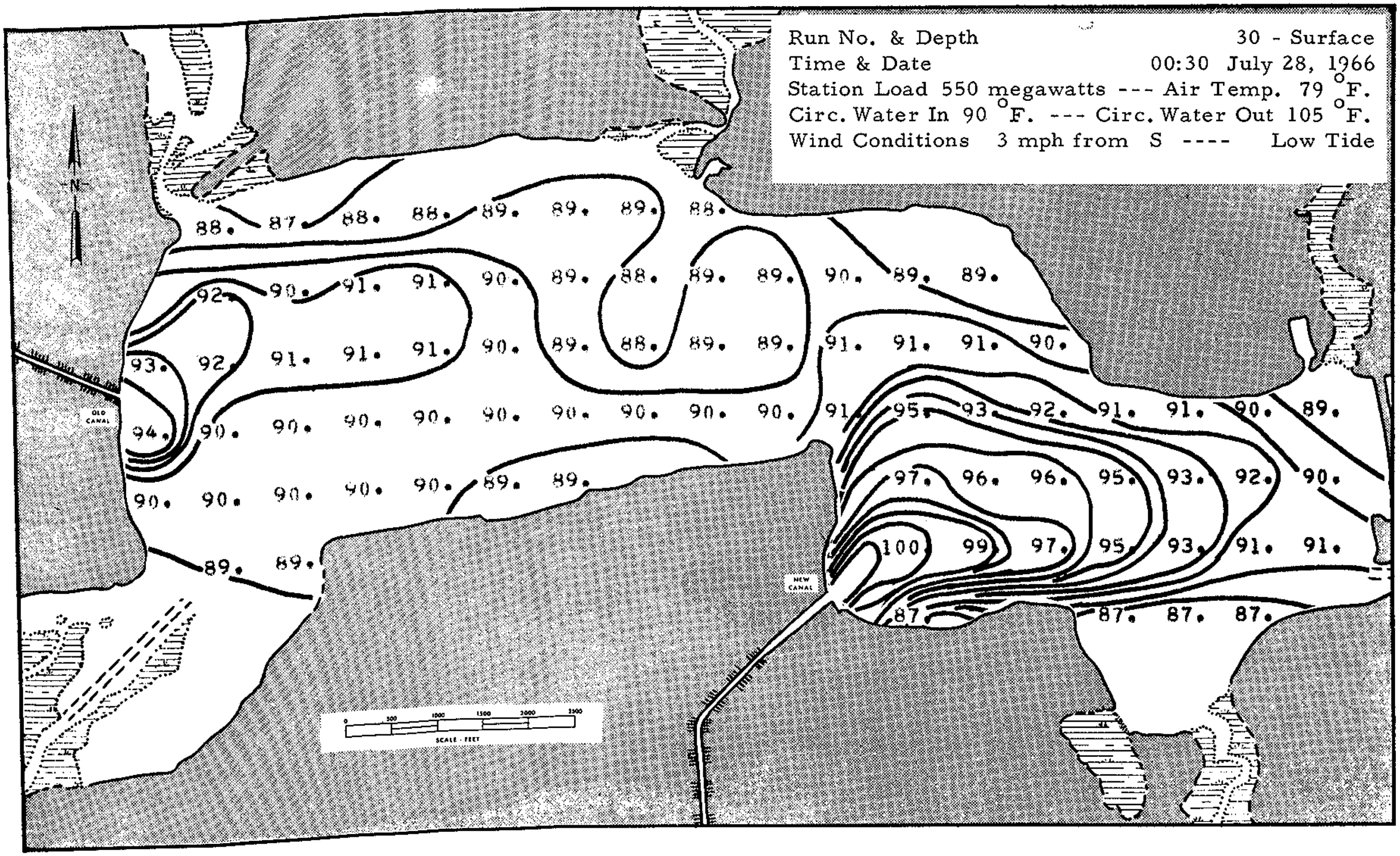


Figure 13

ISOTHERM MAP - RUN NO. 30 - SURFACE

The weather conditions during this low tide survey were normal for the season. The air temperature was 79 degrees and falling since the low of 76 degrees occurred six hours later. The relative humidity was high at 79 percent. The cloud cover was 80 percent with an indeterminate ceiling height. The winds were from due south and were three to six miles per hour, however, there had been higher winds of nine to 14 miles per hour in the preceding nine hours as indicated by the Weather Bureau data. The wind measured six feet above the lake with field instruments was variable from zero to five miles per hour from the south.

The lake surface was variable from occasional dead calm to six-inch waves. From the temperature data, however, there appeared to be essentially complete mixing with only minor areas of slight stratification.

The average temperature of each layer of the upper three feet and the relative heat content is shown in Table V. The similarity of the average temperatures is evidence of the rather thorough mixing although the precision is probably not as great as implied in the table.

Table V

AVERAGE TEMPERATURE AND RELATIVE HEAT CONTENT OF THE UPPER THREE FEET OF CLEAR LAKE FOR RUN NO. 30

Layer	Thickness (feet)	Volume (acre-feet)	Average Temperature (^{o}F)	Relative Heat[a] Content (billion Btu)
1	0.75	864	90.4^{o}	137
2	0.75	864	89.8	136
3	1.50	1,728	89.9	272
All	Upper 3	3,456	90.0	545

[a] Heat content above 32 degrees F base temperature

Source: Southwest Research Institute

The area of the section of lake studied was 1,150 acres and the section boundaries are shown in Figure 7.

The distribution of temperature is shown in Table VI and since there was insignificant stratification, the percent of volume and percent of area figures are identical.

Table VI

TEMPERATURE DISTRIBUTION IN CLEAR LAKE FOR LOW TIDE CONDITIONS - RUN NO. 30

Temperature (degree F)	Percent of Lake Volume[a] or Surface	
	Percent	Cumulative Total Percent
102	1	1
101	1	2
100	1	3
99	1	4
98	1	5
97	2	7
96	3	10
95	3	13
94	1	14
93	5	19
92	5	24
91	15	39
90	25	64
89	18	82
88	9	91
87	9	100

[a] Basis: Upper three feet of water in 1,150 acres

Source: Southwest Research Institute

From the same considerations as made in the discussion of the high tide temperature distribution, the normal bulk temperature of Clear Lake was from 88 to 91 degrees and the normal bulk temperature of Galveston Bay was 86 to 87 degrees for the conditions during this series of surveys. Therefore, the temperatures of 92 and over were the effect of the heated water discharge and these temperatures represented 24 percent of the volume of the upper three feet of Clear Lake. The normal Clear Lake temperatures represented 67 percent of the lake volume and the remaining nine percent of the volume was approximately the same as Galveston Bay water.

The heated area of the lake extended eastward as it was carried by the tide but also extended rather far north under the influence of the wind. A temperature of 91 degrees reached the north shore and was from top to bottom at that point. The cooler subsurface water flowed out with the tide which accounted for the higher average temperature of the lake.

The relative heat content data in Table V will be discussed further as it is compared with other runs in the next subsection.

Comparison of 1966 Results. The relative heat content data in Table III and Table V for Run No. 29 and Run No. 30, respectively are essentially identical insofar as the upper three feet of water is concerned. The lake volume at the high tide run (Run No. 29) was one-third more than at the low tide run due to a one-foot tide elevation difference. Therefore, the bottom one foot of water must be assumed to be at approximately the same average temperature as the average temperature measured at two feet for layer number three as shown in Table III. This would amount to an overall average lake temperature estimate of 88.4 degrees or only slightly lower than for the upper three feet of water. This bottom foot of water would thus have a relative heat content of about 164 billion Btu and thus the total relative heat content was 698 billion Btu.

The advected heat by tidal flow can be assumed to be the relative heat quantity in 1,150 acre-feet of water at the bay temperature of 86 degrees. This is equivalent to 169 billion Btu. The decrease in heat content between this high tide and the following low tide was 152 billion Btu. The heat discharged from the power plant during this same time was approximately 37 billion Btu which was discharged over a 15-hour period. The net result was therefore the dissipation of 20 billion Btu from the lake by radiation and evaporation. Since the time involved was from about 9 a.m. to midnight the greatest dissipation occurred during the night hours. Actually, the heat content would have increased during the day until sundown when the decrease would have started.

The heat dissipated from low tide to the next high tide conditions some nine hours later can be estimated since the relative heat content of the lake for the next high-tide run (Run No. 31) was identical to the previous high-tide run. The heat input to the lake from the power plant was 22 billion Btu and the advected heat input from tidal flow was again 169 billion Btu. Therefore, the net lake dissipation was 34 billion Btu during this period by back radiation and evaporation.

At either high or low tide roughly two-thirds of the lake was at normal Clear Lake water temperature. The location of the heated area is affected by tide and winds which can be seen by comparing Figures 12a and 13. The heated area moves back and forth with the tidal flow while the area changes very little in magnitude and the temperature distribution does not shift significantly from high tide to low tide conditions.

The eastern end of the lake contained fairly large areas of water at the normal Galveston Bay temperatures while winds were sufficiently fast to accomplish mixing. When winds were at low velocities to permit stratification, the tide flowed in under the warmer less dense water and similarly flowed out from under the warmer water during falling tides.

Conclusions and Recommendations

The temperature distribution between 1965 and 1966 can best be compared from the data in Table VII in which the data that were developed in the previous subsections have been tabulated. These data which present the temperature distribution in terms of three temperature range classifications can be directly compared. The temperature ranges are (1) normal Galveston Bay water temperatures for the survey conditions, (2) normal Clear Lake water temperatures to be expected under the same conditions in the absence of any heated discharge, and (3) above normal temperatures which are the direct effect of a heated water discharge.

It should be noted that the only major difference in conditions for the two years was in the use of only the new canal in 1965 and the use of both canals in 1966. Other parameters were similar if not identical in both cases.

Inspection of the data in Table VII for 1965 reveals almost identical results for low tide or high tide conditions. In 1966, however, there are some differences which are perhaps significant. There is not a major difference in the above normal temperature distribution but there is some change in the distribution between normal lake and normal bay temperatures.

The differences may have been produced by a combination of two factors which were different. The high tide survey time in 1965 was mid-afternoon and the winds were such that mixing was complete. The high tide survey time for 1966, however, was in the early forenoon following a period of very mild winds and therefore stratification was present. Similarly, the 1965 low tide survey time in 1965 was in the very early morning and the mild winds had permitted stratification while for 1966 the survey time was at midnight and during medium to strong winds which caused essentially complete mixing.

Table VII

PERCENT OF CLEAR LAKE VOLUME IN EACH TEMPERATURE RANGE FOR 1965 AND 1966 AT HIGH TIDE AND AT LOW TIDE

	Percent of Volume[a]			
	1965		1966	
Temperature Range	High Tide	Low Tide	High Tide	Low Tide
Normal Galveston Bay	21%	19%	29%	9%
Normal Clear Lake	63	71	54	67
Above Normal	16	10	17	24

[a] Basis: Upper three feet of 1,150 acres

Source: Southwest Research Institute

The data in Table VII seem to imply a slight increase in the above normal temperature portion of the lake from 1965 to 1966 which would be attributable to the discharge of heated water at the two different points on the lake. However, it would be hasty and imprudent to conclude that the old discharge canal should be abandoned because of the additional heat that can be dissipated before reaching the lake by the use of both canals.

Nowhere in the data for intake temperatures at the Webster Station is there any implication that those intake temperatures are significantly different from the normally expected lake temperatures. Recirculation or short-circuiting of cooling water flow does not therefore appear to be ocurring or to be a potential hazard for the present cooling water flows. The intake temperature appears to vary only under the influence of meteorological conditions.

The interrelation of the two discharges in 1966 was minor and the two heated areas were generally separated by an area of water only slightly above normally expected lake temperatures. In some cases this area was rather narrow but in all cases the two areas were distinct.

Mild wind conditions will allow thermal stratification near the new canal outlet and permit tidal flow to be predominantly subsurface. During these times the heated water spreads over a larger surface area and often reaches entirely to the northern shore. This condition has been observed to occur with some significant frequency although not throughout the entire depth of the lake. In general, the upper half of the lake might be three degrees above the normal lake temperature near the northern shore when the winds are mild and from the south. Should such temperatures occur from top to bottom of the lake in this area, a condition that might reasonably be expected, then the migration route of marine organisms might be temporarily blocked. This possibility should be recognized as a potential hazard.

It is primarily because the portion of the lake that is affected by the heated cooling water can approach 25 percent that additional expansion of generation capacity at the Webster Station is not recommended with the present cooling water system design. To affect greater portions of the lake may not leave a sufficient safety factor to endure a period of adverse weather conditions. The potential hazard of blocking migration routes may be a short duration hazard but should not be overlooked.

Some rapid temperature changes can occur in the lake at a given location. Under the effect of wind, solar radiation, and tide, the temperature at some locations may change by four degrees or more per hour. Thus, any assumption of the existence of a steady state at a given time is not valid.

This rapid change of temperature makes the need for faster methods for synoptic surveys more acute. The preferred method for synoptic studies will be the aerial survey using scanner type infrared instrumentation because of the requirement for speed and for broad area coverage. In spite of the fact that water is opaque to infrared radiation of wavelengths greater than 1.4 microns, and thus only the surface temperature can be measured with infrared instruments, the utility of the method will still be great. The surface temperature is often a good indicator of the subsurface temperatures. When the matter of concern is energy and mass transfer through the true surface, infrared measurements may be superior to surface layer measurements made directly. According to Ragotzkie[3] the infrared thermometer very likely comes closer to indicating the effective surface temperature than any other means. Other more sophisticated aerial methods using the multispectral sensing concept as reported by Holter[2] will become more popular because of the great detail and contrast possible. Serious consideration should be given to this type of data gathering by use of a helicopter or other light aircraft.

IV CLEAR LAKE PLANKTON STUDIES

An investigation of the types and abundance of plankton in the Clear Lake system was made to provide a baseline for comparison of possible future changes in plankton population which might be attributed to excessive temperatures in the lake.[7,8] Members of almost every major group of animals and plants occur in the plankton, at least at some developmental stage, so that identification of individual species becomes a complicated task which was beyond the scope of this investigation. The zooplankton (animal kingdom) are considered here only in relative abundance and are not classified further than zooplankton types. In general, however, there are many forms of zooplankton present in Clear Lake water.

The phytoplankton or algae are the basic food supply in water environments for all zooplankton and higher life forms. The algae are able to utilize energy from the sun to synthesize protoplasm from carbon dioxide and water, a process called photosynthesis. There are over 20,000 species of algae and classification of a specimen to species was not felt germane to this investigation; rather, classification was made into the four major groups: blue-green algae, green algae, diatoms, and pigmented flagellates.

Plankton samples were taken at four sampling stations during July and August of three years — 1965, 1966, and 1967. The sampling stations selected were as follows: Clear Creek at Highway 75, Clear Lake at HL&P old discharge canal, Clear Lake at Harris County Park, and Clear Creek at Highway 146.

Counts from these samples are shown on Table VIII as total zooplankton and phytoplankton at 100X magnification. The numbers are in organisms or clumps per milliliter and are averages of at least six separate counts with both Koehler and Dark Field illumination. The highest average of the two illuminating methods was used. In most cases the Dark Field provided the best illumination. The speed of mobility was used as the major definition between zooplankton and phytoplankton qualified by pigmentation. The only change in plankton counts of sufficient magnitude to be significant is the downward trend shown in Table VIII at the Clear Creek sampling point at Highway 75. Both zooplankton and phytoplankton counts decreased considerably at this station. However, the station is above the influence of the Webster station and plankton changes here are probably the result of other environmental factors, such as dilution by freshwater runoff.

Table VIII

PLANKTON CELL COUNTS IN CLEAR CREEK AND CLEAR LAKE - 1965 to 1967

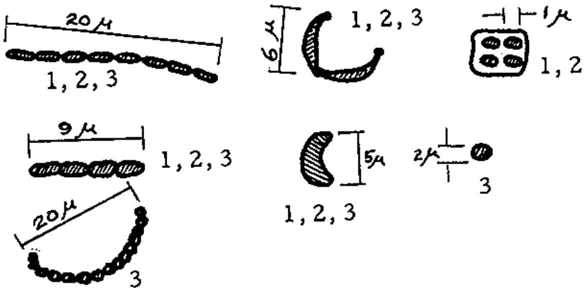
Sample Point	Zooplankton organisms/ml @ 100 x mag.			Phytoplankton organisms/ml @ 100 x mag.		
	1965	1966	1967	1965	1966	1967
Clear Creek at Highway 75	51×10^3	14×10^3	6×10^3	36×10^5	21×10^5	11×10^5
Clear Lake at HL&P old discharge canal	31×10^3	12×10^3	12×10^3	38×10^5	39×10^5	47×10^5
Clear Lake at Harris County Park	51×10^3	14×10^3	23×10^3	18×10^5	21×10^5	47×10^5
Clear Creek at Kemah bridge	26×10^3	35×10^3	18×10^3	26×10^5	37×10^5	19×10^5

1965 sample period - July

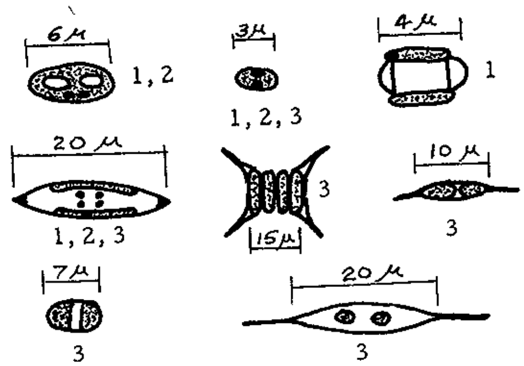
1966 sample period - July 29 and August 3

1967 sample period - August 28

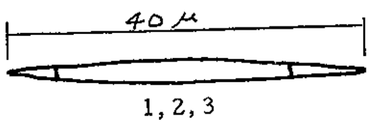
A change in the plankton population was noted over the three years. The major plankton types found during this period are illustrated in Figure 14. The sampling in 1966 showed all of the 1965 types to be present except the green algae in the upper right-hand corner of Figure 14. The 1967 sampling showed ten of the original algae still present in Clear Creek and Clear Lake. In addition, six new algae were also found to be present in sufficient abundance to be recorded. These additional algae are also illustrated in Figure 14. There was not sufficient population change nor emergence of a particularly dominant species in the 1967 sampling which might indicate a major upset in the environment had occurred.



BLUE GREEN ALGAE



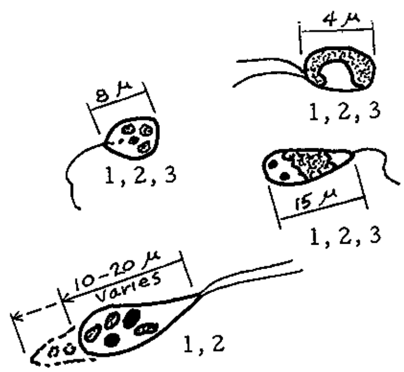
GREEN ALGAE



DIATOMS

Color Legend

- Light Green
- Dark or Blue Green
- Yellow or Brown



PIGMENTED FLAGELLATES

Notes:

1 Present in 1965
2 Present in 1966
3 Present in 1967

Figure 14

ALGAE IN CLEAR LAKE - 1965, 1966, 1967

V TEMPERATURE DISTRIBUTION AT BACLIFF

The P. H. Robinson Generating Station which is located off Highway 146 near Bacliff first began operation in May of 1966. At that time the station had one steam electric unit of 450-megawatt capacity. In April 1967 Unit No. 2, an identical 450-megawatt unit, went into commercial operation. An additional unit of 565-megawatt capacity is under construction and is expected to go into operation some time in late 1968.

A single cooling water system provides service to all units. The cooling water is drawn from Dickinson Bayou and is discharged by canal to Galveston Bay at Bacliff. The temperature limit at this point of discharge has been set at 105 degrees F by the Water Pollution Control Board.

The possibility of interrelation of this heated discharge with that from the Webster Station into Clear Lake prompted the study at Bacliff. The identification of the thermally affected area by size and location was the primary objective.

The small boat which was used at Clear Lake was not considered to be suitable equipment for the large open waters of Galveston Bay. Consequently a larger boat which had been chartered by HL&P to service its temperature recorders in Galveston Bay was used for this field survey. This craft, although safe and seaworthy for these waters, was not fitted for the temperature recording equipment used previously and therefore a manual method of data acquisition was used. The surface water temperatures were measured by a glass dipping thermometer. These temperatures do not reflect the surface film temperatures but are indicative of the temperature a few inches below the water surface. This is directly analogous to what has been called surface temperatures in the Clear Lake studies.

A field survey was made on September 12, 1966 and the resulting data processed into an isotherm map which is shown in Figure 15. This survey was made at high slack-tide and during a period of days when there was a single high and a single low tide daily. The wind was from the north at five to seven miles per hour. The air temperature at survey time was 81 degrees and the relative humidity was 70 percent.

Temperature data for this survey were taken in a grid pattern. The grid points were approximately one-fourth mile apart as estimated by the boat pilot who was experienced in judging distances over water. Three rows of grid points parallel to the shore line were required to identify the area of water which was affected by the heated discharge.

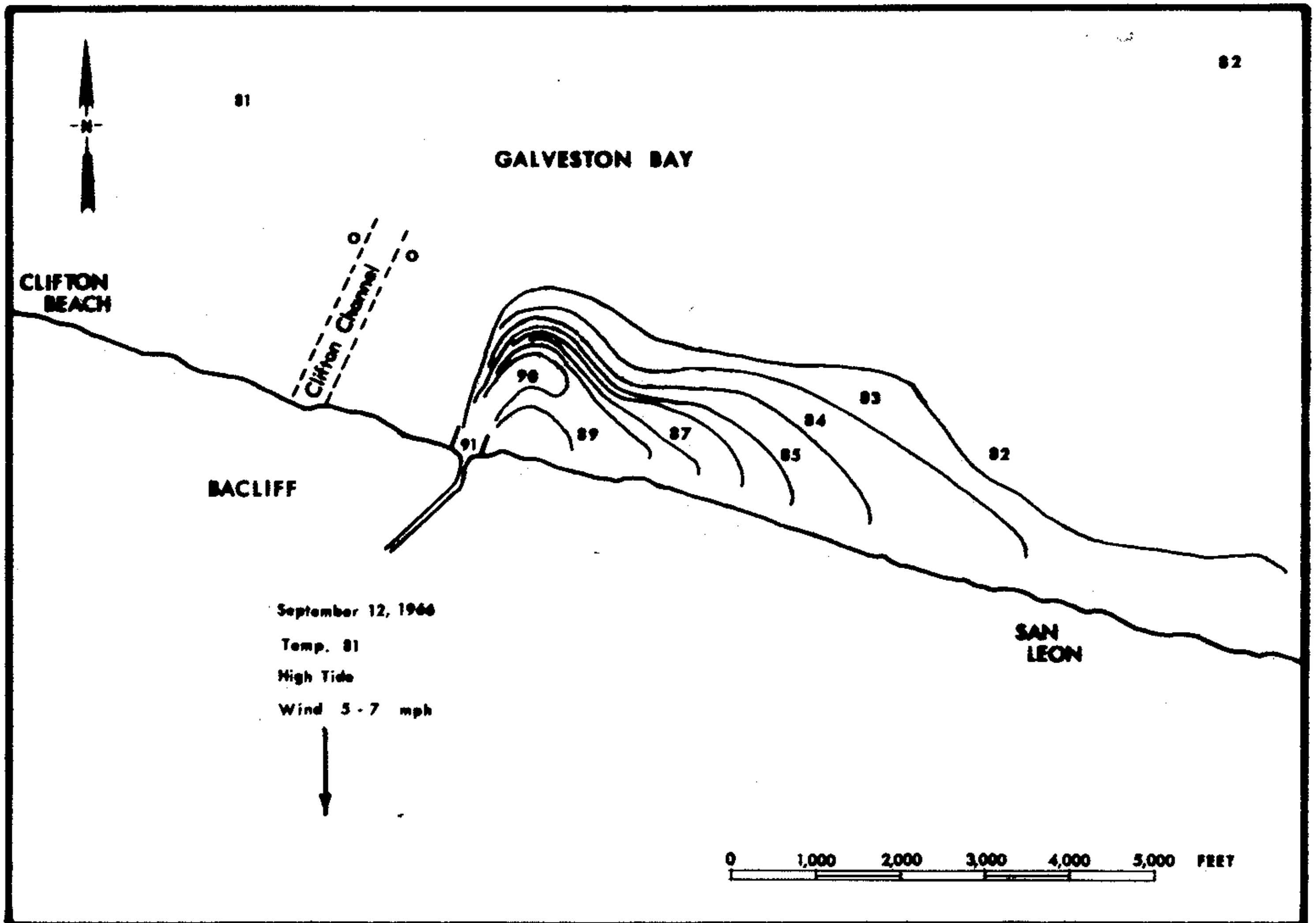


Figure 15

ISOTHERM MAP, BACLIFF, 1966

The results of this survey are illustrated in the isotherm map of Figure 15. Under the influence of the wind, the heated zone lies northeast along the shore for 1.8 miles and reaches 0.4 mile away from the shore. The thermally affected area is 300 acres. The maximum observed temperature at the point of discharge was 91.5 degrees. Temperatures elsewhere in the bay varied from 81 degrees at a point two miles northwest of the canal outlet to 82.5 degrees at the Humble Dock temperature recorder some eight miles to the northeast. Temperatures of 81.5 degrees were observed on the perimeter of the affected zone.

The area of water thermally affected is similar to that in Clear Lake and not greatly different from the results of similar surveys at Smithers Lake. The temperature distribution in this zone of warmer water is also similar to that from the other surveys just mentioned. Approximately one-third of the area is one degree above the normal bay temperatures and just under two-thirds of the area is three degrees or less above the normal temperatures.

The permanent temperature recorders at the ends of the groins at the canal outlet provided a possibility of determining the most probable position of the zone of heated water. If the position of the zone was as it is shown in Figure 15 then the temperature at the recorder on the east groin would be higher. If the temperature at the west groin was higher, then the zone would probably lie more westward from the discharge. Naturally, there would be times when the zone position was such that the temperature at the two points would be equal or nearly equal.

The data from these temperature recorders were analyzed according to this theory for the 1966 and 1967 periods of data collection. The data analysis procedure consisted of nonparametric statistical techniques to determine whether either of the data points had higher temperatures for a significantly greater fraction of the time. The results indicated that the temperatures at the two points were similarly distributed and therefore conclusions regarding most probable zone locations could not be drawn.

It has been evident in all of the similar studies that the wind is the predominant factor in the location of the heated zone and that the area of this zone was relatively constant regardless of its position. There was nothing to indicate that the situation was any different here. However, the effect of tidal currents should not be overlooked. The evidence here was that the tidal effects were overcome by the wind effects since the survey was made at the end of the incoming tide period during high slack-tide and yet the zone was in a position such as would have been expected for the existing wind conditions. The more common southeast winds would be expected to move the zone northwest and therefore cause higher temperatures at the end of the west groin. This condition was not substantiated by data and thus it appeared that there was a general counterclockwise circulation in this area of Galveston Bay.

The worst condition that would be possible as far as interrelation between this heated water discharge and the heated discharge in Clear Creek would be for the zone to extend northwest along the shore under the influence of mild winds. Moderate winds produce turbulence and provide mixing and additional heat dissipation and therefore do not reflect worst conditions. Under the worst conditions, the heated zone would probably extend from two to two and one-half miles from the canal outlet based on this survey and other similar studies. The distance from the Bacliff canal outlet to the Clear Creek channel is 4.3 miles and thus, it is extremely improbable that any interrelation of the two heated discharges could occur.

From previous studies in Clear Lake, the size of the heated zone is not increased in direct proportion to the quantity of heat rejected to the lake. Therefore, it is unlikely that even a several fold increase in the heat rejected at the Bacliff site could elongate the heated zone enough to cause interference with the Clear Lake discharge. Effects of the heated discharge from Bacliff will probably not be observed outside a two-mile radius. The zone of heated water that may be more than two degrees above normal bay temperatures will in all probability not reach more than half this distance. Temperatures more than five degrees above normal bay temperatures will probably not occur outside a radius of 0.6 mile from the discharge point. Subsurface temperatures will be lower than these during more calm periods when stratification might exist although this will not occur very often.

It may be concluded that the chances for the two heated discharges to interrelate is very remote for the present generating capacity of the P. H. Robinson Station. After the No. 3 unit goes into operation, the situation should be reappraised with a somewhat more extensive series of field surveys.

REFERENCES

[1] Edinger, John E., and Geyer, John C., "Heat Exhange in the Environment", EEI Publication No. 65-902, Cooling Water Studies for Edison Electric Institute Research Project No. 49, Johns Hopkins University, Baltimore, Maryland, June 1, 1965.

[2] Holter, Marvin R., "Infrared and Multispectral Sensing", Bio Science, Volume 17, No. 6, p. 376, (1967).

[3] Ragotzkie, Robert A., "Comments on the Validity of Sea Surface Temperatures as Measured with the Barnes Infrared Thermometer", Techniques for Infrared Survey of Sea Temperature, United States Department of the Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Bureau Circular No. 202, p. 53, November 1964.

[4] Hiser, Leland L., and Childers, Ralph E., Technical Progress Report No. 1, "Report on the Study of Temperature Effects in Clear Lake and Galveston Bay", Southwest Research Institute, August 2, 1965.

[5] Childers, Ralph E., Technical Progress Report No. 2, "Oxygen Balance of the Webster Generating Station Cooling Water Canal System", Southwest Research Institute, November 1967.

[6] Childers, Ralph E., Technical Progress Report No. 1, "Temperature Distribution in Smithers Lake", Southwest Research Institute, in press.

[7] Davis, C. C., "The Marine and Fresh Water Plankton", Michigan State University Press, 1955.

[8] Palmer, C. M., "Algae in Water Supplies", U. S. Department of Health, Education, and Welfare, Public Health Service Publication No. 657, 1959.