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COOLING PROBLEMS OF THERMAL POWER PLANTS
PHYSICAL MODEL STUDIES

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Resume

The Alden Research Laboratories of Worcester Polytechnic Institute has for many years conducted physical model studies, which are normally classified as river or structural hydraulic studies. Since 1952 one aspect of these studies has involved the heated discharge from steam power plants. The early studies on such problems concentrated on improving the thermal efficiency of the system. This was accomplished by minimizing recirculation and by assuring full use of available cool water supplies. With the growing awareness of the impact of thermal power generation on the environment attention has been redirected to reducing the effect of heated discharges on the biology of the receiving body of water. More specifically the efforts of designers and operators of power plants are aimed at meeting or complying with standards established by various governmental agencies. Thus the studies involve developing means of minimizing surface temperatures at an outfall or establishing a local area of higher temperature with limits specified in terms of areas or distances. The physical models used for these studies have varied widely in scope, size, and operating features. These models have covered large areas with both distorted geometric scales and uniform dimensions. Instrumentation has also varied from simple mercury thermometers to computer control and processing of hundreds of thermocouple indicators.

COOLING PROBLEMS OF THERMAL POWER PLANTS
PHYSICAL MODEL STUDIES

The early studies of thermal effluent at ARL were a simple extension of the continuing river model program of the laboratory. The previous river model studies had been concerned with hydroelectric systems, harbors, energy dissipators and similar projects. Many had been fixed-bed models using concrete as the finished molded material used to reproduce topography with wooden or steel structures. Thus the earliest thermal models were constructed with a concrete bed with wooden intake and discharge structures. The first thermal study was initiated in 1952 for the Philadelphia Electric Company and was concerned with minimizing recirculation of heated water in the Schylhill River at the Cromby Power Plant with particular emphasis on periods of low river flow. Another aspect of this model study was to insure that the cooler upstream river water was available for condenser cooling and did not bypass the plant intake when needed.

The correct model plant flow was withdrawn from the intake structure and an equal flow from an oil-fired boiler where the properly adjusted temperature rise was introduced through the outlet structure. Density Scaling and Densimetric Froude concepts were used in applying normal scaling to the model design and operation with Reynolds number being maintained well into the turbulent level. The model was constructed out of doors since at a scale of 1: 30 horizontal and 1: 10 vertical the model was over 50 meters long and in an ell shape the model river was 4 to 6 meters wide. With an outdoor model it soon became apparent that the meterology at the model site was critical to the results. Thus it was concluded that to obtain stability and produce consistent thermal results the model tests should be conducted at or near sunrise or sunset (usually a two-hour period). At these two time periods changes in model conditions due to radiation, wind and the like were usually at a minimum.

As the problems associated with heated water release became more difficult and regulations became more restricting the physical models required additional sophistication including model construction, instrumentation and data retrieval and handling.

As indicated above, the earlier models were constructed of sand and gravel coated with concrete which was molded to the required topographic detail (Photo 1). This system produced a model with a large mass and poor insulating characteristics which acted as a heat sink and inhibited changes in model operating temperatures. Current techniques at ARL incorporate the use of plastic materials of low mass and excellent insulating characteristics which minimize the influence of the model mass on temperature changes. These materials facilitate the conduct of tests and also reduce the undesirable influence of outside or ambient temperatures on the model operating characteristics. It has also been determined that the new molding techniques have resulted in better dimensional control for detailed topographic reproduction (Photo 2).

There have been corresponding improvements in water handling techniques and model plant operation. In the latest model studies the condenser cooling water is withdrawn through the intake structure, passed through electrically powered immersion heaters (located close to the model plant) to produce the correct temperature rise and finally discharged from the discharge structure. Thus the time of passage is nearly correctly modeled in addition to flow rate and temperature rise. The electric heaters will, when set to produce the correct temperature rise for the condenser, accommodate any recirculating flow and still produce the correct discharge temperature (Photo 3).

In terms of instruments and data retrieval, considerable progress has been achieved. Early thermal models relied heavily on simple mercury thermometers and manual record-data with the inherent limitations of small numbers of data points and extended time required for a model temperature survey and review.

The present system uses the copper-constantan thermocouple as the basic temperature sensor. This sensor is fabricated at ARL using a wire size of 0.2 mm (Photo 4). The small wire size makes for flexibility and minimizes the amount of obstruction to flow. Usually the wire is purchased in batches from the manufacturer (batch is approximately 30 km in length). This provides better consistency of operation and is not excessive since a 300 probe installation on an average model will requre 10 km or more of wire. Over the past 15 years a number of electronic recording and operating systems have been developed and employed at ARL. The current system has resulted from the difficulties and problems recognized and solved while working with earlier systems. This system consists basically of a switching device or scanner to individual sensors, a digital voltmeter to sense the voltage signals interogate the sensors, a reasonably powerful computer with high speed line printer from high speed paper tape punch and a card reader. The scanner was designed and built at Alden Research Laboratories and it offers several advantages over the commercially available "crossbar scanner" or any other previous scanner system at ARL. It operates faster than the crossbar scanner and is still relatively quiet in operation. It is hermetically sealed to keep out the corrosive action of a moist atmosphere and is electrostatically shielded. The scanner is randomly accessible and any specific sensor is simply called up by the computer. It is designed in a system approach. Unlike the crossbar type, no sequencing is necessary to call up a point. It is continuously expandable in increments of eight points up to over thirty thousand total points. Hookup is faster and neater than crossbars while servicing can be easy and quick. The system is as economical as the crossbar and to date very accurate results have been obtained.

The computer controls the entire operation and a software package has been written to enable the computer to perform a variety of data acquisition services. It is generalized enough to enable each model to apply its own test conditions, and can perform nearly all of the tasks required including scans of the model, verify probes during test, print out of location and thermal maps, produce cross-sections, tabulate data, cause of change temperature modes, average sequential scans, calculate thermal stratification factors, and perform backup functions (Figures 1 and 2). An entire test program may thus be preprogrammed to enable the model operator to concentrate on controlling test conditions and observing results. The high speed-line printer provides the model operator with immediate model information necessary to make decisions on future testing and possible model changes. The high speed paper tape reader and punch permits model specifications to be entered and punched paper tape to be generated for backup purposes (Photo Nos. 5 and 6).

The system has been used to handle data from remote models up to 1 km from the central area. A separate data acquisition system is thus no longer required for each model. Instead, a minimal set of interfacing equipment is needed at each new model to share in the flexibility of the computer based data acquisition system. The Indian Point III model at ARL has successfully gone on line, and now can receive instructions from the computer via telephone cables as well as send data from storage and treatment.

Memory disks have now been added to the system to allow expansion of the operation to time-sharing between model jobs as well as to better facilitate mathematical programming. Where it is feasible, model jobs other than thermal data acquisition may be handled equally well.

The advantages of such a system include development of the accurate synoptic resolution of the temperature pattern over a model. This provides not only a fine data base for analyzing results of a test but permit decisions on direction of future tests and the model program to be made "on the spot" and in a matter of minutes after completion of a specific test.

Finally although the decision making role is still in the hands of ARL engineers, it is believed that using the latest system provides for data retrieval to be more readily and accurately produced. Then the model work and its resulting information can proceed with more confidence and certainly more expeditiously.

It is in order, therefore, to turn to some examples of ARL physical model studies of thermal effluent problems and to indicate resulting solutions. Also where possible it will be shown how the model data compared with prototype measurements carried out after the model studies were completed. Insofar as possible different situations such as river, reservoir, estuarys, and ocean locations will be covered in order to indicate a variety of problems and consequent differences of attack and/or solution.

As a river situation the Martin's Creek plant of Pennsylvania Power and Light Company is a recent example. Located on the Delaware River it is on a section of the river where the state boundary between New Jersey and Pennsylvania is at the center of the stream. There is a 5 state Delaware River Basin Commission making an additional regulatory body involved beyond the federal and two state governments. It was imperative not to encroach on the New Jersey half of the stream with more than the accepted 5F temperature increase at the water surface.

The existing circulating water system for the two units at Martins Creek consisted of an intake at the plant and a long (500 m) open canal downstream for a discharge (Figure 3).

The testing program, which involved a number of diffuser variations, produced a 23 port diffuser discharge located on the plant side of the river and only 70 meters downstream from the plant intake. The exit velocity for each nozzle was approximately 5.0 m/sec and the area of opening was adjusted to provide a flow rate proportioned according to the intercepted area of the river cross section (Figure 4). Thus the momentum energy available for entrainment of river water was "tuned" to the minimum river flow and adjusted to take advantage of the available river water for mixing without inducing an eddy or reverse flow on the far side of the river. As indicated by the plot, the 5F isotherms were well within 800 meters of the plant and complied with the regulations (Figure 5).

The Seabrook Nuclear Power Plant of the New Hampshire Public Service Company is located on the Atlantic Ocean coastline and is planned with an offshore submerged intake and multiport diffuser outlet (Figure 6 and 7). The plant will have two generating units with a 850 MW capacity each. The temperature rise across the condensers is 20C and the flow rate is 55 m^3/s. The physical model at a scale of 1/120 involved an offshore area approximately 2500 meters by 2500 meters including both the intake and discharge areas. From field studies the ocean currents due to tides and wind were documented and subsequently designed into the operating parameters of the model. It was planned to use the near field data developed by the model to input the analytic analysis of the far field effects of the plant discharge. The temperature sensors (300 copper-constantan thermocouples were used in model) were located to record critical operating temperatures in addition to the majority of the thermocouples placed to record surface temperatures over the model. The data was developed as a plot of surface isotherms for the near field area (Figure 8). The model results were then extended to far field predictions by convection and dispersion analytic techniques (Figure 9).

In addition to the temperature patterns for the heated discharge the physical model provided additional information necessary for design. In the case of the Seabrook model, studies were made of the scour patterns on the ocean bottom at each nozzle. As a result of the studies the upward inclination of each nozzle from the ideal horizontal direction was determined. Thus the scour of bottom material was eliminated or minimized.

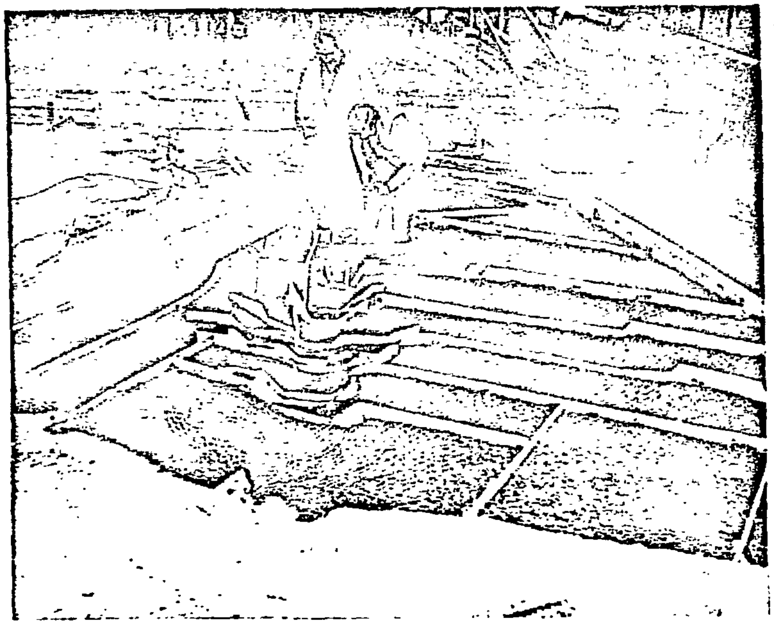
At the Brayton Point Power Plant of the NEP 3 units with a total capacity of 1125 MW withdrew cooling water from the Taunton River on one side of Brayton Point and discharged the heated water to the Lee River on the opposite side. The resulting patterns of heated water were not satisfactory and a model study was initiated to develop a satisfactory solution. A physical model to a scale of 1/300 horizontal and 1/45 vertical was constructed to include the upper Narragansett Bay area (Figure 10). In order to remove the heated water from either the Taunton River and the Lee River a discharge canal was constructed to the southern end of Brayton Point with a surface discharge structure. A submerged manifold had been investigated in a preliminary study and rejected due to the shallow depths in the upper bay (3 meters max.). The surface jet with 8C temperature rise was produced by a sheet piling restriction placed in accordance with the model study results. The jet velocity varies with the tide stage and ranges between 2.5 m/g to 4 m/s. The resulting plume produces a surface temperature pattern with 2C temperature at a distance from the outfall no greater than 300 meters (Figure 11). This was within the limits prescribed as being necessary as the initiation of the model studies.

The Roseton Plant of the Central Hudson Power Company is located on the west bank of the Hudson River about 60 km north of New York City. The site is within one kilometers of the company's Danskammer plant. The Danskammer plant has five steam units totaling 500 MW and a shoreline intake and nearly shoreline surface discharge for the cooling water. The planned Roseton Plant had an intake adajacent to the Danskammer intake but a discharge structure and concept to be developed from a physical model study.

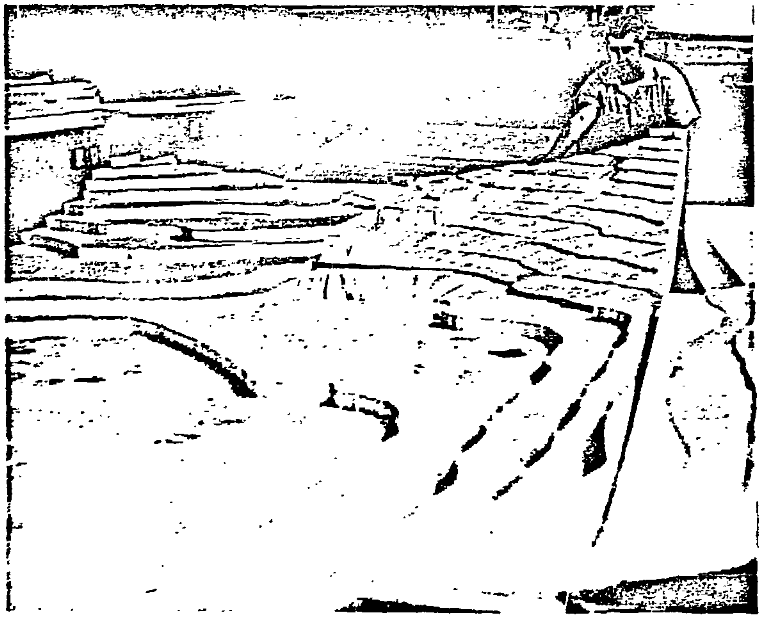
A 1/90 scale model covering approximately 4 km of the Hudson River including both plant sites. The model was equipped with automatic gates and flow controls so that tidal flow and superimposed river flows were reproduced continuously at the correct time scale (Figure 12).

As a result of the model studies a manifold diffuser was developed for a location about 100 m offshore of the Roseton plant. The multi-jet discharge diffuser was set on the river bottom and arranged to jet the flow normal to the river and downstream. The resulting surface isotherms showed less temperature increase for the Roseton units than from the Danskammer units (Figure 13 and 14).

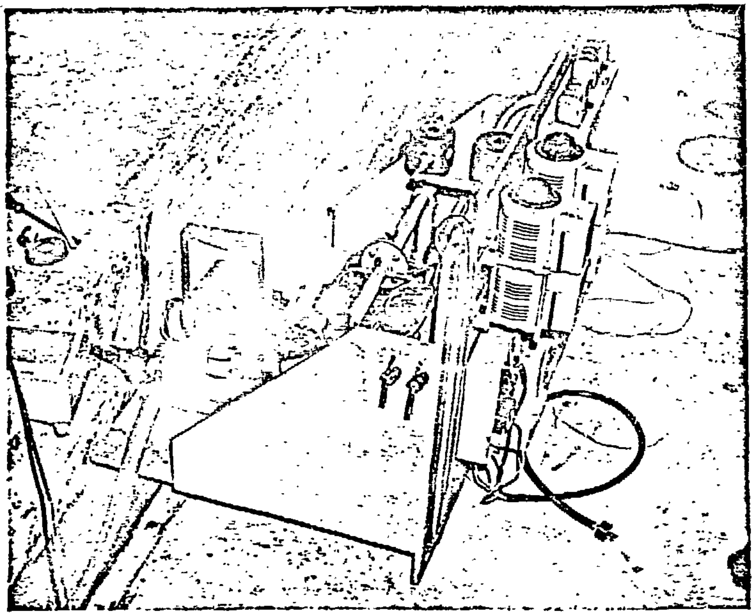
In summary it has been the experience at ARL that the thermal discharge problems associated with both power plant operation and the environmental safeguards can be studied successfully with physical models. The latest experiences in this area indicate that the best and most complete solutions to these problems have been developed by a combined use of physical and analytical modeling. This combination of studies promises to be the correct approach to these problems for a considerable time to come.



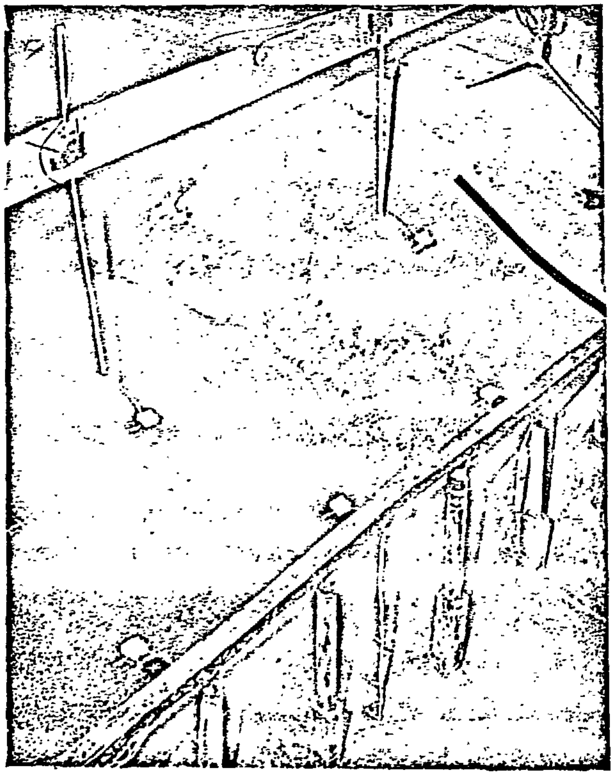
Photograph 1 Topography Modeled with Concrete



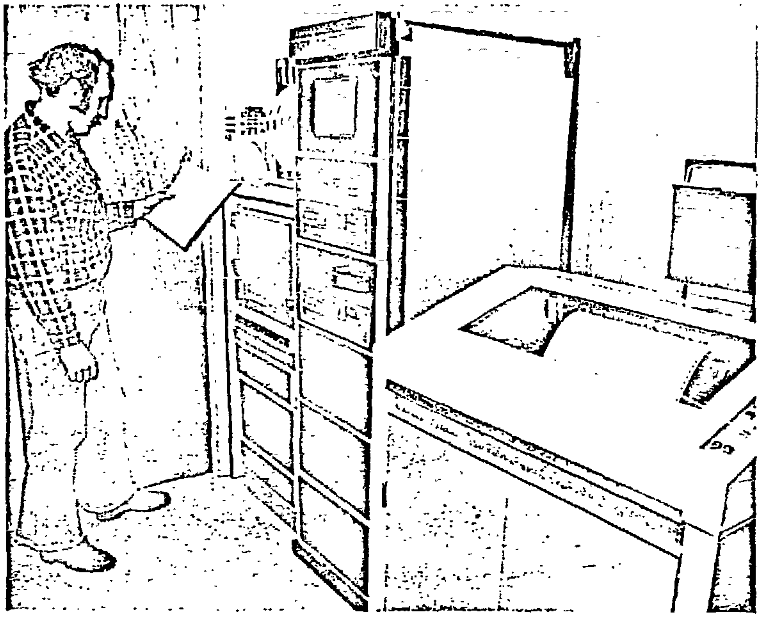
Photograph 2 Topography Modeled with Styrofoam



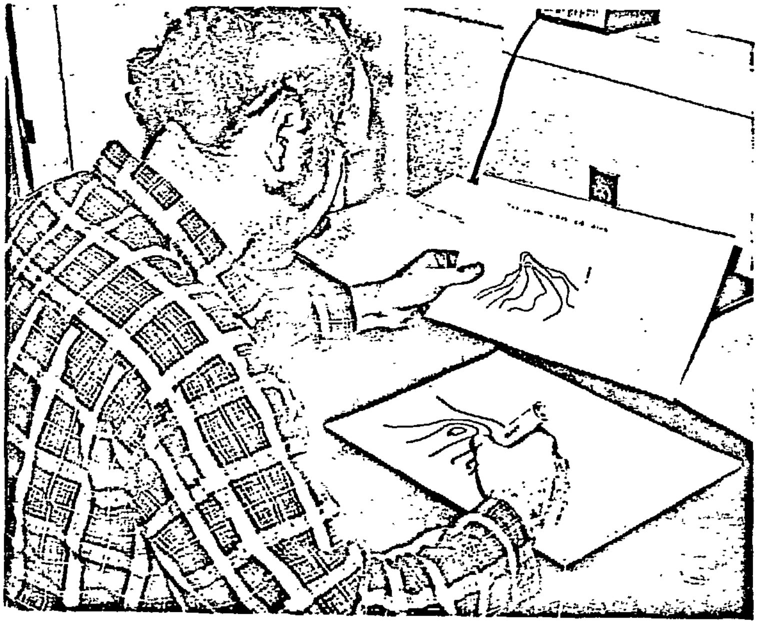
Photograph 3 Model Plant Flow and Heating Unit



Photograph 4 Thermocouple Probe on Float

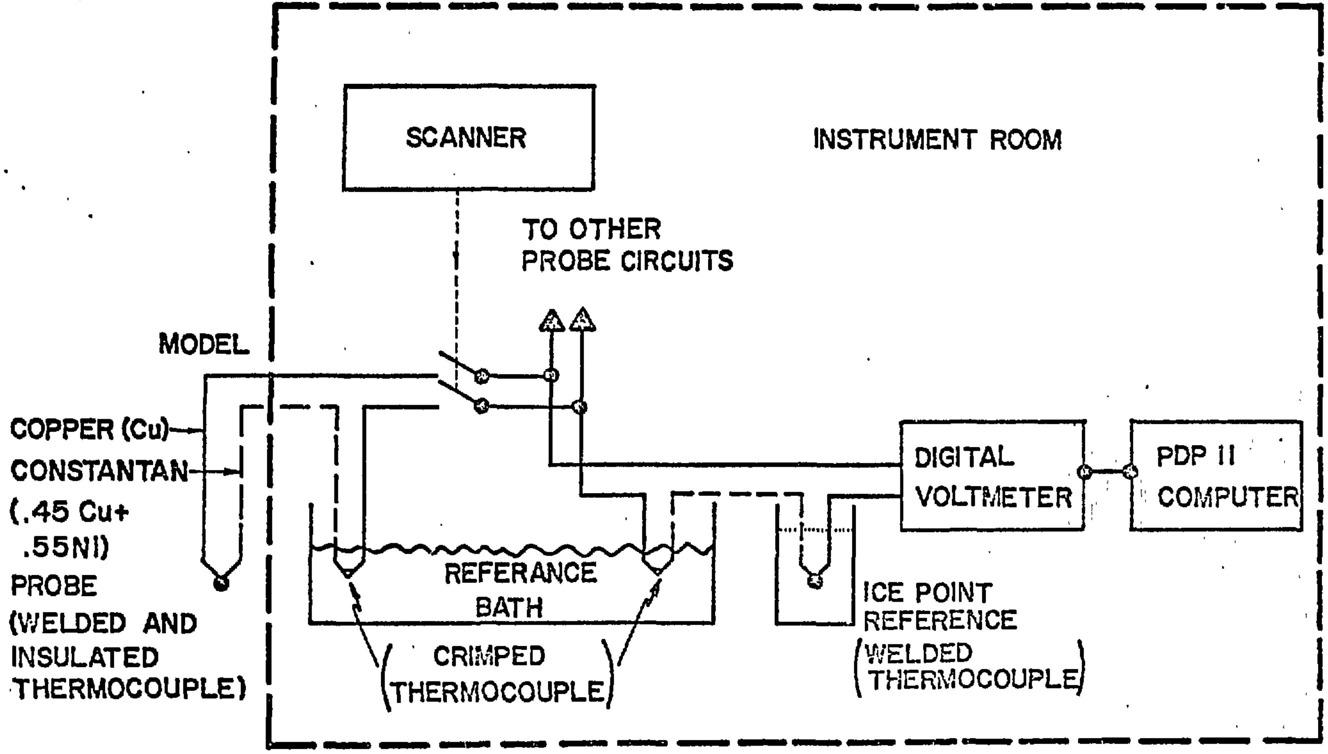


Photograph 5 Data Retrieval System



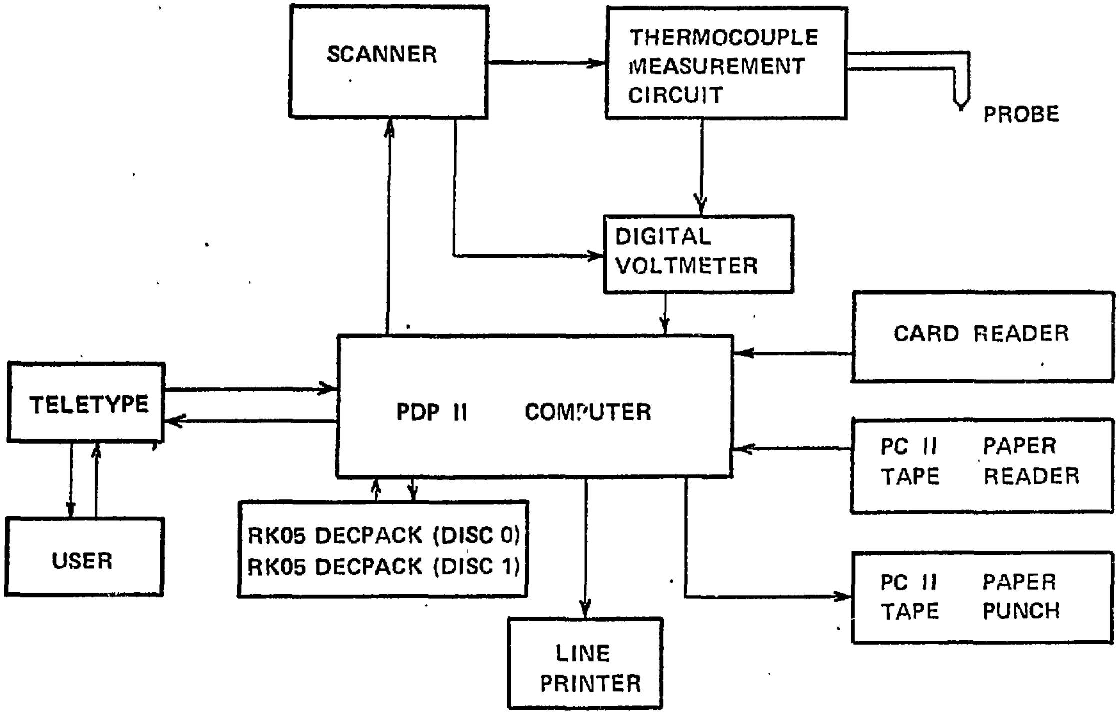
Photograph 6 Isotherms from System Print-out

FIGURE 1



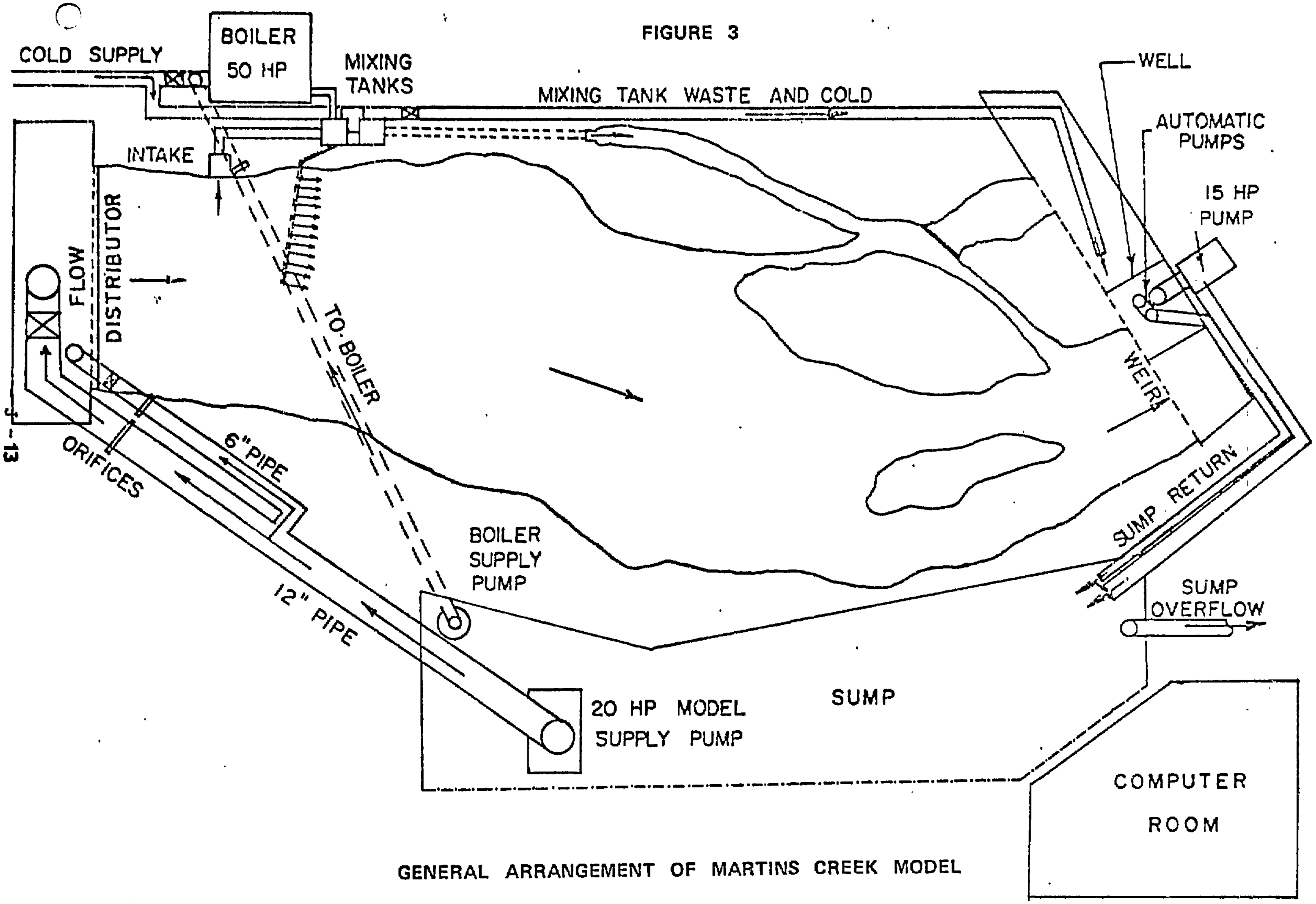
BLOCK DIAGRAM TEMPERATURE SENSING SYSTEM

FIGURE 2



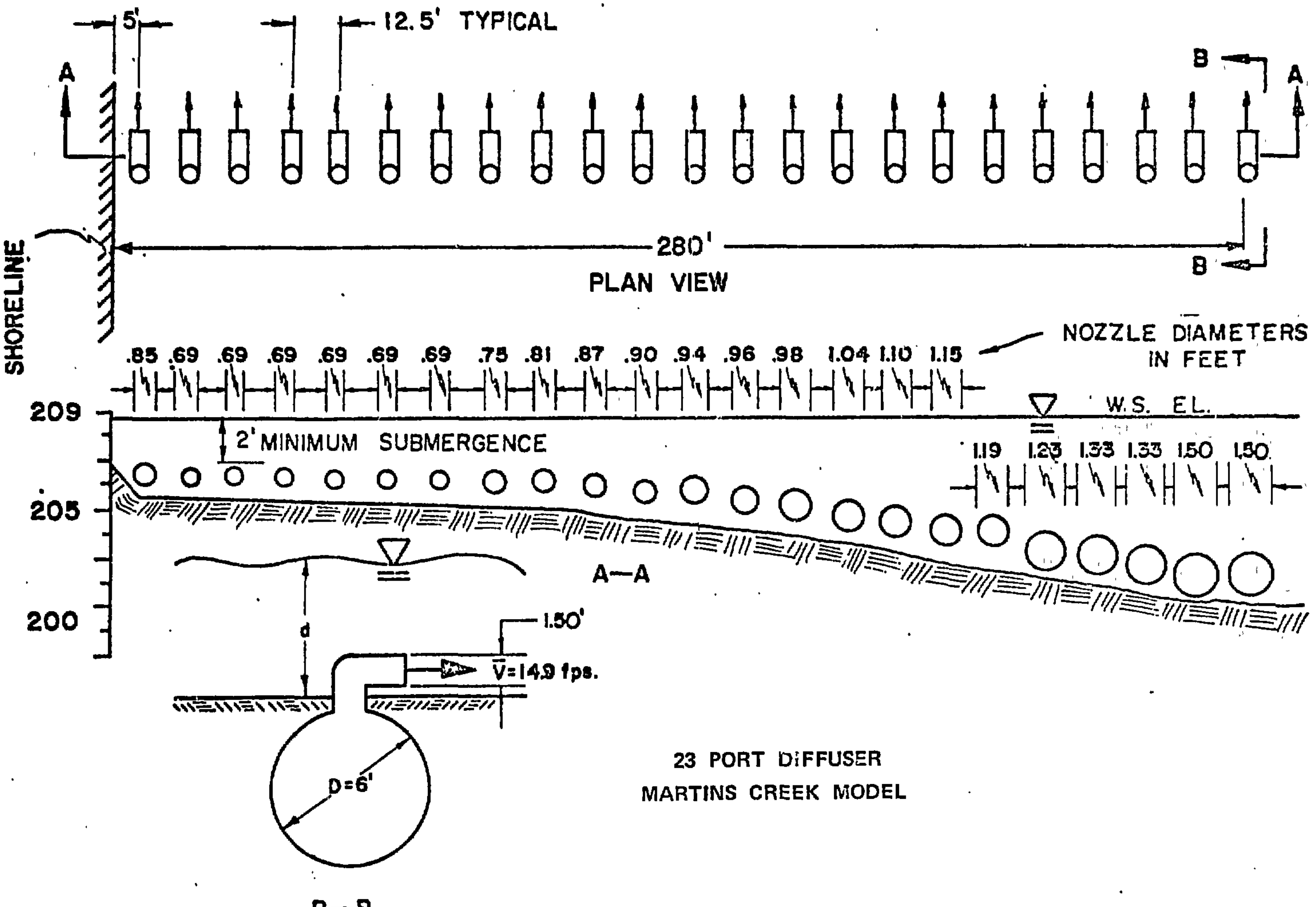
BLOCK DIAGRAM DATA ACQUISITION SYSTEM

FIGURE 3



GENERAL ARRANGEMENT OF MARTINS CREEK MODEL

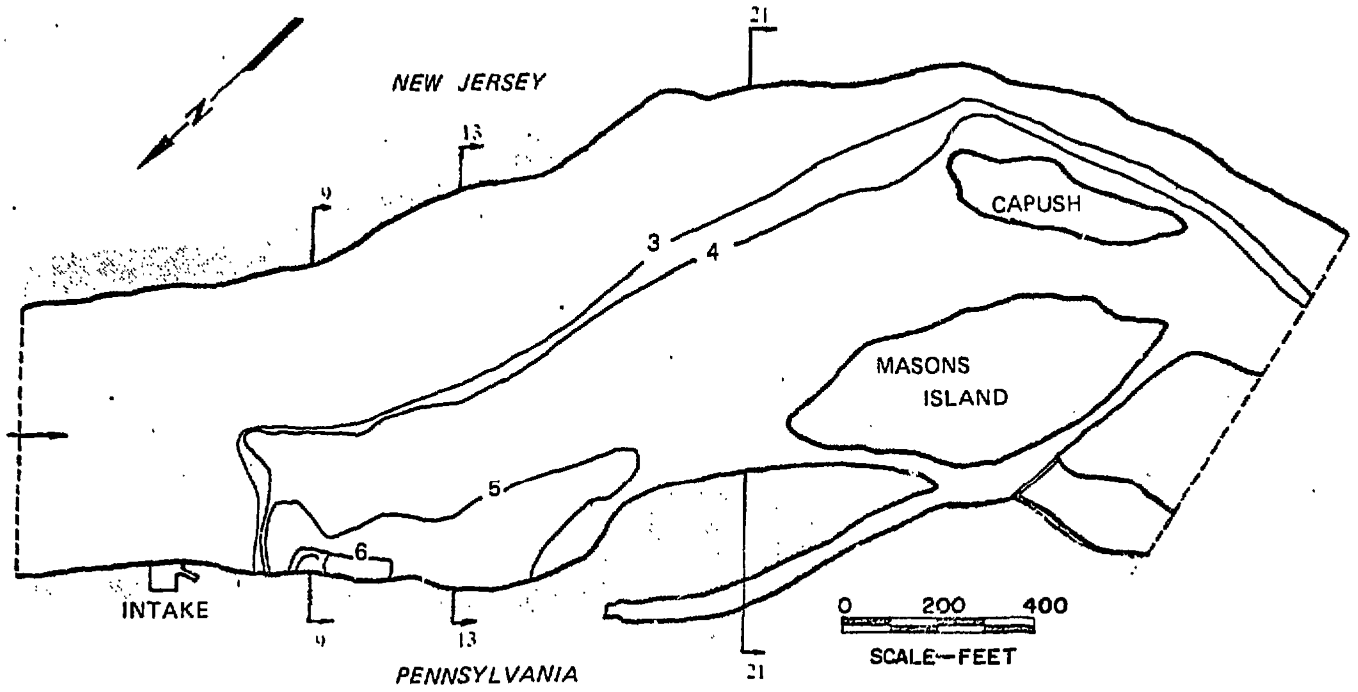
FIGURE 4



23 PORT DIFFUSER
MARTINS CREEK MODEL

B—B

FIGURE 5



Plant Conditions

Cooling Water Flow 277 cfs

Intake Temperature 66.9 °F

Temperature Rise 29.9 °F

Outfall Configuration S-6

River Conditions

Flow 2500 cfs

Ambient Temp. 66.9 °F

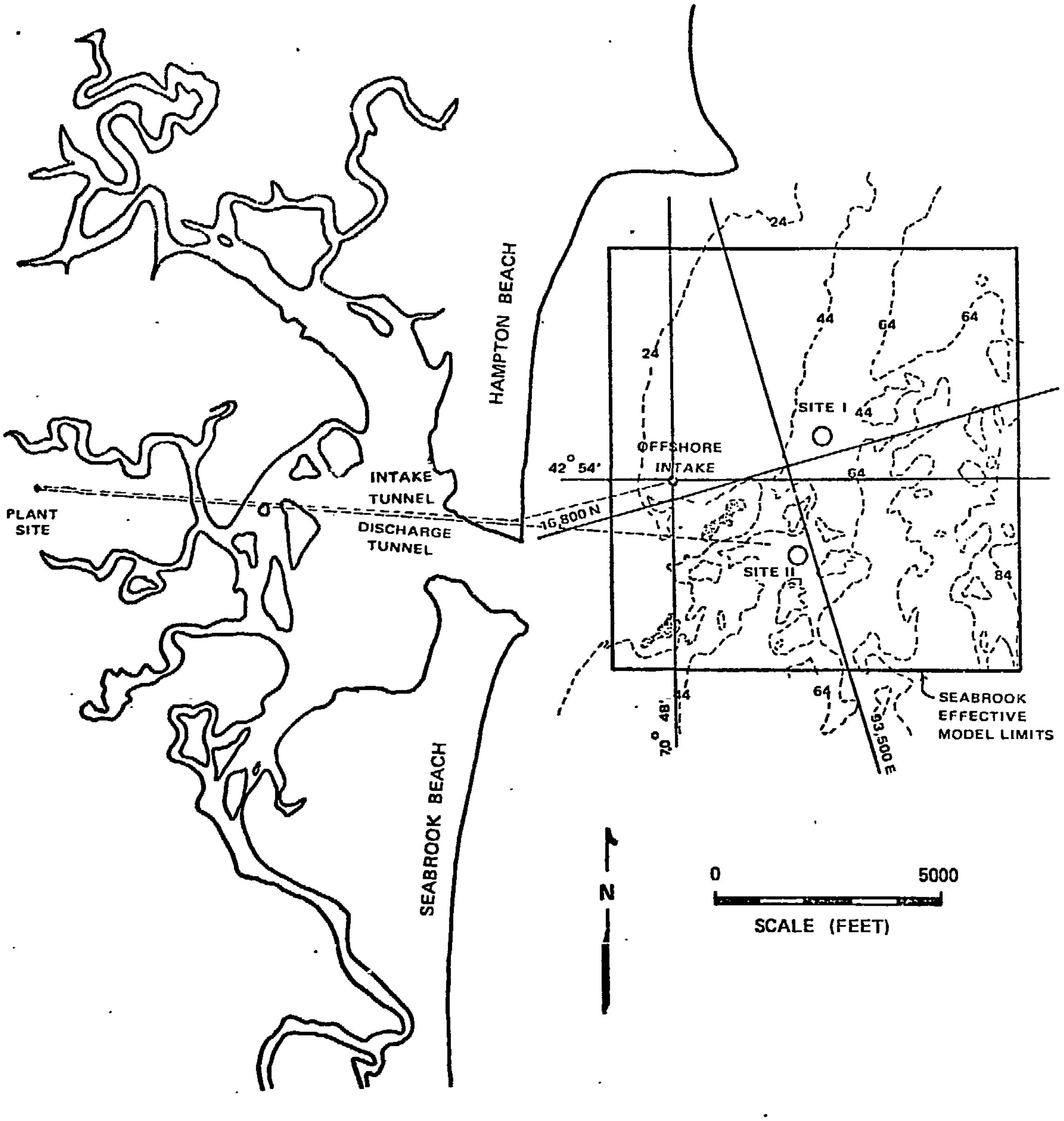
Stage 209.0 ft.

TEMPERATURE RISE ABOVE AMBIENT
MARTINS CREEK MODEL

Test Number 38

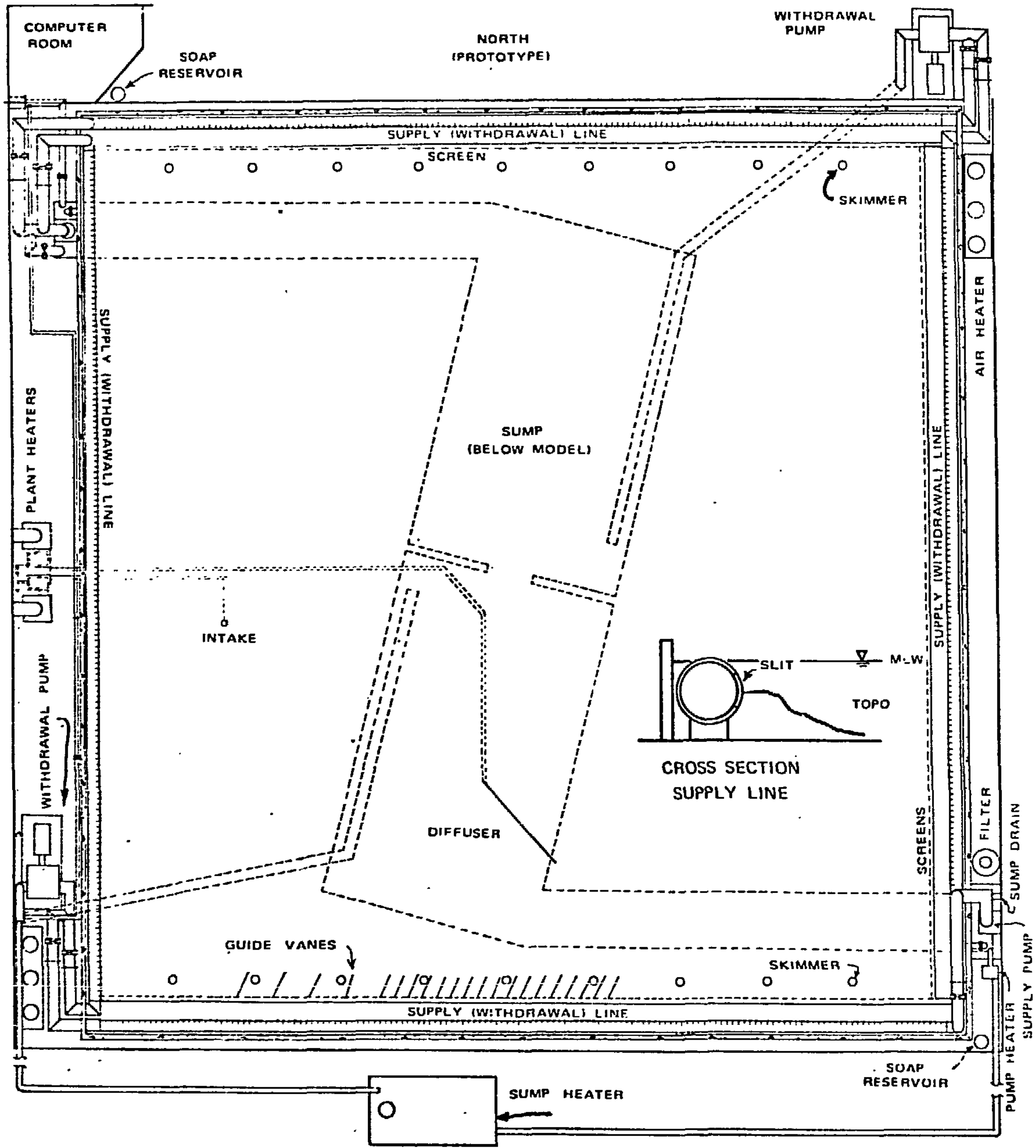
Date 3-9-73

FIGURE 6



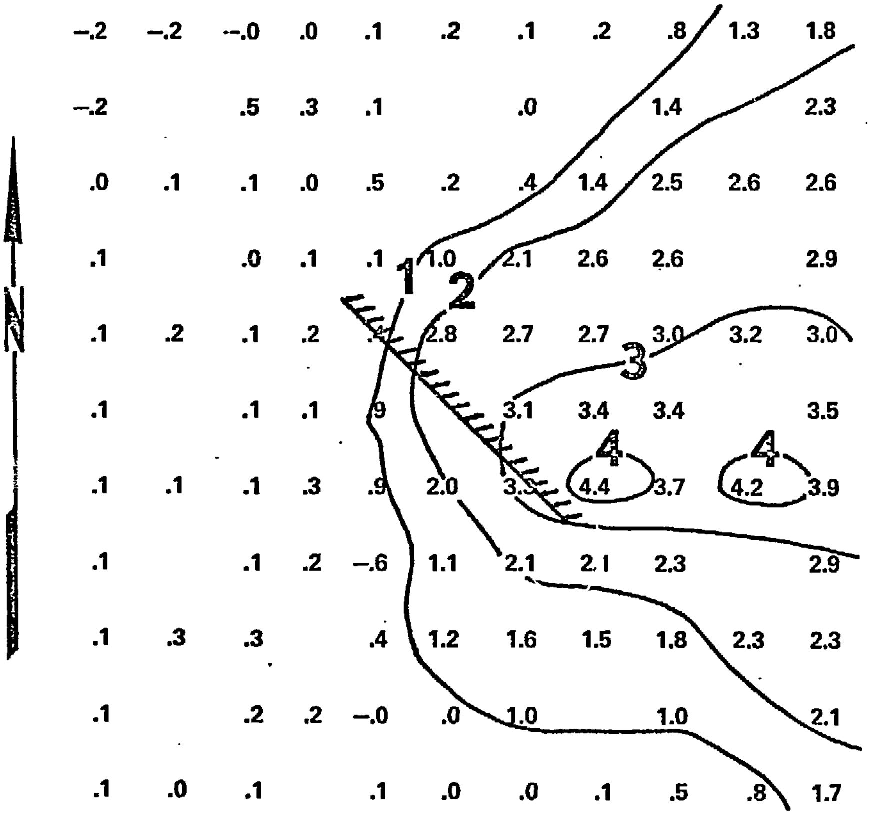
LOCATION OF MODEL AREA
SEABROOK NUCLEAR PLANT

FIGURE 7



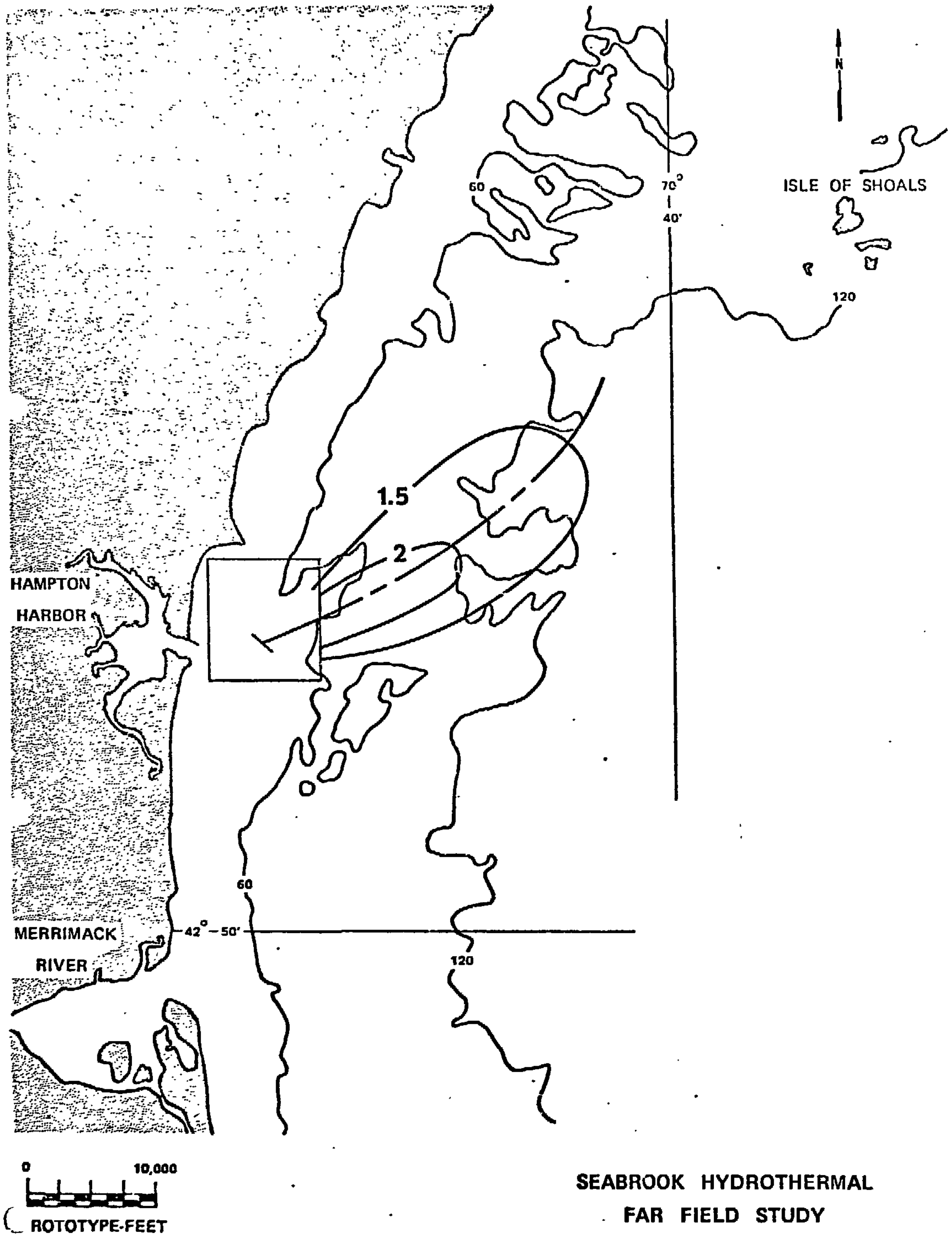
GENERAL ARRANGEMENT OF MODEL
SEABROOK NUCLEAR PLANT

FIGURE 8



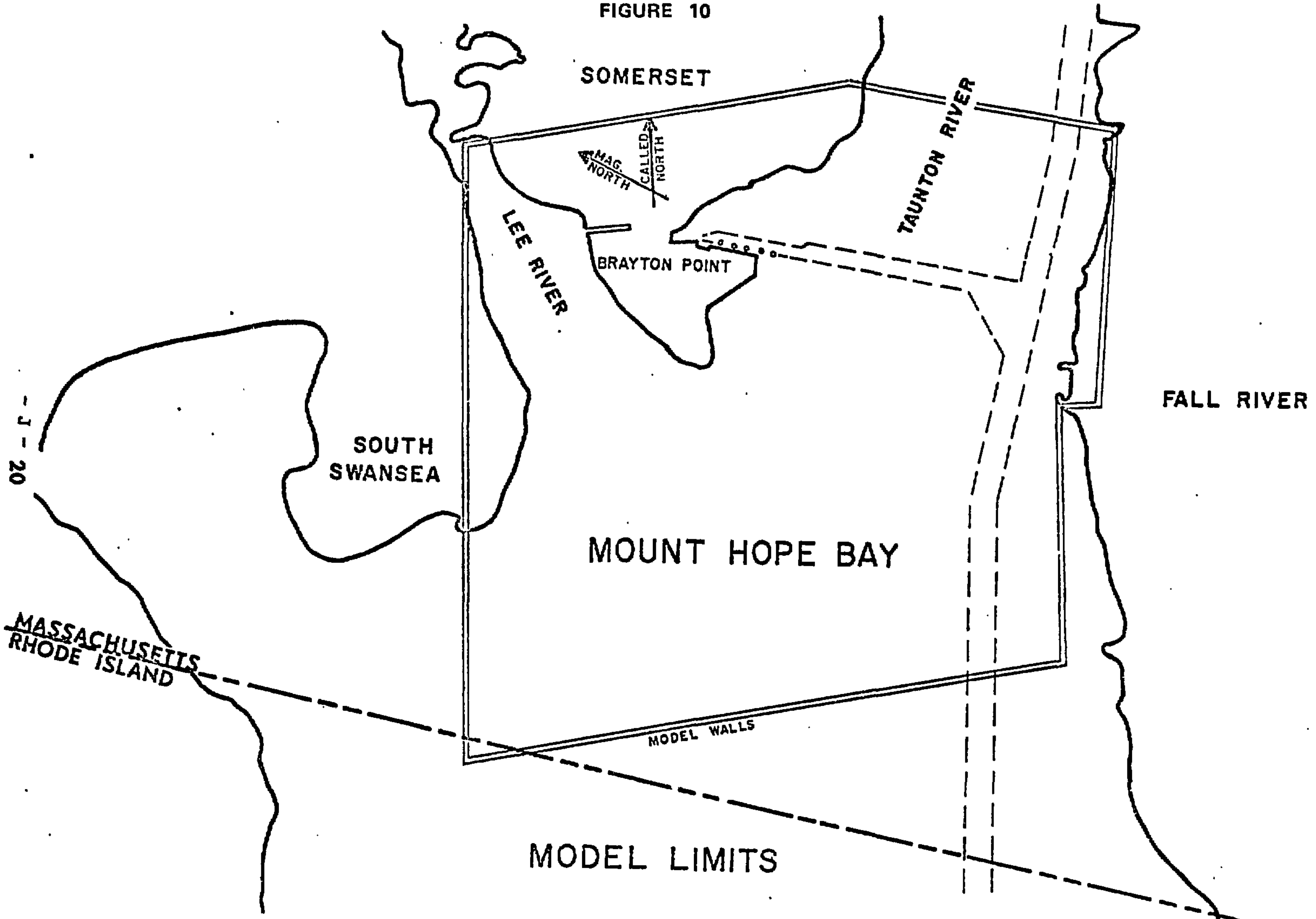
SURFACE ISOTHERMS
SEABROOK NUCLEAR PLANT

FIGURE 9



SEABROOK HYDROTHERMAL
FAR FIELD STUDY

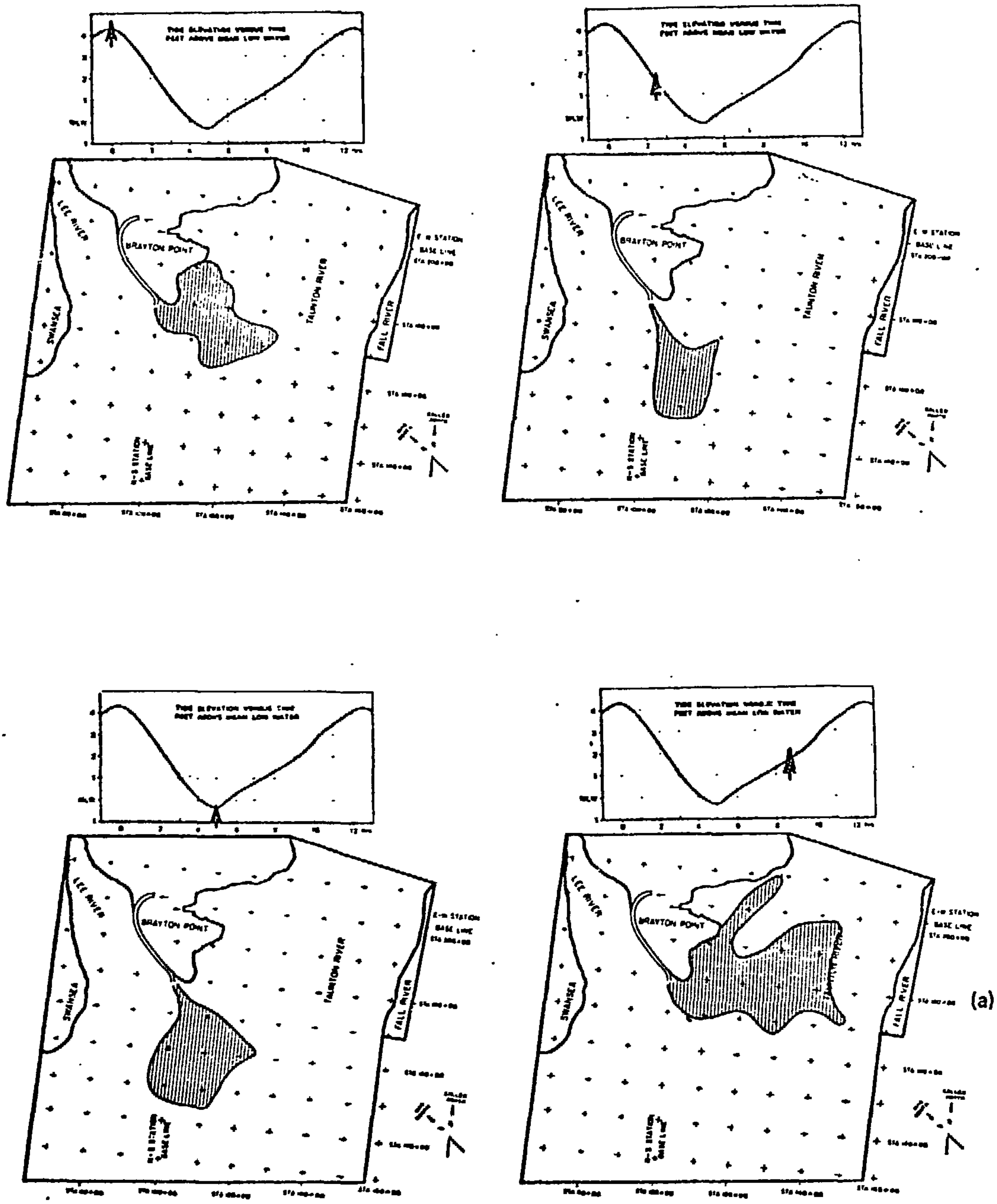
FIGURE 10



MODEL LIMITS

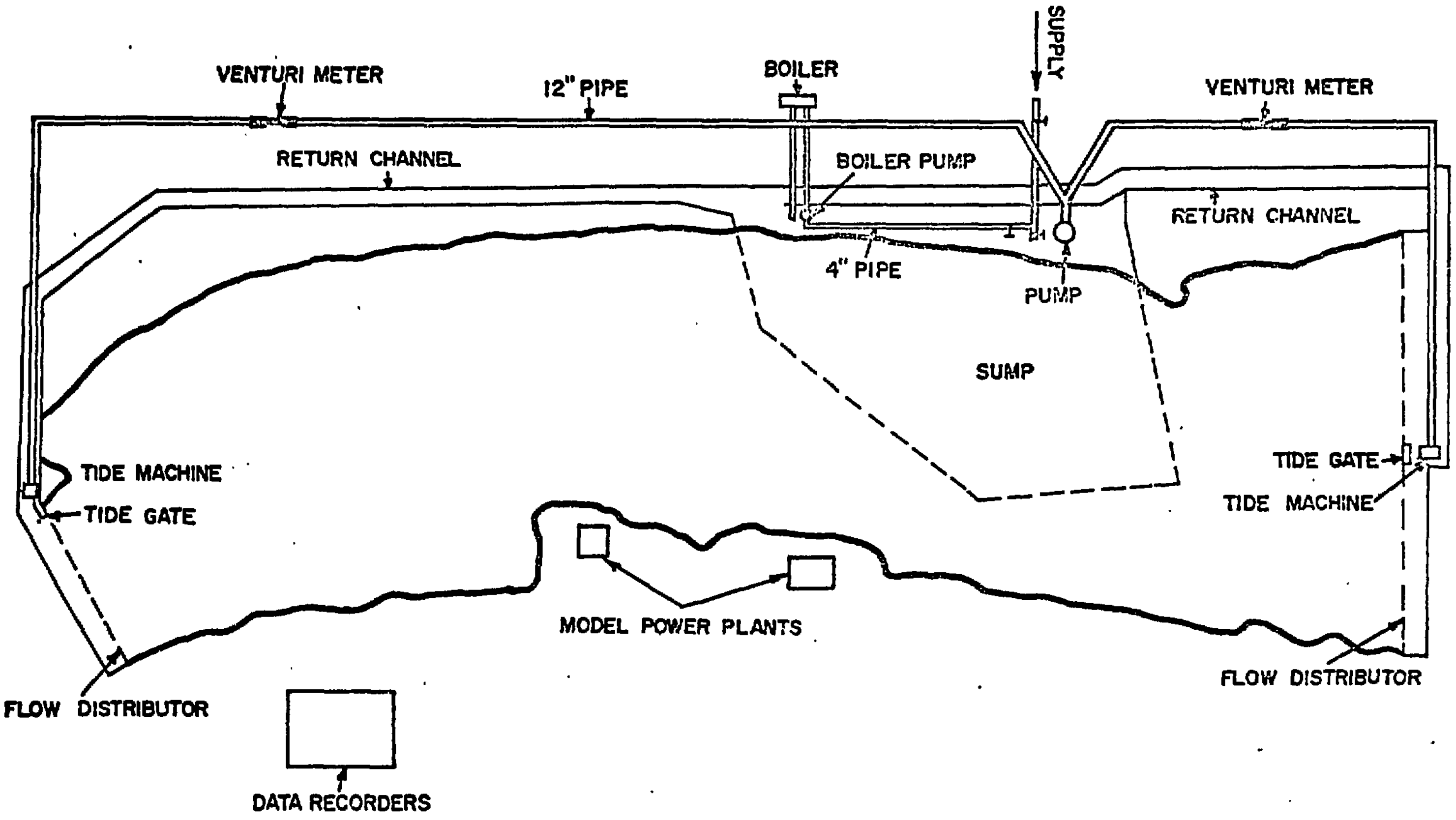
BRAYTON POINT PLANT

FIGURE 11



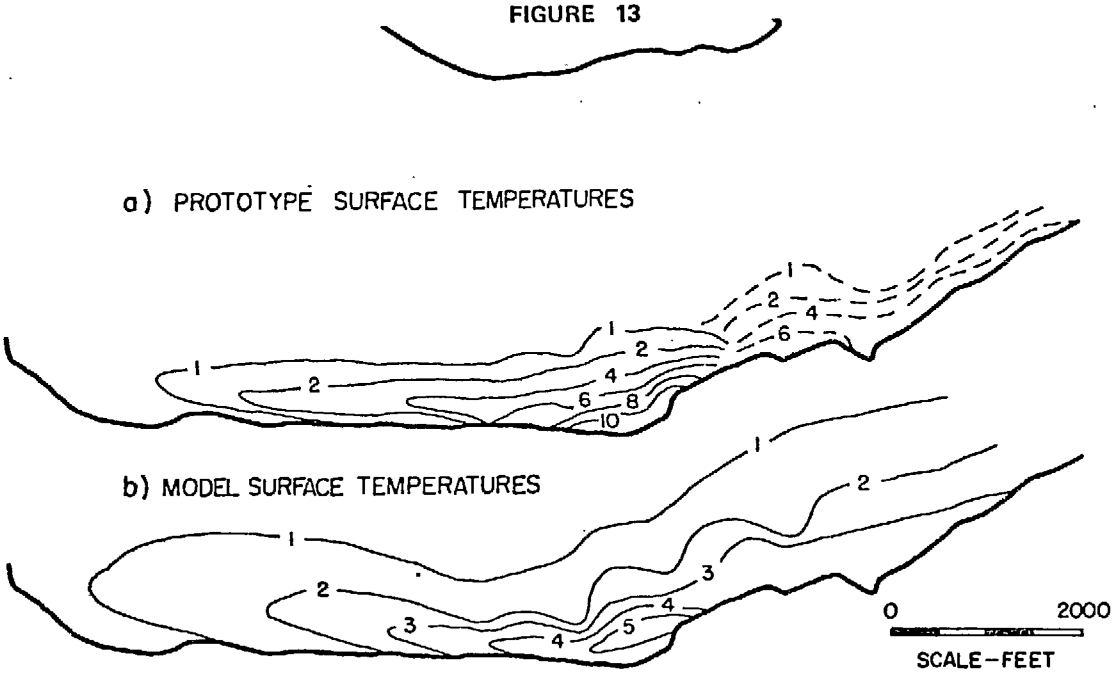
BRAYTON POINT SURFACE ISOTHERMS

FIGURE 12



GENERAL ARRANGEMENT OF MODEL
ROSETON PLANT

FIGURE 13

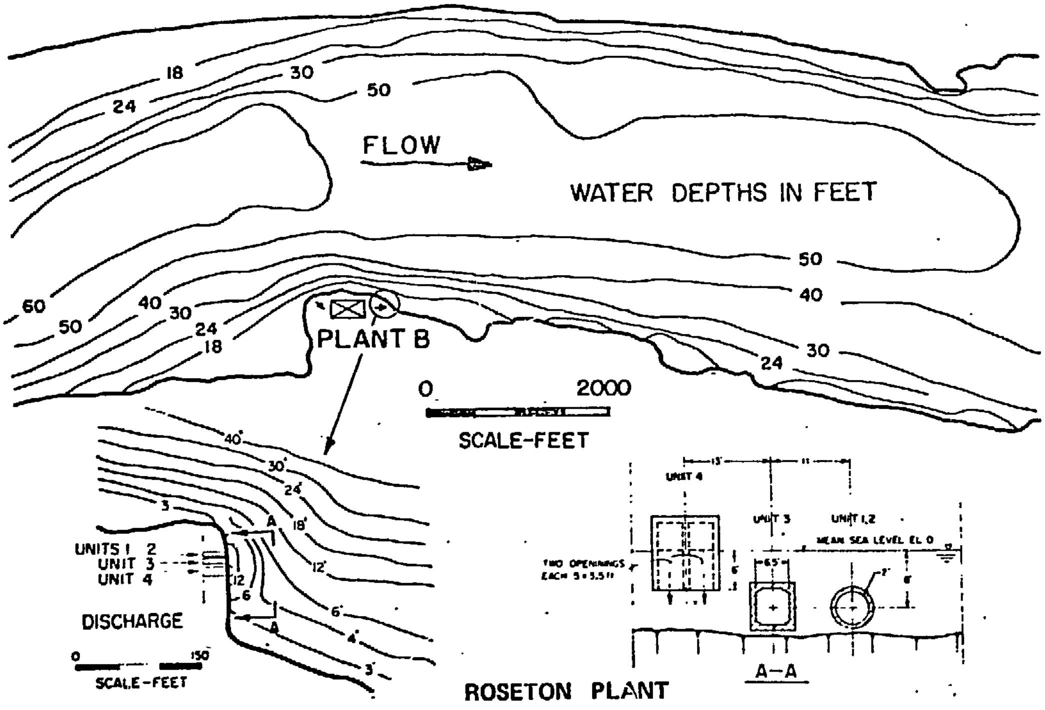


a) PROTOTYPE SURFACE TEMPERATURES

b) MODEL SURFACE TEMPERATURES

ROSETON PLANT

FIGURE 14



ROSETON PLANT