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DETAILED TECHNICAL REPORT

"FEASIBILITY OF REMOTE SENSING FOR DETECTING THERMAL POLLUTION"

PART I: FEASIBILITY STUDY

PART II: IMPLEMENTATION PLAN

by

T. Nejat Veziroglu and Samuel S. Lee

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA CONTRACT NAS10 - 8402



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Department of Mechanical and Industrial Engineering

University of Miami

Coral Gables, Florida

December 1973

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16. Abstract Heated waters from power plants discharged into rivers, lakes and estuaries can cause thermal pollution thereby disturbing the ecological balance by increasing the temperature levels and causing turbidity. The problems associated with thermal pollution are compounded by recent trends of building more and larger nuclear power plants in order to meet the growing energy demand. It therefore becomes important to have the capability to detect thermal pollution and to be able to alleviate it. The first part of the report, covering the feasibility study, indicates that (1) using passive remote sensing methods, today it is possible to detect water surface temperatures within plus and minus one degree with a resolution of 0.3 mile radius from spacecraft and the resolution is improving with time, (2) using active remote sensing methods, techniques and instruments could be developed for remote sensing of vertical temperature and turbidity distributions in oceans, and (3) it is feasible to develop a generalized three-dimensional model to predict the motion, temperature and salinity of thermal plumes within waters to which they are discharged. The second part of the report, covering the implementation plans, include (a) the development and testing of a universal analytical model to predict three-dimensional temperature and salinity distributions in coastal regions receiving hot discharges, (b) improving the accuracy of the thermal remote sensing systems by directly relating them to thermal radiation from the sea surfaces and by better accounting for the absorption in the atmosphere, and (c) the development and testing of an active remote sensing system to measure the water turbidity.			
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FORWARD

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PART I: FEASIBILITY STUDY

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Part I: Feasibility Study

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I. INTRODUCTION

Many industrial plants, especially electric power generating plants, use large quantities of water for cooling purposes. When heated waters from such industrial plants are discharged into rivers, lakes and estuaries, they can disturb the ecological balance and destroy the natural habitat of aquatic life by changing the temperature levels. In rivers the hot discharge waters can cause miles of hot sections which act as thermal barriers and prevent fish from going upstream to their spawning grounds. In regions of high ambient temperatures, such as along the East Coast of Florida, the hot discharges can cause excessive estuarine temperatures. This in turn increases the evaporation and results in an overall increase in the level of salinity. Turbidity of mineral origin can be generated by the dislodging and suspension of sediments by currents such as those caused by hot discharges. Turbidity of biological origin can be generated by phytoplankton growth in thermally suitable environments. The above outlined processes can ruin the marine environment as far as ecological, fishing and recreational interests are concerned.

A major source of thermal pollution of rivers, lakes and estuaries is the hot water discharge from the condensers of fossil and nuclear fueled power plants. The demand for electric power in the United States has doubled about once every ten years since 1900 and indications are that the rate of increase will be even greater in the coming decades. About 5500 BTU of thermal energy are produced for every kilowatt hour of electricity generated by a conventional power plant. Nuclear powered plants, being less efficient, produce about 10,000 BTU per kilowatt hour. This means that the doubling time for hot discharges, the cause of thermal pollution, is less than 10 years.

In order to meet the growing cooling water requirements, it is projected that by 1980, thirty-two percent of all steam electric stations will be located adjacent to estuaries or on open sea

coasts. The problems associated with the release of these large volumes of heated water are compounded by recent trends within the power industry. Large plants, including more nuclear powered generators, are being built, and groups of these units will be located at a single site. Thus the United States, and the world, face a potential problem in environmental alteration of enormous proportions, particularly in estuarine and coastal marine waters.

In order to come up with solutions to the above stated environmental problems, the feasibility of Remote Sensing for Detecting Thermal Pollution has been investigated. In the first part of this project, the emphasis is on the feasibility study of the development of a generalized three-dimensional, predictive, analytical model for determining the water temperature distribution caused by thermal discharges. The study includes an investigation of the feasibility of using remote sensing to quantitatively measure water temperatures, salinity content, turbidity, and other parameters that are pertinent to the model development. It also includes a study concerning the manner in which remote sensing measurements together with the in-situ measurements could be used to provide boundary conditions needed for the model evaluation.

Figure 1 relates the various phases of the present study. Remote sensing data are to be used to provide initial and boundary conditions for the mathematical model. The in-situ measurements serve three purposes, i.e., 1) to supply the ground truth data for remote sensing, 2) to provide boundary conditions for the model, 3) and to obtain data for the verification of the model. The site study is needed to investigate potential sites for the application of the model.

The system approach has been used to conduct this feasibility study. Figure 2 shows the steps followed. In the first stage, a careful literature search has been carried out, and information has been gathered to obtain necessary data for the subsequent stages of the study. Existing one- and two-dimensional models

have been carefully analyzed. The requirements for remote sensors and in-situ measurements have been investigated. The inputs obtained from the first stage have been critically examined and evaluated. Alternatives have been considered. After a trade-off study, a general three-dimensional model has been chosen. The feasibility of the model formulation, development testing and verification have been studied.

The emphasis has been placed on the use of remote sensing measurements to provide the necessary inputs for the model. The present study has been carried out in four phases, i.e., 1) The Mathematical Model Study, 2) The Remote Sensing Study, 3) The Ground Truth and In-Situ Measurements Study, and 4) the Site Studies. These four phases of study are closely related and have been conducted concurrently. The details of these phases of work are presented in the following sections. A conclusion of this feasibility study and recommendations are given at the end of this part of the report.

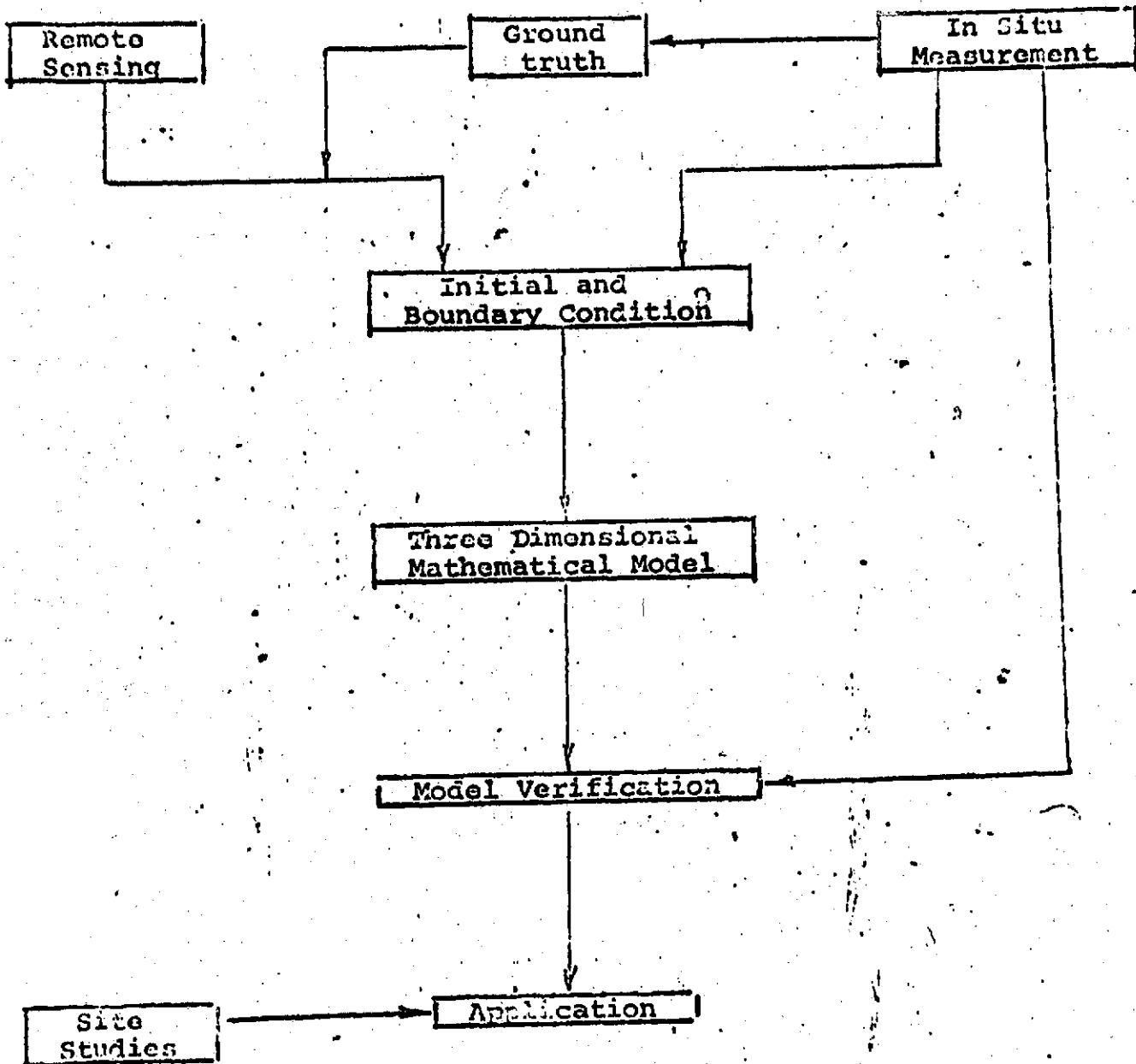
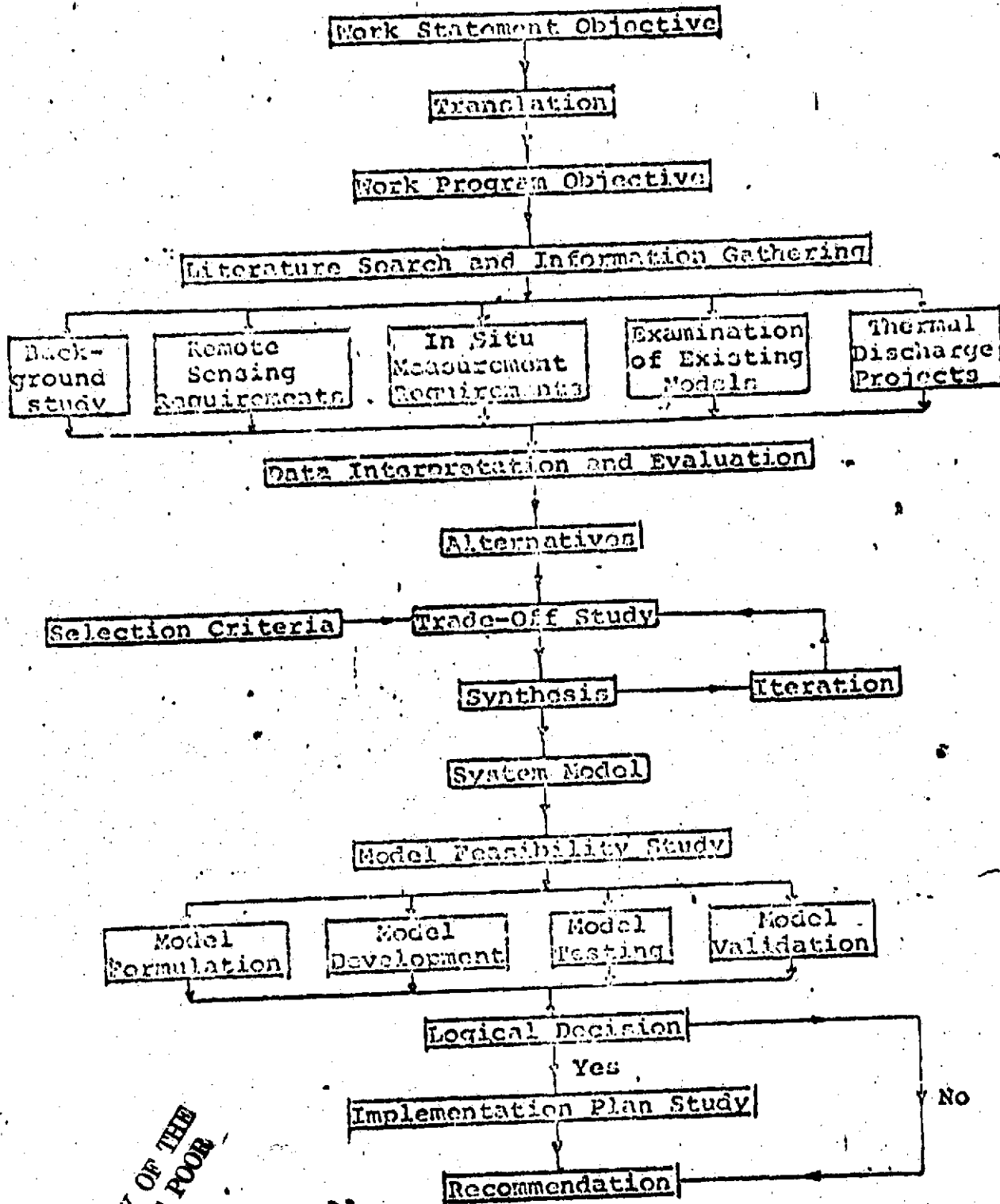


Figure 1. Relations Between Various Phases of the Study

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Fig. 2- Flow Chart for System Model Study

II) MATHEMATICAL MODEL

A) REVIEW OF EXISTING MODELS

In recent years, due to the increase of power generation plants, there is a growing concern about the problem of thermal pollution caused by such plants. Typically, cooling water for a plant is withdrawn from a nearby body of water and is circulated once in the condenser cooling system to carry away the rejected heat. The heated water is then discharged into an adjacent natural water body such as a lake, river estuary or coastal waters. Eventually, this excess heat is transferred from the surface of the water to the atmosphere by evaporation, convection, or conduction.

Thermal effects of power plant discharges can be categorized as occurring within two main regions. In the immediate vicinity of the discharge, the temperature and velocity distribution are governed by properties of the flow discharge with subsequent mixing of cooler ambient water. This region is known as the 'near field'. Within this near field, ambient fluid is entrained into the discharge from the surrounding water. Surface heat losses are in general negligible because of the relatively small surface area available for heat transfer to be effective. Therefore, the chief mechanism for temperature reduction in this region is by dilution. Outside the near field is a much more extensive region with heat transfer processes governed by natural heat dissipation processes. This region is known as the 'far field'. Typical modes of energy transfer within this far field include convection and diffusion in the interior of the fluid body and evaporation, radiation plus convection from the surface.

The prediction of the temperature and velocity distribution of the near and far field involves understanding a

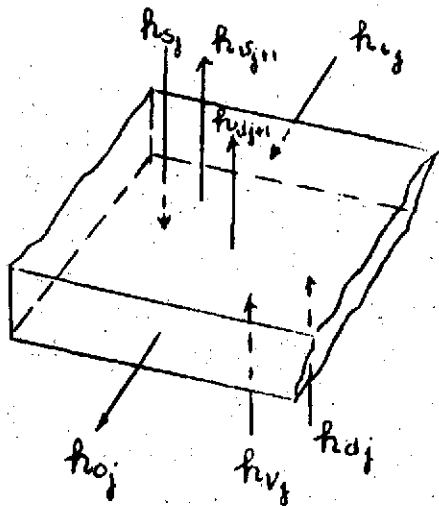
variety of fluid mechanical and thermodynamical phenomena. For example, in the mixing region of the near field, the discharge can be considered to be a turbulent buoyant jet characterized by a turbulent shear flow region which increases in size away from the jet.

Outside of the jet, the surrounding region may be considered to consist of nonturbulent potential flow. Theoretical analyses of both buoyant and nonbuoyant jets have been based on the assumption that the temperature and velocity distributions are given by similarity functions. That is, lateral profiles of temperature as well as velocities maintain similar shapes as the jet spreads in diameter. The theoretical problem to be solved here involves being able to predict the change in the centerline (maximum) velocities and temperatures along the axis of the jet.

In order to predict temperature and velocity distributions of the far field, one has to solve simultaneously the energy and momentum equations of the fluid. The transfer of heat in this region is dictated by advection and turbulent mixing of the ambient water. In contrast to the near field, the set of equations which govern the motion and temperature distribution of the far field do not have similarity solutions. Therefore, the nonlinear system of equations has to be solved numerically. A discussion is now made on the numerical models which are used to solve the problem of the far field.

Two dimensional analysis of the far field time dependent temperature distribution has been treated in two different but physically similar approaches. The first approach, based on energy balance principles, is sometimes known as the "energy budget." This technique has been used by Park and Schmidt (1972) for a numerical model of heat dissipation of a power plant cooling bay. In Park and Schmidt's analysis, the prediction of temperature involves two separate considerations, the energy transfer between the bay and its environment and the internal energy transport within

the bay. To simplify the calculations, it is assumed that the discharge rate is prescribed and there is no circulation in the bay. As a first step, the interior of the bay is uniformly divided into vertical sections each containing a finite number of thin horizontal control volumes or elements within which mass is conserved. The temperature of each element is governed by the conservation of energy equation which accounts for energy advected by horizontal and vertical flows (h_v , h_o , and h_i), energy diffused at the upper and lower boundaries of the element (h_d) and short wave radiation absorbed within the element (h_s). For the j th element shown in the figure, the rate of change of energy H_j within the volume is given by:



$$\frac{dH_j}{dt} = h_{s_j} - h_{i_j} - h_{o_j} - (h_{v_{j+1}} - h_{v_j}) - (h_{d_{j+1}} - h_{d_j}) \quad (1)$$

The various energy fluxes of equation (1) can be expressed in terms of the temperatures at elements j , $j+1$ or $j-1$. To calculate the advective energy exchange, the thermal discharge is assumed to be equally divided among the top six elements in all sections. For the surface elements, the rate of gain or loss of energy from external sources (excluding advection) is obtained from an energy balance involving five heat transport mechanisms, namely, solar radiation (h_s), atmospheric radiation (h_a), black body radiation (h_b), evaporation (h_e), and convection (h_c). The surface energy budget is expressed mathematically as:

$$h_{net} = h_s + h_a - h_b - h_e + h_c \quad (2)$$

where h_{net} is used in place of h_g in eqn. (1) for a surface element. Numerical integration of eqn. (1) then results in the prediction of temperatures for each section of the bay. A similar heat balance model has been used by Ryan and Harleman (1971) to predict annual temperature changes in a stratified lake.

A simple heat budget model has been proposed by Rooth and Lee (1972) for estimating steady state thermal anomaly areas from hot discharges. The model is based on the physical concept that since cooling is a surface process, the rate of heat loss depends only on the surface area distribution of thermal anomaly and not on the thickness of the warm layer. On the assumption that the dominant heat transfer process is due to evaporation and sensible heat flux, the equation obtained for estimating the thermal anomaly area A associated with temperature T is given by:

$$\frac{\partial}{\partial A} [(T - T_a)q] = C_D U [C_p \rho_a + L \rho_{sw} \frac{\partial}{\partial T} \ln \rho_{sw}] \quad (3)$$

Here C_D is a known drag coefficient, U the wind speed, q the discharge rate, T_a the ambient equivalent temperature, L the latent heat of evaporation of water, C_p the constant pressure specific heat of air, ρ_a the density of air and ρ_{sw} the saturated water vapor density at T . For given values of U, q, T_a and the initial temperature at point of discharge T_e , the integrated form of equation (3) is solved by a graphical method to obtain a thermal anomaly area A .

The usefulness of the graphical approach lies in its simplicity and ease of operation for providing a first quick look in power plant design considerations. Because it deals only with the prediction of thermal anomaly surface areas under steady state conditions, the same technique cannot be used for discharges that are influenced by transient motion such as due to tidal effects for estuaries which are open to the ocean. Moreover, advective heat transfer due to currents which, in many situations, are comparable to surface heat losses has not been taken into account in this method.

A major drawback of the heat budget type of analysis is that velocity distributions (or discharge rates) must be prescribed before advective transport terms can be calculated. In many problems, the velocity field is not known and may depend on forcing functions such as tidal motion, wind stresses, pressure gradients and density variations. To achieve a correct coupling between thermodynamics and fluid motion it is necessary to solve the energy and momentum equations simultaneously. Due to the complexity of both equations, many solutions are now possible only because of the rapid advances made in the development of finite difference techniques.

A two dimensional hydrodynamic flow model (Dean 1971) has been developed by the Coastal Engineering Department of the University of Florida to predict water elevations and the discharges of the Biscayne Bay Card Sound system. Because of irregular bottom topography of the Bay system, flow restrictions and barriers are introduced in the model. Hydrostatic motion is assumed and tidal effects are accounted for by introducing a η related to the change in free surface elevation. Formulas of shear stresses are developed to model the frictional effects of irregular bay bottom topography to the flow. The original three dimensional equations of motion are integrated over the vertical coordinate to produce variables of volume flux components q_x , q_y instead of velocity components u and v . The equations are further simplified by: 1) Neglecting horizontal nonlinear convective acceleration terms and 2) neglecting barometric pressure variations across the Biscayne Bay/Card Sound area. With these stated assumptions, the x and y components of the equation of motion are given by:

$$\frac{\partial q_x}{\partial t} = \beta q_y - gD \frac{\partial \eta}{\partial x} + \frac{1}{\rho} (\tau_{\eta x} - \tau_{bx}) \quad (4)$$

$$\frac{\partial q_y}{\partial t} = -\beta q_x - gD \frac{\partial \eta}{\partial y} + \frac{1}{\rho} (\tau_{\eta y} - \tau_{by}) \quad (5)$$

Here β is the Coriolis parameter, g the gravitational constant, D the total depth, ρ the water density, τ_{η} the wind stress and τ_{bx} the bottom stresses which can be expressed in terms of the volume flux components. To complete the set, the continuity equation is given by:

$$\frac{\partial \eta}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = S \quad (6)$$

where S is a volume flux per unit area of free surface due to rainfall. Equations (4) to (6) are expressed in finite difference form and are integrated to compute water surface elevations and discharges throughout the bay system as a function of time. The variable forcing functions that are considered are tides, winds, power plant cooling water intake and discharge, and fresh water runoff. As a continuation of the investigation, the computed hydrodynamic data is used as input for a dispersive model. In this case, a finite difference formulation of the two dimensional dispersion equation is solved to predict the advective and dispersive transport of a conservative constituent discharge by the plant. Thermal effects, one of the main considerations in thermal discharge problems, cannot be predicted by this dispersion model because heat is a nonconservative quantity when surface heat exchange mechanisms are taken into account.

B) PROPOSED MODEL

It is proposed to develop a general three-dimensional mathematical model capable of predicting the flow, temperature and salinity field of a large body of water affected by thermal discharge from a power plant. The model is described by a set of conservation equations which take into consideration the effects of tidal motion, wind action, thermal convection and diffusion, as well as surface heat exchange between the water and atmosphere. The thermal transport mechanisms considered here are general enough so that this model can be used for predicting thermal discharge effects at any geographic location. For different discharge sites, the only modification of the model required is a respecification of the correct boundary conditions, dictated by a new site topography. In the proposed model, the necessary initial and boundary conditions will be provided by collected remote sensing and field data. The model may be tested for accuracy by comparison with periodic collection of remote sensing and field data.

A case study of special interest to the Miami area is the thermal pollution created by the heated discharge of Turkey Point power generating plants. The availability of past Turkey Point field data plus the convenience of collecting additional data from this nearby discharge presents a unique opportunity of testing the proposed model. It is to be emphasized that the model is generally applicable to any discharge site.

Up to the present time, theoretical models which have been developed to simulate thermal discharges have been two dimensional ones. There have been few attempts to model the more realistic three dimensional nature of the discharge problem. There are several reasons which point to the necessity of using three dimensional analysis:

- (1) The topography of the thermal discharge areas in bays, oceans or lakes can be modeled accurately only in three dimensions.
- (2) Thermal discharges spread both horizontally and vertically in a body of water. The penetration of warm surface water to lower cooler water may affect the ecology of the lower depths. An understanding of the three dimensional trajectory of thermal discharges requires analysis of the motion in three dimensions.
- (3) Thermal discharges induce three dimensional convection and circulation patterns which cannot be resolved by two dimensional modeling.
- (4) Observations of the Turkey Point thermal discharge indicate an unusual vertical movement of the plume.

Prior to a discussion of the model, it is instructive to first consider the geography of the region under investigation. As a case study, the Turkey Point site will be considered. The bay systems that are affected by the thermal discharge of Turkey Point consist of Biscayne Bay, Card and Barnes Sound. The region that is proposed for the model incorporates an area of approximately 36 to 12 miles extending from the Rickenbacker Causeway in the North to the causeway between Barnes Sound and Blackwater Sound in the south. The primary communication between the bay system and the Atlantic Ocean is through an opening of

approximately ten miles in length located at the northeastern limits of lower Biscayne Bay. In addition, several small inlets are present in the southeastern part of the bay system connecting lower Biscayne Bay and Card Sound to the ocean. The average mean low water level in the Bay system is approximately 10 feet and the bottom topography is irregular due to the presence of many limestone sills interlaced by numerous channels. This represents the domain of computation for the model.

Within this domain, the conservation equations for the body of water will be numerically integrated by using a three dimensional numerical scheme as proposed by Hirt and Cook (1966). This scheme is an extension of a two dimensional computation technique known as the Marker and Cell (MAC) Method by Harlow et al (1972) and has been used to model three dimensional free surface flows over a rough terrain. The MAC scheme will be used to solve the hydrodynamic equations of mass and momentum conservation given in the x, y, and z (vertical) directions by:

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} = -\frac{1}{\rho_0} \frac{\partial p}{\partial x} + \frac{1}{\rho_0} \frac{\partial \tau_{zx}}{\partial z} \quad (7)$$

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} = -\frac{1}{\rho_0} \frac{\partial p}{\partial y} + \frac{1}{\rho_0} \frac{\partial \tau_{zy}}{\partial z} \quad (8)$$

$$\frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} = -\frac{1}{\rho_0} \frac{\partial p}{\partial z} - \left(\frac{\rho - \rho_0}{\rho_0} \right) g \quad (9)$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = \sigma_s \quad (10)$$

The velocity components u, v, w, are in the x, y, z, (vertical) directions respectively. β is the Coriolis parameter, p the pressure, τ_{zx} and τ_{zy} the horizontal shear stress components with other components being considered negligible. The effects of density (or temperature) variations are assumed to influence the fluid motion through a Boussinesq Approximation which consists

of the addition of a buoyance term. Under this approximation density ρ is considered to be constant (ρ_0) except for the buoyancy term in eqn. (9). The mass source or sink term σ_s in eqn. (10) represents the mass gained by the bay at the water discharge mass loss at the intake and/or any fresh water runoff along the edges of the bay.

The thermodynamics is coupled to the motion through an equation of state and the energy and salinity conservation equations. These are given by:

$$\rho = \rho_0 - [a(T - T_0) - b(S - S_0)] \quad (11)$$

$$\frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z} = \frac{\partial}{\partial x} (K_{H,x} \frac{\partial T}{\partial x}) + \frac{\partial}{\partial y} (K_{H,y} \frac{\partial T}{\partial y}) + \frac{\partial}{\partial z} (K_{H,z} \frac{\partial T}{\partial z}) + Q_H \quad (12)$$

$$\frac{\partial S}{\partial t} + u \frac{\partial S}{\partial x} + v \frac{\partial S}{\partial y} + w \frac{\partial S}{\partial z} = \frac{\partial}{\partial x} (K_{S,x} \frac{\partial S}{\partial x}) + \frac{\partial}{\partial y} (K_{S,y} \frac{\partial S}{\partial y}) + \frac{\partial}{\partial z} (K_{S,z} \frac{\partial S}{\partial z}) \quad (13)$$

For temperature T and salinity S , the mean values are given by T_0 and S_0 respectively while eddy diffusivities are given by K_H and K_S . Internal heat source of the thermal discharge is represented by Q_H while a , b are constants.

Since tidal motion is a major consideration, the free surface boundary condition is given by:

$$\frac{\partial \eta}{\partial t} + u \frac{\partial \eta}{\partial x} + v \frac{\partial \eta}{\partial y} = w + q_s \quad \text{at } z = \eta \quad (14)$$

where η is the free surface height as measured from the mean water level and q_s the volume flux per unit area of fluid across the surface due to evaporation and precipitation.

Altogether there are 8 variables (r, v, w, p, ρ, T, S and η) for the eight equations (7) to (14). The initial and boundary conditions associated with the set equations will now be stated.

In order to start the integration, a specification of the entire field is required. That is, the values of each of

the variables have to be prescribed at an initial instant over the entire region of integration. It is proposed that this field data will be extracted from remote sensing and in situ measurements. During integration, boundary conditions are then imposed and the interior field may be calculated from governing equations which describe the motion of flow. The boundary conditions that are required for the solution are:

At free surface, $z = \eta(x, y)$:

$p = p$ atmosphere

τ_{zx} is a specified wind stress

S is specified, and T is obtained from remote sensing data. As an analytical check to the model T may be calculated through applying an energy budget at the surface. This energy budget will consist of a balance between radiation, latent heat and sensible heat transfers across the atmospheric-water interface expressed mathematically as:

$$q_{\text{surface}} = q_s - q_b - q_e + q_c$$

where q_{surface} is the net heat flow at the surface. The heat flux terms on the right side of (15) are:

q_s - net short-wave radiation flux

q_b - back radiative heat flux = $\sigma(T_w + 460)^4$

q_e - evaporative heat flux = $f(U)(e_s - e_a)$ and

q_c - convective heat flux = $\frac{0.0102 q_e (T_a - T_w)}{(e_s - e_a)}$

The temperature T_w and T_a denote values at the water surface

and atmosphere. The evaporative heat flux q_e is a function of the wind speed U and the vapor pressure at temperature T_w denoted by e_s minus the vapor pressure e_a .

2) At the bottom and lateral boundaries:

$$u = v = w = 0$$

P is calculated by the hydrostatic condition

T is specified

S is specified

3) At the inlets:

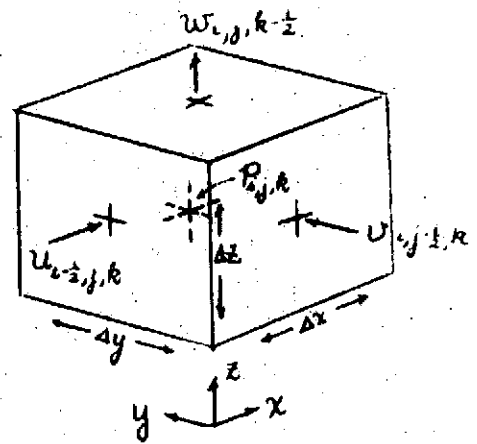
Specified volume flow rate into Bay from Ocean; specified ocean tidal height.

C.) THE MARKER AND CELL (MAC) METHOD

The three-dimensional extension of the Marker and Cell (MAC) Method developed by the Los Alamos group (Welch et al, 1966) is considered to be used in solving the set of governing equations as it has the advantages of the convenience in treating free surface problems. A brief description of this method is given below.

There are two co-ordinate systems used in MAC method calculations: The primary one covers the entire domain of interest with three dimensional rectangular grid of finite difference cells, each of dimensions Δx by Δy by Δz . The cells are numbered by i, j, k representing grid positions in the x, y, z , directions respectively. The field variables describing the flow are directly associated with these cells. For the MAC method, a particular placement of field variable quantities relative to the cell (as shown in figure) is of considerable importance to attain rigorous finite difference mass conservation.

In addition to the primary coordinate system of finite difference cells, there is a coordinate system of particles whose motion describe the trajectories of fluid elements. These particles serve only as massless "markers" (hence the name Marker and Cell) of the centers of mass of the elements of fluid and contribute nothing to the dynamics. Each cell may contain several of such particles. The particles perform two unique functions: First, they show which cells are surface cells into which the surface boundary conditions should be applied. Second, they show the motion of the fluid particles at various times throughout the progress of the calculations.



As in most other fluid dynamics computing methods for transient problems, the MAC method works with a time cycle or "movie frame" point-of-view. This means that the calculation proceeds through a sequence of cycles, each advancing the entire fluid configuration through a small but finite increment of time Δt . The results of each cycle act as initial conditions for the next one, and the calculation continues for as many cycles as is desired. A more detailed description of the computation procedures involved in the present calculations is now reviewed in the following section.

D.) METHOD OF COMPUTATION

The entire bay system is first divided into a set of rectangular cells which approximates as closely as possible the topography of the system. Each cell is marked or "flagged" as being of a certain type depending on whether the cell represents a solid wall, a free surface, empty space, a cell full of fluid and/or a boundary or corner cell. One set of flow variables ($u, v, w, p, T, S,$ and ρ) is associated with each cell. Each variable is located either in the interior or on the boundary of the cell. The governing equations (7) to (14) are then expressed in finite difference form. A time dependent solution of the finite difference equations is obtained by advancing the flow field variable and starting from the vertically prescribed field in a succession of short time steps Δt . Each time step consist of the following four separate calculations:

- 1) Velocity components are explicitly advanced in time using the previous state of flow to calculate accelerations caused by advection, pressure gradients, and body forces. For example, the u -velocity time advancement is given by

$$u(x, y, z, t + \Delta t) = u(x, y, z, t) + \frac{\partial u}{\partial t} \Delta t$$

where $\frac{\partial u}{\partial t}$ is calculated from equation (14) with the field values given at time t .

- 2) Adjustments are made to insure mass conservation. This is done by adjusting the pressure through iteration in each cell in such a way that there is no mass flow in or out of the cell. This adjustment must be performed for all cells.
- 3) The new velocity field is then used to update the temperature and salinity field. A new free surface is produced by moving the set of marker particles to their new positions. For example,

the u component calculations are given by:

$$\chi_k(t+\Delta t) = \chi_k(t) + u_k \Delta t$$

where u_k denotes the u velocity component for the k^{th} particle.

- 4) The new density field is calculated by substituting values from the new temperature and salinity field into the equation of state (11).

This completes one cycle for the time step from t to $t+\Delta t$. The next cycle is then initiated and the computational sequence (1) to (4) is repeated up to a desired number of time steps.

E.) DATA DISPLAY

For three dimensional flow calculations, the computer data obtained as an end product is necessarily large. There are several methods which can be used to present such data in an easily comprehensible form.

An effective technique is to display such a velocity field, free surface configurations, etc. using computer generated perspective pictures. A hidden-line perspective view plot routine for displaying data in an Eulerian mesh has been developed by Cook and Hirt of Los Alamos Laboratory and is available for use. By constructing two perspective pictures from slightly different viewing points and viewing them in a stereo slide view, it is possible to produce three dimensional stereoscopic views of data plots.

For programs employing marker particles, the most descriptive pictures and easiest to obtain are those of particle configurations. Each marker has an x, y, z coordinate stored in the computer memory. By plotting these coordinates and drawing the boundaries that define the systems, a picture showing the shape of the fluid and its relationship to the confining walls

of the system is obtained. In order to convey complete information about details of the flow, velocity vector plots may be used. For each cell in the system a velocity vector, starting at the cell center with a length proportional to the cell velocity and in the direction of the local flow, can be drawn. These velocity vectors, when plotted in selected planes in a region of interest, can give a fairly good idea of the flow. For a better visualization of full three dimensional flow pattern, velocity vectors can be plotted in stereo using two slightly different perspective views.

A useful method for showing scalar fields such as pressure, temperature and salinity is to generate contour plots. This is accomplished by plotting lines of constant values of the scalar quantity separated by a prescribed contour interval. The effect is the same as that of geographical contour maps where contours represent a certain altitude. In three dimensions, contour plots may be displayed as perspective pictures.

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III. REMOTE SENSING

A. Introduction

In considering the measurement of the temperature, salinity, and other properties of the sea by remote sensing, several methods suggest themselves. These may be divided into two categories, passive and active. Among the passive methods are photography with near infrared film, scanning imagery in the middle and far infrared, and microwave methods. Active methods include side-looking radar, Liar and Raman spectroscopy. These remote measurements may be carried out either from satellites or from airplanes. Satellites are most useful for large scale effects and eventual automatic surveillance, while airplanes are more suitable for detailed analyses where information is desired on scales smaller than those presently available from satellites.

B. Water Surface Temperature Measurements by Infrared Imaging

The infrared portion of the electromagnetic spectrum lies between the visible and microwave regions (0.78μ to $1,000\mu$). The existence of this "invisible" radiation was discovered in 1800 by Sir Frederick William Herschel, who used a thermometer to detect the energy beyond the red portion of visible "rainbow" produced by a prism. In 1861, Richard Bunsen and Gustav Kirchoff established the principles underlying infrared spectroscopy. After a century of further progress, the uses of infrared technology have been extended to a host of applications. Among them is the use of infrared sensors for producing images of remote scenes. These devices (remote-sensing systems) have been used on the ground, in airplanes, and in space vehicles. Compared with their radar counterparts, these devices are small, lightweight, and require little electric power. Like radar, infrared systems operate under both daytime and nighttime conditions. However, infrared systems are hampered by clouds and rain - a problem radar systems do not have when sufficiently low frequencies are used. The two important features of infrared surveillance systems which give them an advantage over radar are

the high spatial resolution achievable with relatively simple designs and the fact that they operate passively; i.e. they do not need to illuminate the ground scene artificially in order to record an image.

1. Basic Principles

Passive methods of heat measurements are based upon the fact that all bodies above absolute zero radiate electromagnetic energy to their surroundings: the higher their temperature, the more they will radiate. The most efficient radiator at a given temperature is the so-called "black body" which is also a perfect absorber. The radiation of a black body is described by the famous Planck Radiation Laws:

$$I_{\lambda T} = \frac{2hc^2}{\lambda^5} \cdot \frac{\Delta\lambda}{e^{\left(\frac{hc}{k\lambda T} - 1\right)}} \quad \text{(III-1)}$$

Here, h is Planck's constant, c is the velocity of light, λ is the wavelength, $\Delta\lambda$ is wave range, k is Boltzman's constant and e the base of natural logarithms.

Formula 1 gives the energy emitted per second from a square centimeter of surface at absolute temperature T at wavelength λ in a wavelength band of width $\Delta\lambda$ into unit solid angle. Putting in values we obtain (for a 1 micron band):

$$I = \frac{1.192 \times 10^{-16}}{\lambda^5 (e^{1.44/\lambda T} - 1)} \quad \text{watts/cm}^2 \text{ ster. } \mu$$

For example at the sun's surface if we take the black body temperature to be 5500°K at $\lambda = 6000 \text{ \AA}$ (0.6 μ) we obtain $I = 6000 \text{ watts/cm}^2 \text{ ster. } \mu$.

The emission from a black body versus wavelength is plotted in Figure IV-1 with temperature as a parameter. One can see from this figure that the emission maxima

move toward longer wavelengths with decreasing temperature. The emission maximums from the sun with surface temperature about 5500°K are near 0.5 micrometer (in the green-yellow region of the visible spectrum). At the earth's ambient temperature (approximately 300°K), the maximum is at about 10 microns. The region of most interest, therefore, in the passive measurement of surface temperatures is in the region 8-14 microns, the so-called thermal infrared region.

Looking at Figure 1, one might conclude that the sun's own light would tend to drown out the emission from the earth's surface, but this is not so. This is because the sun is at a great distance, and the curves in Figure 1 are calculated for the hot surfaces themselves. At the distance of the earth the sun subtends about 1/2° or about 7.6×10^{-5} steradian. The maximum irradiance arriving at the top of the atmosphere from the sun is therefore $6000 \times 7.6 \times 10^{-5}$ or about 1/2 watt/cm² per micron. The sun's radiation is compared to the emission at 50°F (300°K) in Figure 2. We notice that at 10 microns, the arriving sunlight is more than 100 times less intense than the emission from the earth. In the near infrared, around 1 microns, the situation is reversed and the sunlight is more than a million times brighter than the earth's emission. At much longer wavelengths than 10 microns, the amount of emission from the earth is very small, so the advantage of the 8-14 micron region for passive temperature measurements is clear.

The use of the black body equation (1) must be corrected if accurate temperatures are to be measured. These corrections are principally as follows:

- 1) Departure of the sea from a true black body, and
- 2) Effects of the atmosphere through which the measurements are made. The corrections are to be discussed herein.

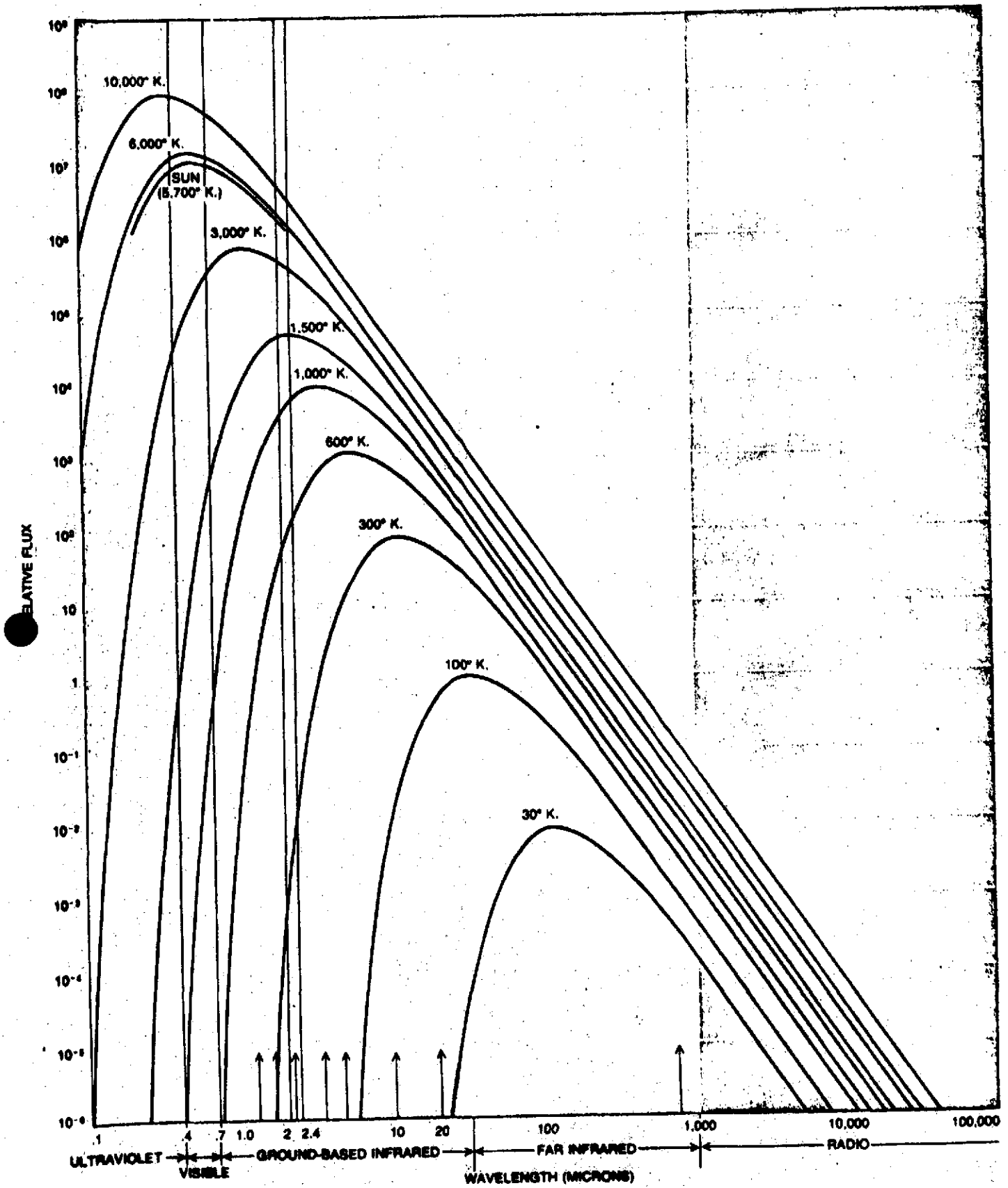


Fig. III-1 Emissions from a black body versus wavelengths

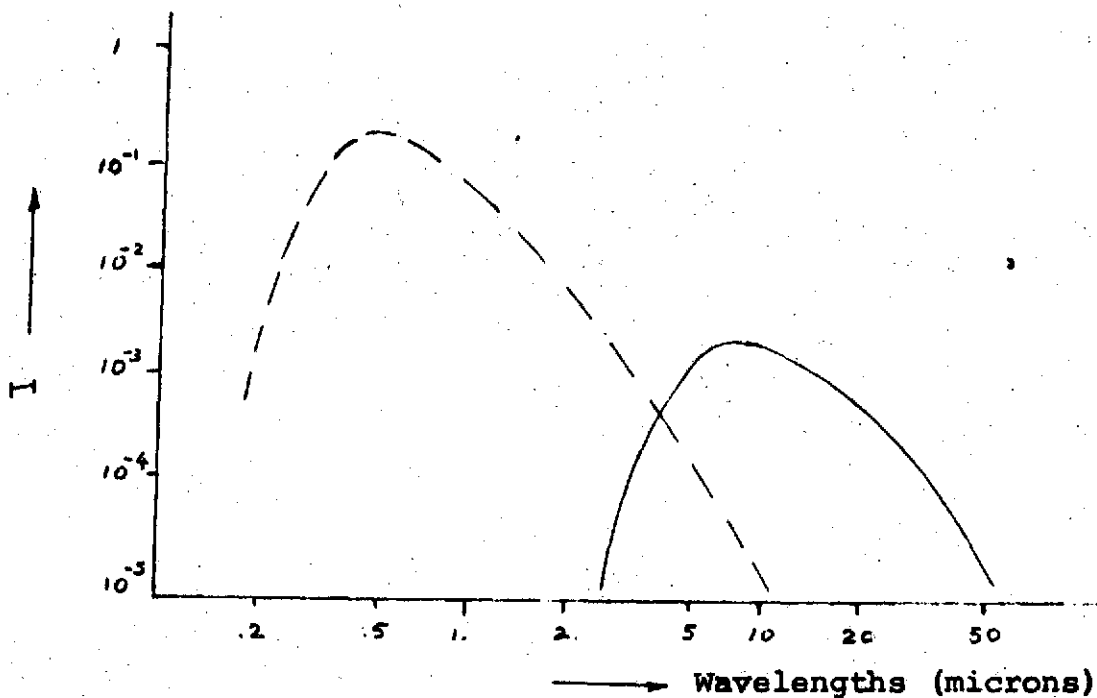


Fig. III-2 Comparison of radiation at earth surface from the sun and the emission of black body at 50°F (300°K)

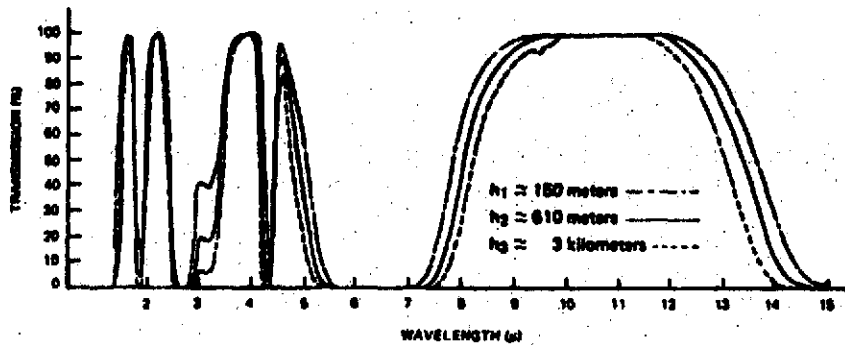


Fig. III-3 Plot of atmospheric transmission spectra as a function of altitude, H .

2. Correction for Nonblackness

A radiometer measures radiance, R, that is the flux of radiation per unit solid angle per unit wavelength per unit area. The radiance is composed of an emitted and reflected part, namely

$$R = \epsilon I + r N \quad \text{(III-2)}$$

where R is the radiance of the surface, I is the radiance of a blackbody at surface temperature from Eq. 1, ϵ and r are the emittance and reflectance of the surface, and N is the radiance falling on the surface (the sky radiance).

The emittance of a plane water surface viewed at normal incidence has been measured as 0.986 and its reflectance as 0.014 (Saunders, 1970). Saunders (1968) also shows that the surface roughness of the ocean does not influence these values appreciably. Using a Model PRT5 Airborne Radiation Thermometer (ART) manufactured by the Barnes Engineering Company, Saunders has computed the nonblackness correction values for various conditions. Some typical computed values are shown in Table III-1 below.

TABLE III-1 ART NONBLACKNESS CORRECTION FOR PRT5

<u>Cloud Type</u>	<u>Cloud Height km</u>	<u>Range of Cor- rection °C</u>
Clear		0.5-0.7
Dense cirrostratus overcast	8	0.4-0.55
Altoctu or altostratus overcast	6	0.25-0.4
Stratus or stratocumulus overcast	3	0.2
Stratus or stratocumulus overcast	2	0.1
Stratus or stratocumulus overcast	1	0.1

It can be seen from this table that the necessary corrections are relatively small, usually less than half a degree centigrade. If this correction is required for more accurate measurements, one practice in the field is to record visual observations of cloud cover and to introduce a slowly varying correction to the measured signal. A more sophisticated procedure may be to record sky radiance

continuously with a second instrument and to make a more rapidly varying correction.

3. Atmospheric Transmission

The infrared region of the spectrum is characterized by regions of intense atmospheric absorption. At these wavelengths, molecular absorption becomes very significant, in addition, atmospheric gases play a role. Each of the various gases that comprise the atmosphere has its own characteristic infrared-absorption spectrum. The gases that have the most significant effect include CO_2 , N_2O , H_2O , and O_3 . For those portions of the infrared spectrum where one or more of these gases is strongly absorbing, the atmosphere is essentially opaque. The spectral intervals at which the atmosphere is reasonably transparent are (approximately, in microns) 0.7-1.35, 1.35-1.8, 2.0-2.4, 3.5-4.1, 4.5-5.5, 8-14, 16-21, and 780 - 1,000. Those transparent spectral regions are called windows as shown in Figure III.3. It is interesting to see that the 8-14 micron band, which is useful for surface water temperature measurements as described above, is also provided with a window. However, corrections for these atmospheric effects still have to be made if accurate remote measurements are required.

Saunders (1967) described a method of successively viewing the ocean surface normally and obliquely to determine the corrections for the Airborne Radiation Thermometer measurements. Saunders (after 1970) revised his procedure to view the surface only normally with an improved Airborne Radiation Thermometer (Model PRT5 by Barnes Engineering Company). Shaw and Irbe (1972) developed an atmospheric model and a computer program to evaluate theoretically the relative importance of the environmental effects under given meteorologic conditions and produce an adjusted water surface temperature based on this evaluation. In addition, a relatively simple graphic method based on the theoretical

study was derived. Both methods have been tested and found to give useful adjustments for atmospheric effects. On the basis of these two existing theoretical models (Saunders 1970; Shaw and Irbe 1972), Tien (1973) established simple analytical forms for atmospheric corrections for ART measurements of water surface temperatures.

The expression for the radiance measured through a column of air is

$$N_s - N = - \int_0^u (N_s - B_o) \frac{d\tau}{du} \cdot du \quad (\text{III-3})$$

where $N_s - N$ is the correction to the observed radiance due to the air column, B_o is the radiance of a black body at the air temperature, τ is the transmittance of the air, u is the incremental intervening mass of air, and U the total mass of the air between the sensor and the sea surface. Some of the absorption of the air in the infrared is due to water vapor, so that to calculate τ , the absolute humidity in the air column should be measured. Also, since B_o is dependent on temperature (Equ. III-1) the temperature lapse-rate must also be known. Fortunately, the corrections are small if the height from which the measurements are made is not too great, and approximate values can often be used. Further, in the area where horizontal mixing is good, one correction will suffice for the whole region as long as the height of observation is constant.

It turns out that (Hovis, 1970) if the observations are made between 11 and 12.5 micrometers, much of the atmospheric absorption (and therefore emission, by Kirchoff's Law) can be avoided. This further reduces the corrections necessary. By using an interference filter to narrow the band and by observing from moderate altitudes we can estimate that the corrections will be kept small (less than 1°C.)

4. Commercially Available Infrared Scanner Systems

There are a variety of infrared scanners commercially available at the present time. Among them, the Bendix Thermal Mapper (BTM) and Barnes Airborne Radiation Thermometer (ART) have been used by many research groups for water surface temperature measurements. A brief discussion of these two systems are given below.

a. Bendix Aerospace Systems Division

Bendix Thermal Mapper

Bendix first introduced its thermal infrared Line Scanner, the Bendix Thermal Mapper (BTM), in 1966. It consists of three basic modules: the Scan head, the control-console power-supply module, and the roll-compensation unit. The standard BTM has a temperature difference sensitivity of 0.5°C with indium antimonide detector filtered to 3 to 5.5 microns. It is small, light and simple enough to go on a light, twin-engine aircraft. It includes a self-contained film cassette so that the system could be handled much as a standard aerial photographic system, with a roll of 70mm film as the immediate output, ready for processing upon landing. The standard model does not have the capacity of magnetic tape recording and multiple channels, and would require a modification if feasible.

This thermal mapper was used in February 1969 to obtain Thermal Infrared Imagery and Thermal Contours at Turkey Point Power Plant south of Miami, Florida. Isotherms of surface water temperature were derived from thermal mapper imagery (3.7 to 5.5 micron region) by means of measured water temperatures and densitometer values. The actual water temperatures were provided by the University of Miami and six surface measurements were used as "ground truth" for the densitometric analysis. Twenty densitometer profiles were made parallel to the scan lines on the imagery and the resulting percent transmittance values converted to temperature values. Fluctuations in density from one scan line to the next required that the

gray area at the edge of the image be used as a reference assumed to be 25% transmittive. The densitometer profiles were converted to temperature at intervals of 1°C and plotted on a base map and used to manually construct the thermal contours. The resulting isotherms are within $\pm 0.5^\circ\text{C}$ of the actual surface temperature and provide a good method for acquiring quantitative temperature measurements over a large area. Isotherm derived from this mapping is shown in the Figure III-4 below.

The Bendix Co. later introduced two modified models, Bendix Thermal Mapper Model LN-2 and Model LN-3. They are equipped with the more popular Mercury-Cadmium-Telluride (Hg:Cd:Te) detector (peaked at 10 microns) with a filtered spectral bandwidth of 8 to 12.5 microns. The data of these thermal mappers can be tape recorded.

One of the problems that may be encountered in using this thermal mapper for the proposed study is that the standard thermal mapper was calibrated against known temperature black-body references in the laboratory but once settings for gain and level were changed to accommodate the dynamic range of actual data in the field, the absolute value of this lab calibration was lost. Thus, it will be necessary to have at least two known temperature and emissivity targets identifiable in the data for calibration. This proved to be a problem for users who required true rather than related radiometric data.

Bendix Modular Multiband Scanner

Bendix recently introduced a new scanner system called Modular Multiband Scanner (M^2S). It is a true (fully calibrated) imagery radiometer. M^2S not only has blackbody references, it also carries its own UV visible reference, a quartz-halide lamp which is transfer calibrated from the National Bureau of Standards. There is also a skylight reference in this same spectral region.

The M^2S is a fully digital machine. The data is recorded

on high density digital tape in eight bit words for each pixel. Thus, the system has a dynamic range of 256, over eight times that of the thermal mapper analog film recorder which was limited by the film to 30:1.

One drawback of the M²S system is its weight. With the tape recorder and an inevitable camera or two, the payload in a light aircraft, equipped with M²S, will be about 300 lbs and up, depending on the cameras. This is apt to exceed safe operating limits for a single engine aircraft. However, a light twin should be quite satisfactory.

The Bendix Co. has been flying its system in a Beech Queenaire aircraft and Swiss Air Photo is going to use it in the same type of aircraft. NASA Lewis Center plans to install its scanner in a DC-3, and NASA Houston is using a P3A. Researchers from Japan and Argentina have also adopted the M²S for their remote sensing usage.

The aforementioned scanners can be either purchased or leased from Bendix. They have equipped aircraft and can also fly missions for their customers.

b. The Airborne Radiation Thermometer (ART) by the Barnes Engineering Company, Stanford, Conn.

The Barnes Engineering Company first introduced Model IT-2S infrared thermometers around 1966. It was later modified to be models IT-3 and PRT-5. The Airborne radiation thermometer (ART) is considered to have the capacity of reliably measuring the apparent black body surface temperature of a large body of water in a relatively short period of time. It has a band-pass filter system which limits the wavelengths detected by the radiometers to the general region from 7.5 to 16 μ ms. This filter window is centered approximately on the "water vapor window" at 10 μ m and is close to the maximums in the Planck emission curve for 300°F.

The ART has been used by many research groups and the experiences of some of these groups in using it for water

surface temperature measurements are discussed briefly below.

Richards and Massey (1966) in a technical report entitled "An Evaluation of the Infrared Thermometer as an Airborne Indicator of Surface Water Temperatures", gave a complete description of the installation of the ART in the aircraft, the problems encountered in obtaining reasonably smooth and accurate temperature readings, and the conduct of ART test.

Shaw and Irbe (1972) of the Canada Atmospheric Environment Service have used ART in their investigation since 1966. In their operation, the ART was installed initially in a Lockheed 14 aircraft. Later it was flown in a Beechcraft 18 and Piper Aztec C aircraft. A strip chart recorder conducting a continuous temperature trace was connected to the ART. Comparisons between ART temperature readings and surface temperature measurements were obtained in several ways. During the early evaluation of the instrument in 1965-1966, the aircraft was flown over the Great Lakes research vessel CCGS Porte Dauphine at several heights above the water. Simultaneous ART temperature readings and ship bucket temperature were recorded. On later routine ART survey flights in 1967-1971, comparisons were made between ART readings and bucket temperature on the Porte Dauphine and on the limnological ships of the Canada Center for Internal Waters (CCIW). Readings were taken from floating thermistors on CCIW buoys in Western Lake Ontario and from thermistors monitored on dams across the St. Lawrence River at Cornwall, Ontario, and Lachine, Quebec. Upon adjustment of ART readings for environmental effects, the airborne remote water surface measurements have been able to obtain an accuracy within 0.5°C of the observed water temperature.

Saunders (1970) of Woods Hole Oceanographic Institution has also used ART for remote measurements of ocean surface temperatures. After corrections for nonblackness of the ocean and for absorption and emission in the intervening atmosphere are made, they can achieve an absolute accuracy of $\pm 0.2^{\circ}\text{C}$ when measurements are made carefully from low altitude.

c. Texas Instruments RS-310 Airborne Infrared Imaging System

Texas Instruments has introduced a Model RS-310 Airborne Infrared Imaging System. It is reported to have a 8-14 microns thermal band with 0.5-10°C accuracy in remote surface temperature measurements. The scanner can scan to a 90 degree field of view with 1.0-5.0 mrad. resolution. The company claims that this system is better than the Bendix Thermal Mapper. However, detailed information is not available at this time. Consequently we are unable to make a thorough survey of this system.

5. Related Spacecraft Programs

a. The Earth Resources Survey Flight Programs

In the Earth Resources Survey Program of the National Aeronautics and Space Administration (NASA), three space flight experiments are included: The Earth Resources Technology Satellite A (ERTS-A), launched in March 1972; the Earth Resources Experiment Package (EREP) of the manned Skylab orbital facility, launched in April 1973; and ERTS-B which is not yet launched. The ERTS-A and B sensor payload consists of (1) a multispectral tv system using return-beam vidicon (RBV) cameras, (2) a multispectral scanner (MSS) system, and (3) a data collection system for collecting data from sensors at known locations in the earth. The MSS is sensitive to the following wavelengths: band 1, 0.5 to 0.6 μm ; band 2 0.6 to 0.7 μm ; band 3, 0.7 to 0.8 μm ; band 4, 0.8 to 1.1 μm ; band 5, 10.4 to 12.6 μm (ERTS-B only). Comparable ground resolutions for the scanner are approximately 80 meters, except for band 5, which is 220 meters.

Since the ERTS-A does not provide the wavelengths that are suitable for our proposal studies and the ERTS-B is not yet firmly scheduled for launch in the very near future,

it seems that spacecraft may not be able to play a major role in the first phase of the proposed project. However, the use of available satellite programs should not be excluded from this study. While aircraft may be recommended to be used as the basic remote sensing platform in the first phase of the project, the results should be translatable to spacecraft and satellite programs of the future. If a suitable thermal band from ERTS-B or DAPP become available during the project, they can be correlated with the ground truth and aircraft remote sensor data. The small scale ground truth and aircraft data can be space averaged to match the image resolution of the satellite data. Also, it may be possible to expand the small scale model of the area to be investigated to larger scale geographic areas commensurate with the resolution of existing satellites.

Furthermore, data collected from the ground truth stations may be telemetered by UHF radio in the ERTS data collection system (DCS) format so that it can be recorded aboard the remote sensor aircraft as well as relayed by the satellite DCS. The ERTS DCS will permit data collection from the sensors in the investigated area on days when the aircraft is not in use. The General Electric Company has built UHF radio transmitting DCS units for the ERTS and Ball Brothers Research Corporation has recently built similar units for relaying data to the ERTS or GOES data collection systems. G.F. Andrews of the Radar Meteorological Laboratory has already designed the interface equipment for coupling temperature thermistors and a tipping bucket rain gauge to these ERTS DCS ground stations. However, it may be mentioned that, while the complementary use of these two systems (the spacecraft and the aircraft) are to be considered in the developmental stage of the proposed study, the ultimate goal is to evolve a system which utilizes spacecraft as the main instrument of remote data gathering.

b. The Data Acquisition and Processing Program (DAPP).

It is learned that a unique and valuable data system employed by the Department of Defense and the U.S. Air Force's Air Weather Service (AWS) has been made available to the public recently. The DAPP satellites are in polar orbit, approximately 450 nautical miles above the earth and have a period of one hour and 41 minutes. Normally, two satellites will be in operation and they can provide imagery data over any spot on the earth 4 times a day in a six-hour period. Real time data within the acquisition range, approximately a radius of 1500 miles of the receiving station, is provided to the tactical sites while the Air Force Global Weather Central (AFGWC) receives stored data of global coverage. The DAPP are provided with four spectral intervals capability, namely 1) VHR data in the 0.4 to 1.1 microns range with 0.3 nautical miles resolution. 2) WHR data in the 8 to 13 microns wavelengths with 0.3 nautical miles resolution. 3) HRD data in the 0.4 to 1.1 microns range with 1.5 nautical miles resolution and 4) IR data in the 8 to 13 microns wavelengths with 1.5 nautical miles resolution. The infrared products (WHR and IR) receive emitted thermal energy from 310°K to 210 degrees K. It is also provided with the flexibility to receive 1 degree increments in grey shade steps from 2 to 16. There are also available other enhancement options such as processing the visual imagery through the IR mode to delineate hydrological features. It is expected that a vertical temperature profile radiometer (VTPR) and a microwave radiometer will be included in the future.

It seems that the DAPP program has provided with the required Thermal Band and other capabilities for remote sensing of water surface temperatures. Before the ERTS-B becomes available, the DAPP may be considered to be used for the proposed study.

6. The NASA Kennedy Space Center Remote Sensing Facility

Presently the Kennedy Space Center has a C-45-H TRI-BEECHCRAFT (NASA-6) equipped with photographic sensors, instrumentation sensors and radiometers for Earth Resources Survey. It is also equipped with an environmental measurements system for meteorological measurements such as air temperatures and dew point. The infrared scanner can provide two spectral channels (3-5.0 and 8-14 microns) with an instantaneous field of view of 2.5 mrad. Its data output can be magnetic tape imaged on film or computer processed. It can also provide real time CRT image. The data analysis facility in the Kennedy Space Center includes a digicol, a microdensitometer, an additive color viewer, a zoom transfer scope, a photointerpretation station, a stereo viewer, a versatile plotting table, variscan, a thermal scanner, and analog tape drives. They are expected to add a multispectral analyzer, a Digicolor, a Planimeter, two microdensitometers, a versatile plotting table, a stereo plotter and a viewer printer in the near future. The 8-14 micron thermal band is suitable for water surface temperature measurement and the well equipped data analysis facility should be very useful in the proposed study.

C. REMOTE SENSING OF WATER VERTICAL TEMPERATURE PROFILE
SALINITY AND TURBIDITY

The feasibility of measuring water temperature in depth, salinity and turbidity remotely has been studied carefully. Many ideas have been given serious investigations. Some possible approaches are discussed below.

1. MEASUREMENTS OF WATER TEMPERATURE IN DEPTH AND SALINITY

In the measurement of water temperature in depth and salinity remotely, the active method of using laser beams is considered. Laser beams can be directed downward into the sea and the resulting upward emission (fluorescence) measured. These measurements can probe deeper layers of the water, because unlike passive methods where infrared must be used, visible light for which the ocean is more transparent can be used for active measuring. The most transparent part of the spectrum for the open ocean is in the blue-green, where under exceptional circumstances penetration of 100 meters is practical.

A pulsed laser beam can be directed into the ocean. Returning fluorescent radiation can be timed and its depth or origin determined. Frequency shifts (Brillouin effect) are observed proportional to the sound velocity in the water, which can be directly related to temperature under conditions of constant pressure and salinity. Pressure can be directly measured knowing the depth, and so, if a constant salinity can be assumed in the open ocean the temperature can be measured as a function of depth.

The relation between sound and velocity and the factors it depends on (pressure, temperature, and salinity) is given by a simplified version of Wilson's formula,

$$C = 4422 + 0.0182y + 11.25T - 0.045T^2 + 4.3(S-34) \text{ ft/sec.}$$

Where y = depth in feet

T = temperature in degrees F and

S = salinity in parts per thousand

There are more accurate versions of this relation but these are quite complicated and only differ from the above in second-order correction terms. For the purpose of this discussion, this formula suffices. In the open ocean (non-estuary type condition) the salinity would be quite constant and its variation could be ignored. Then, since the sound velocity and the depth would be measured, the temperature could be calculated from the above relation. An interesting alternate, provided that the measurements are sufficiently accurate, could exist for measurements in bays and estuaries where the salinity would be expected to undergo marked changes. Using other methods to determine temperature remotely, the salinity could be measured by this technique without using any sensors in the ocean. In some pollution and oceanographic studies, salinity is an important parameter and its remote measurement could prove very valuable. It should be understood that the calculations using this new method would use a more exact relationship than the version presented in this report.

2. MEASUREMENT OF TURBIDITY

A Raman pulsed lidar operating in a low absorption region near 0.47 micron, Figure III-4, can be used aboard the aircraft to penetrate beneath the sea surface and monitor types and amounts of major constituents of the sea water. The Raman frequency-shifted signals backscattered from the sea should provide the signatures for each constituent. The amplitude of each Raman shifted signal should indicate the concentration of that particular constituent.

The pulsed lidar can give a bottom profile of the bay along the flight path of the aircraft. It also should be possible to measure the turbidity of the sea water by placing reflectors at specific points at known depths and measuring the attenuation of the lidar signals reflected from those targets. The lidar would need to be carefully calibrated in terms of signal amplitude in order to obtain absolute values of turbidity.

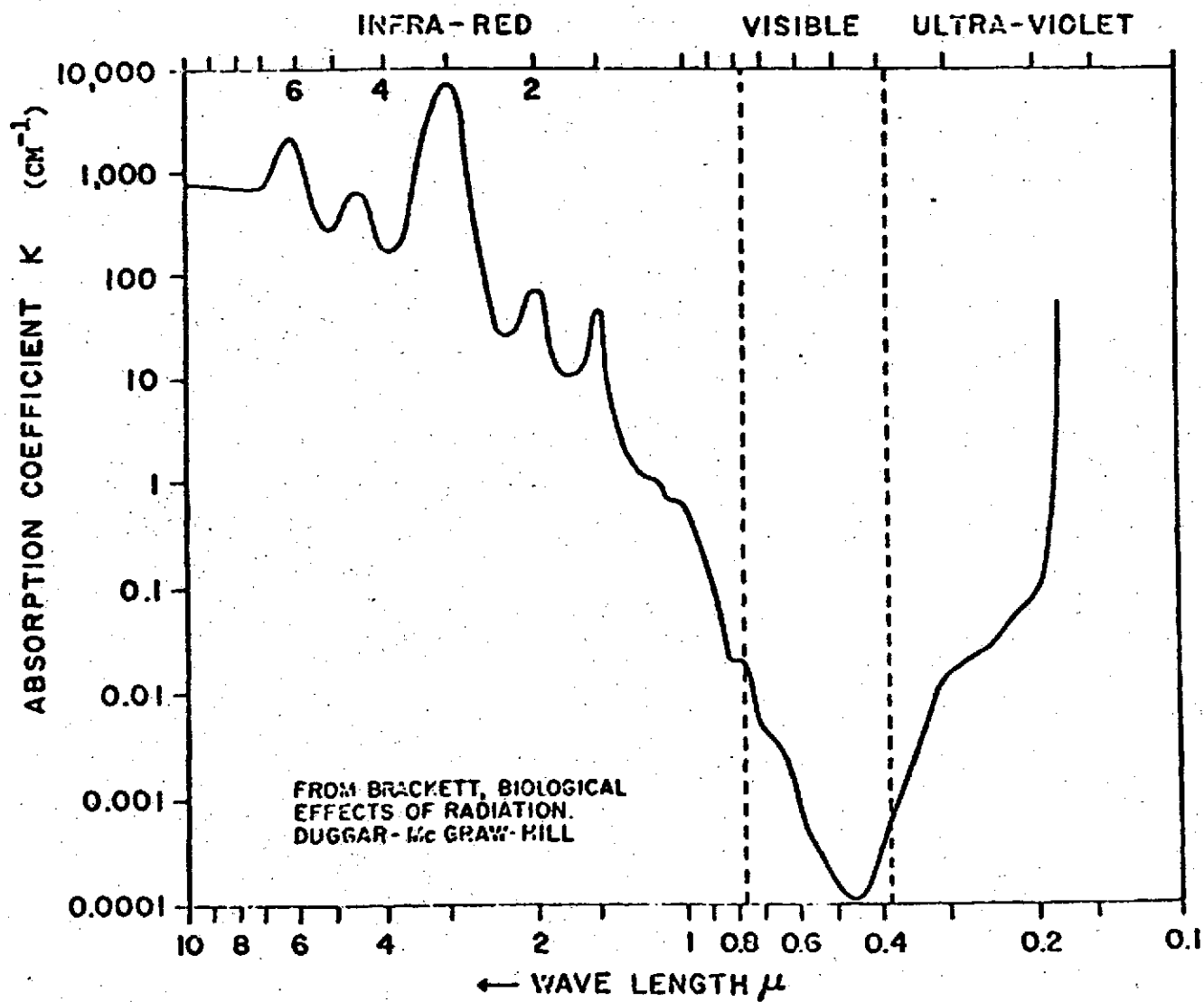


Fig. III-4 ABSORPTION OF RADIATION BY SEA WATER

Also, the attenuation measurements would have to be correlated with some ground truth turbidity measurements. Decibels attenuation per meter would equate to specific turbidity values. The narrow beam aperture of a lidar would provide excellent resolution in the water from aircraft altitudes.

D. DATA FORMAT, PROCESSING AND ANALYSIS

In the early stage of the project, probably it would be best to record the airborne remote sensor data in analog fashion on magnetic tape along with date, time, geographic location, and any other necessary information. The analog data can be converted to digital on the ground for processing. This will permit experimentation to determine the optimum analog-to-digital conversions and avoid poor prior choices in digitizing. Also, spectral studies can be made of the full bandwidth original data whenever desired.

Ultimately, automatic digital data processing should be used for all the airborne remote sensor data as well as for the corresponding ground truth data. Space-scale interpolations and extrapolations of the data can be done by computer and isolines of the results can be drawn automatically for the area under studied. Also, correlation coefficients can be computed automatically.

A computer routine called Fast and Easy Time Series Analysis (FESTSA) may be employed for data analysis. This system is developed by Stephen R. Jacobson in the University of Miami Computing Services. It is used to perform analysis of time or frequency related data with a minimum of computer knowledge. This analysis is performed with filtering, power spectrum, correlation, transform, statistical, and spectral matrix techniques. Time series analysis has been used extensively in the physical sciences, engineering and economics. It is now being used on other data-gathering fields such as medical sciences, psychology, and sociology. This type of analysis is extremely useful for modelling physical processes. A time series is a linear array of data points that are related to some independent variable, such as, but not necessarily time. This data may be obtained by automatic sampling and recording equipment, hand tabulation, or numerically produced by a mathematical model. The data points may be stored in any machine readable form for input to FESTSA.

The system itself is composed of a set of FORTRAN subroutines. These subroutines, in addition to data analysis, utilize an efficient and convenient method of data storage and retrieval. Besides the analysis routines, a number of data manipulation and visual representation routines have been included to provide a complete software package for data analysis.

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IV. GROUND TRUTH AND IN-SITU MEASUREMENT

A. Basic Requirements

The purpose of the in-situ measurement is three-fold:

1. to provide ground truth data for remote sensing.
2. to provide boundary conditions for the mathematical model.
3. to provide a check as to the accuracy of the model.

The variable measurements that are required by this investigation are:

1. surface water temperature for remote sensing-ground truth
2. vertical water temperature profile
3. vertical water salinity profiles
4. temperatures and salinities from horizontal transects
5. continuous monitoring of water temperatures
6. current measurements
7. dissolved oxygen measurements.
8. turbidity measurements
9. water level heights

Thus, in each case we are presented with the task of determining the variable to be measured, the method of acquiring the data, and the instrument to be used.

a. Surface Water Temperatures for Remote Sensing-Ground Truth

The temperatures of the surface water in the estuary are important parameters with respect to the ground truth of the remote sensing operation. The temperatures may be obtained in two general ways. The first method uses a point data source. This may be accomplished by the use of buoy installations, using the Endeco Type 137 Temperature Data Buoy System, which senses and records the temperatures at several surface locations, and records the data at one of the buoys. The second basic method is by use of the Bissett-Berman Thermosalinograph for transect data. This transect data provides a continuous temperature record across a horizontal path within the estuary. For measurement of

temperature at any point in the estuary, at any depth, the Martek Mark III Water Quality Analyzer would be an ideal instrument.

b. Vertical Water Temperature Profiles

Vertical temperature profiles are generally of one or two types, either continuous plots, or generalized plots, obtained by interpolating between many data points. The continuous method results in a continuous plot of temperature versus depth. The basic instruments used are bathythermographs for deep work, and STD's (salinity-temperature-depth meters) for deep or shallow work. In a situation where the desired data range may be from 0-10 meters, or from 0-100 meters, an STD, such as the Plessey Model 9040 Telemetering STD would be very practical and versatile. The array type systems incorporate several single temperature sensors on a vertical line to give several points of temperature versus depth. The degree of possible interpolation depends heavily on the distance between points, and on density stratification. The array of sensors might be lowered then raised, or put in continuous operation by using an in-situ, or telemetry data gathering system. A possible array system might consist of a number of Plessey Model 40005 Temperature Sensors arranged on a cable, suspended vertically into the water.

c. Vertical Water Salinity Profiles

The measurement of vertical salinity profiles is very much like that of vertical temperature profiles, that is, continuous or array. Thus the Plessey Model 9040 Telemetering STD would be very practical, since accurate data is obtained by simple lowering and raising of the STD. The array method would also be similar to that of the temperature measurement as only the Plessey Model 6015 Conductivity Sensor would be used.

d. Temperatures and Salinities from Horizontal Transects

The acquisition of transect data is extremely important for two main reasons. First, the infrared scanning of temperature on an estuary or bay result in a "map" of thermal areas, and transect data show temperature contours in a fast and accurate

way. Second, the contours of temperature and salinity around a thermal discharge area tell much about the mixing mechanisms of the estuary, which are important, since the installation of fixed data stations depends on determination of the "critical points" of circulation and thermal concentration within the estuary. For transects, the Bissett-Berman Model 6600T thermosalinograph is an excellent system which, when installed on a small surface craft, permits fast, accurate transects providing the necessary data.

e. Continuous Monitoring of Water Temperatures

The continuous monitoring of water temperatures is important to the remote sensing aspect of study, and to the mathematical model aspects. The continuous monitoring, as needed at say six buoys, could be performed by the Endico Type 137 Temperature Data Buoy System. In other cases of continuous measurement, the incorporation of temperature measurement with the measurement of other parameters would be useful, and, before installations are made, studies of such comprehensive systems as the Kahlsico Hydrolab System, or the Endico Type 146 Environmental Monitoring System should be made.

f. Current Measurements

The measure of current is important for the mathematical model, and for the study of the estuarine circulation pattern. The type of meters used depends on the accuracy required, and on the type of installation. The Plessey M027/2M Direct Reading Current Meter is a very simple device that measures the current as it is suspended from a ship, but an operator is needed. In contrast, instruments such as the Endico Type 110 Remote Reading Current Meter, or the Plessey M021 Recording Current Meter are in-situ devices that record data, and long term measurements are possible.

g. Dissolved Oxygen and Turbidity Measurements, and the Application of Comprehensive Systems

The measure of such "specific" variables as dissolved oxygen

content, turbidity, and even pH is probably best performed by one of the many "comprehensive" data systems. These systems are typically very versatile, and may be adopted to the situation at hand through the manufacturer's design and counsel, and the installation of the system. Such available systems are the Plessey Submersible Water Quality System, the Martek Mark III Water Quality Analyzer, and the Endico Type 146 Environmental Monitoring System. Since with any measure of dissolved oxygen or turbidity, the investigator would more than likely benefit from the knowledge of other parameters, such as salinity and temperature, the use of one of these "comprehensive" systems is recommended. Close cooperation between the investigator and the supplying company would result in the most efficient and complete use of equipment, money, men and time.

h. Water Level

The measure of water levels at specific points is an important operation. The circulation and water movements within an estuary are greatly affected by the various levels within the water. Measurement of specific water levels at given times is important, and may be accomplished by use of the Fischer-Porter ADR-Electronic Timer Tide Gauge.

B. Survey of Instruments - Variables to be Measured and Applicable Instruments

i) Temperature

1. temperature at a point

- a- Kahlsico Reversing Thermometers-very accurate, yet impractical for large amounts of data.
- b- Prodelin Data Acquisition System
- c- Aanderaa Meter Model 4-buoy
- d- Martek Mark II & III Water Quality Analyzer portable
- e- Plessey Submersible Water Quality System #MM4 buoy
- f- Plessey Model 4005 Temperature Sensor buoy
- g- Plessey STD System model 9040 telemetering
model 9060 self contained

- h- Kahlsico Hydrolab System comprehensive
- i- Endeco-Remote Reading Current & Temperature Meter Type 110-boat
- j- Endico Temperature Data Buoy System Type 137
- i- Endico Type 138 Remote Reading/Recording Current & Temperature Recorder
- l- Endico Type 146 Environmental Monitoring System - Comprehensive.
- m- Beckman Envirobridge-Salinity-Temperature-Bridge-Model EV5
- n- Beckman Envirometer-Conductivity-Temperature Meter-Model EV6

2. Temperature Profile - Vertical

NOTE: Systems mentioned are those specifically designed for profiling, though systems of point-recording instruments on a line may give general vertical profiles.

- a- Plessey-Model 9040 Telemetering STD
 - b- Plessey-Model 9060 Self-contained STD
 - c- Kahlsico #202WA125 Bathythermograph
3. Temperature Profile - Horizontal
- a- Bissett-Berman Model 6600T Thermosalinograph
 - b- Plessey - Model 6600T Thermosalinograph

ii) Current

- 1- Prodelin Water Acquisition System
- 2- Aanduraa - Model 4
- 3- Plessey - M021 Recording Current Meter bulletin
- 4- Plessey M027/2M Direct Reading Current Meter - need operator
- 5- Kahlsico #232WA060 Current Meter
- 6- Kahlsico-Gemware Model #232WA080 Current Meter
- 7- Endeco Type 110 Remote Reading Current Meter
- 8- Endeco Type 138 Remote Reading/recording Current and Temperature Recorder
- 9- Endeco Type 146 Environmental Monitoring System

iii) Salinity

1. Salinity at a point

- a- Prodelin Data Acquisition System
- b- Aanduraa Meter Model 4
- c- Martek Mark II & III Water Quality Analyzer
- d- Plessey Submersible Water Quality System MM4
- e- Plessey Model 6015 Conductivity Sensor
- f- Plessey STD Systems - Model 9040 Telemetry
Model 9060 self contained
- g- Kahlsico Hydrolab System
- h- Endico Type 146 Environmental Monitoring System
- i- Beckman Envirobridge - Salinity - Temperature
Bridge - Model EV5
- j- Beckman Envirometer - Conductivity - Temperature
Meter - Model EV6

2. Salinity Profile - Vertical

- a- Plessey STD systems - Model 9040 Telemetry
- b- Plessey STD system - Model 9060 self contained

3. Salinity Profile - Horizontal

- a- Bissett Berman Model 6600T Thermosalinograph
- b- Plessey - Model 6600T Thermosalinograph

iv) Dissolved Oxygen

- 1- Prodelin Data Acquisition System
- 2- Martek Model DOA In-Situ Dissolved Oxygen Monitor
- 3- Martek Mark II & III Water Quality Analyzer
- 4- Plessey MM4 Submersible Water Quality System
- 5- Kahlsico Hydrolab System
- 6- Endico - Type 146 Environmental Monitoring System

v) Turbidity

- 1- Prodelin Data Acquisition System
- 2- Martek XMS in-situ Transmissometer
- 3- Endico Type 146 Environmental Monitoring System
- 4- Beckman Envirotrans Model EV4 Turbidimeter

vi) Data Acquisition Systems

NOTE: Most of these systems are quite versatile, and require adaptation to particular needs.

- 1- Prodelin Data Acquisition System
- 2- Martek Model EDR Environmental Data Recorder
- 3- Maetek Series DAS Data Acquisition & Telemetry System
- 4- Endico Type 146 Environmental Monitoring System

vii) Miscellaneous Instruments

- 1- Fischer-Porter ADR-Electronic Timer-Tide Gauge
- 2- Martek Model HMS in-situ pH monitor
- 3- Plessey M024/2 Tuned Hydrophone Receiver
- 4- Plessey M091/1 Tape Translator
- 5- Plessey Model 4031 Sound Velocity Meter
- 6- Beckman Enviroeye Model EV3- Electronic Secchi Disc
- 7- I.B.R. - Model AXBT-25000 - Air-Deployed Expendable Bathythermograph
- 8- I.B.R. - Expendable Shallow-Water Surface Current Probe - Model XSSC
- 9- I.B.R. - Expendable Depth/Mass Transport/and Surface Current Probe - Model XDTC

viii) Comprehensive Systems

NOTE: These Systems are in general very versatile, and are highly adaptable to the needs of the investigation. Note the appendix for the detailed review of these systems, keeping in mind that the actual system configuration and operation are dependent on the specific data needs of the investigator.

- 1- Prodelin Data Acquisition System
- 2- Martek Mark III Water Quality Analyzer
- 3- Martek Model EDR Environmental Data Recorder
- 4- Martek Series DAS Data Acquisition & Telemetry Systems
- 5- Plessey - Submersible Water Quality System
- 6- Kahlsico Hydrolab System
- 7- Endeco Type 146 Environmental Monitoring System

C. Feasibility of Ground Truth-In-Situ Measurement, and an Example of a Possible System

The task of measuring the variables, in relation to remote sensing, at the surface water, and within the estuary, appears to be a highly feasible operation. The basic plan consists of two phases. The first is a basic operation, performed to get a qualification "feel" for the ranges of parameters to be measured, and an insight into the dynamic action of the estuary. The second phase is the continuous monitoring and study of the estuary.

The basic parameters to be measured in the first phase are temperature, salinity, and velocity. Both vertical and horizontal data are needed. The basic objectives of the first phase are to provide ground truth, to determine the ranges of the parameters, and to study the general circulation patterns, in order to find out the "critical" or significant areas of mixing or stagnation. Transects and point studies are needed, with the observations performed by use of instruments such as the Plessey Model 9060 or 9040 STD, and the Bissett-Berman Model 6600T Thermosalinograph, with the Plessey MO27/2M Direct Reading Current Meter.

The second phase of data acquisition involves the continuous monitoring of many parameters, and transect studies to provide ground truth, and to study estuarine processes. The study of the many parameters, temperature, salinity, current, depth, dissolved oxygen content, turbidity, and pH, is possibly best performed by such a system as the Endeco Type 146 Environmental Monitoring System. The transect studies can be obtained by the Bissett-Berman Thermosalinograph.

Presented here is an instrument system which would provide essentially all of the data necessary in the study. This is not necessarily a "minimal" system, yet may be called a "basic" system. Modifications or additions might be necessary as specific needs or interests arise, but this system should provide a good

measurement system for ground-truth in-situ needs. The Bissett-Berman Model 6600T Thermosalinograph is necessary, in that very complete surface temperature and salinity data may be obtained quickly, and with a high degree of accuracy. The Martek Model Mark III Water Quality Analyzer would be very useful, in that it measures the water temperature, conductivity, dissolved Oxygen, and pH at any depth. The Endeco Temperature Data Buoy System Type 137 would provide continuous monitoring and recording of water surface temperatures at several points, by a system of data buoys and a central data collection station. Current velocity information is necessary, and may be obtained by use of the Plessey M027/2M Direct Reading Current Meter. This basic system is subject to economic considerations, and further development would have to emphasize this aspect.

Table IV-1 presents the basic information on parameters to be measured, the general method used, and an example of an instrument which might be used in each case. Diagram IV-1 presents the basic data acquisition process in symbolic form. Diagrams IV-2 and IV-3 show the general data acquisition scheme applied to a general estuary in the horizontal and vertical, respectively.

The study of the ground data is a direct, necessary and somewhat straightforward operation. Commercially available instruments provide a data acquisition system which, when designed properly, will provide an accurate, complete, and relatively inexpensive method of data study.

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V. SITE STUDIES

In order to demonstrate how the proposed model may be applied to different sites of existing and future nuclear power plant sites, many sites around the country were investigated. Special emphasis was placed on the Florida Power and Light Company's power plant facilities at Turkey Point and Hutchinson Island. These two plants provide an interesting topographical contrast for the testing of the mathematical model's universal nature. The Turkey Point plant is located on a shallow lagoon type estuary while the Hutchinson Island plant will discharge into an offshore shelf. The proximity of both sites to Kennedy Space Center and the University of Miami will enable more convenient coordination of ground truth and airborne remote sensing efforts. Brief outlines of twelve prospective users of the model and associated surveys are presented in this section. These sites are divided into four geographical categories, namely, A) Florida, B) Atlantic Coast, C) Pacific Coast and D) Great Lakes. The plants are classified by their size, type of reactor, cooling system and topography. A summary of this study is given in Table V-1 of this section. More detailed information on these sites may be found in Appendix B of Part I of this report. The information has been compiled from the Environmental Reports and Impact Statements from the various plants and from the Nuclear News, a publication of the American Nuclear Society.

A. GEOGRAPHICAL REGION: FLORIDA

1. PLANT: Turkey Point; Florida Power and Light Co.

GEOGRAPHICAL DESCRIPTION: The Plant is located on a small point of land in Biscayne Bay, a shallow lagoon type estuary.

CAPACITY AND TYPE:

Unit 1	oil	432	MWe
Unit 2	oil	432	"
Unit 3	pwr	728	"
Unit 4	pwr	728	"

TOTAL 2320 MWe

COOLING SYSTEM: The total discharge is 4250cfs: The original once through circulating water system discharged water approximately 3°C above ambient into Card Sound. The system was later modified to go through a network of canals. Details of the system and related studies are given in the appendix.

REMARKS: For use in testing the mathematical model, data acquired from previous ground truth studies may be used.

2. PLANT: Hutchinson Island; Florida Power and Light Co.

GEOGRAPHICAL DESCRIPTION:

The site for the Hutchinson Island Nuclear Power Plant consists of approximately 1,132 acres on Hutchinson Island in St. Lucie County about halfway between Fort Pierce and Stuart on the east coast of Florida. The site is generally flat, covered with water, and has a dense vegetation characteristic of Florida coastal mangrove swamps. At the ocean shore the land rises slightly in a dune or ridge to approximately 15 feet above mean low water.

CAPACITY AND TYPE: One PWR unit with a capacity of 850MWe will enter service by 9/75, and will be complemented by a second identical unit by 9/79.

COOLING SYSTEM: The circulating water system will discharge to the Atlantic Ocean by means of a canal and pipeline terminating in a two-part Y type discharge at a depth of 20 feet. Both parts will be 7.5 feet in diameter and the discharge

velocity from each part will be about 13 fps. The temperature rise of the cooling water will be 24°F at full load of 850MWe For normal full load at 745MWe the temperature change will be 21°F.

REMARKS: Florida Power and Light Co. has sponsored and is presently undertaking numerous environmental studies of Hutchinson Island to insure that the condenser cooling water discharge will be compatible with the existing ocean environment.

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B. GEOGRAPHICAL REGION: ATLANTIC COAST

1. PLANT: Brunswick Steam Electric Plant; Carolina Power and Light Co.

GEOGRAPHIC DESCRIPTION:

The plant is located in Southport, North Carolina on the Cape Fear estuary.

CAPACITY AND TYPE: One unit, a BWR of 821 MWe output is now operating; an identical plant will enter service in 12/74.

COOLING SYSTEM: A high velocity jet (10 fps) 2750cfs, 18°F above ambient temperature, is the discharge of a once through cooling system.

REMARKS: Typical seasonal observed ambient temperatures in the discharge area.

Jan. 11.0°C, April 10.2°C, June 20.2°C, Aug. 28.5°C, Oct. 21.7°C.

2. PLANT: Shoreham Nuclear Power Station; Long Island Lighting Co.

GEOGRAPHICAL DESCRIPTION:

On Long Island Sound.

CAPACITY AND TYPE: The 819 MWe BWR will commence operation by 6/77

COOLING SYSTEM: A multiport diffuser will discharge 1320cfs of water 19.7°F above ambient to Long Island Sound.

REMARKS: A thermal plume parallel to shore and of small maximum temperature difference from ambient is expected.

3. PLANT: Millstone, Northeast Utilities

GEOGRAPHICAL DESCRIPTION:

Near Waterford, Conn. at the tip of Millstone Point on Long Island Sound.

CAPACITY AND TYPE: Eventually three units will operate on the site. Unit one is a 652 MWe BWR. Unit two and three will be PWR of 828 MWe operating by 11/74, and 1750 MWe operating by 10/79, respectively.

COOLING SYSTEM: A once through circulating water system will

result in the discharge of 4155cfs at a maximum full load temperature rise of 20°F.

REMARKS: Dye dispersion studies have been used to identify discharge plume characteristics.

C. GEOGRAPHIC REGION: PACIFIC COAST

1. PLANT: Humboldt Power Plant; Pacific Gas and Electric Co.

GEOGRAPHIC DESCRIPTION:

The Humboldt power plant is located on the shore of Humboldt Bay, Calif., a bay with insignificant fresh water sources, where tidal currents are the principal exchange mechanisms.

CAPACITY AND TYPE: Two fossil and one nuclear unit (BWR) of 172 MWe total production (68 MWe nuclear) are located on the site. The plant has been operated since 8/63.

COOLING SYSTEM: A once through circulating water system of Bay water is used to cool the condensers. The maximum total flow is 230.4 cfs at 7.3 fps. The average temperature rise of the effluent is 18°F above ambient.

REMARKS: Extensive infrared remote sensing and ground truth studies by Bendix Co. and other contractors have been undertaken to delineate the extent of the area affected by the thermal discharge.

D. GEOGRAPHICAL REGION: GREAT LAKES

1. PLANT: Zion Nuclear Power Station; Commonwealth Edison Co.

GEOGRAPHICAL DESCRIPTION:

The Plant is located by the shore of Lake Michigan, approximately half the distance between Chicago and Milwaukee.

CAPACITY AND TYPE: 1100 MWe, BWR, completion expected by 12/73.

COOLING SYSTEM: Discharge will be from two submerged jets 760 feet from shore and 159 feet north and south of the inlet line 45° angle with inlet.

ΔT max = 20°F.

PLANT: Point Beach Nuclear Plant; Wisconsin Electric Power Co. and Wisconsin Michigan Power Co.

GEOGRAPHICAL DESCRIPTION:

The plant site is in Two Creeks, Wisconsin on the shore of Lake Michigan.

CAPACITY AND TYPE: Two PWR units of 497 mwe each began operation in 12/70.

COOLING SYSTEM: Jet discharge 150 feet off shore 18' below lake level. $Q_{max} = 700000$ gpm

$\Delta T_{max} = 19.3^\circ F$

When ambient water temperature is below 40°F

$Q_{max} =$ variable 520000 to 428000 gpm

$\Delta T_{max} = 31.5^\circ F$; Therefore T_{max} outfall = 71.5°F

PLANT: Kewaunee Nuclear Power Plant; Wisconsin Public Service Co.

GEOGRAPHICAL DESCRIPTION:

On the shore of Lake Michigan in Kewaunee County, Wisconsin.

CAPACITY AND TYPE: A PWR of 540 mwe which is expected to enter service 12/73.

COOLING SYSTEM: Circulating water 413000 gpm, $\Delta T = 20^{\circ}F$ in winter; 287000 gpm, $\Delta T = 28^{\circ}F$ in summer.

4. PLANT: Donald C. Cook: Indiana & Michigan Electric Co.
American Electric Power

GEOGRAPHICAL DESCRIPTION:

Lake Township, Berrien County, Michigan, about 11 miles south-southwest of the center of Benton Harbor. An area of 650 acres along the eastern shore of Lake Michigan.

CAPACITY AND TYPE: Two identical units employing PWR's to produce 100 MWe began operation in 1972.

COOLING SYSTEM: The circulating water system pumps water from intake structures on the shore of Lake Michigan and returns the heated effluent to discharge elbows 1100 feet from shore. With both units operating at design load 2260 million gpd $20^{\circ}F$ above ambient temperature is discharged.

REMARKS: The cooling system is designed to minimize mixing with lake water and maximize heat loss to the atmosphere.

PLANT: Enrico Fermi, Detroit Edison Co.

GEOGRAPHIC DESCRIPTION:

The plant is within the limits of Newport, Michigan, on the shore of Lake Erie.

CAPACITY AND TYPE: The nuclear unit is a BWR 1150 mwe.

COOLING SYSTEM: Blowdown discharge is the only effluent to enter Lake Erie, the bulk of the cooling is done by a closed system.

REMARKS: The maximum flow to the lake is 1200 gpm; at a ΔT of $12^{\circ}F$ in July and $23^{\circ}F$ in Jan.

<u>Plant</u>	<u>Unit</u>	<u>Net MWe</u>	<u>Type</u>	<u>Commercial Operation</u>	<u>Cooling System</u>
<u>Florida Power & Light Co.</u>					
Turkey Point (Florida City, Fla.)	#3	725	PWR	7/72	Biscayne Bay by canal network system, Total 4250 cfs discharge.
	#4	725	PWR	4/73	
St. Lucie (Hutchinson Island, Fla.)	#1	850	PWR	12/74	Discharge to Atlantic Ocean by means of a canal and pipelines 21°N 24°F temp. rise.
	#2	850	PWR	9/79	
<u>Atlantic Coast</u>					
Brunswick (Southport, N.C.)	#1	821	BWR	12/75	High velocity jet, once through 2750 cfs, 18° F above ambient.
	#2	821	BWR	12/74	
Shoreham (Brookhaven, N.Y.)	1	819	BWR	6/77	Multiport diffuser, 1320 cfs 19.7° F above ambient
Millstone (Waterford, Conn.)	#1	652	BWR	12/70	Once through, 4155 cfs with max. 20° F temperature.
	#2	828	PWR	11/70	
	#3	1,150	PWR	10/79	
<u>Pacific Coast</u>					
Humboldt Bay	#3	68	BWR	8/63	Once through, 230.4 cfs at 7.3 cfs with 18° F above ambient.
<u>Great Lakes</u>					
Zion (Zion, Ill)	#1	1,100	PWR	6/73	Submerged jet into Michigan Lake 20° F temp. rise.
	#2	1,100	PWR	12/73	
Point Beach (Two Creeks, Wis.)	#1	497	PWR	12/72	Submerged jet, 150 feet off shore into Michigan Lake. 19.3°N 31.5° F temp rise
	#2	497	PWR	10/72	
Kewannee (Carlton, Wis.)	1	540	PWR	12/73	413,000 gpm into Lake Michigan with 20° N 28° N temp. rise.
Donald C. Cook (Bridgeman, Mich.)	#1	1,054	PWR	9/74	1,570,000 gpm into Lake Michigan 1100 off shore with 20° F above ambient.
	#2	1,054	PWR		
Fermi (Newport, Mich.)	#1	1,150	BWR	4/77	A closed system but with blowdown discharge into Lake Erie.
	#2	1,150	BWR	8/81	

VI. DISCUSSION OF RESULTS / CONCLUSION

In this feasibility study, the advantages and shortcomings of many existing mathematical models for the thermal discharge study have been carefully analyzed. Many alternatives have been considered. After a trade-off study on the many possible approaches, a general three-dimensional model has been recommended. This model is universal in nature, and includes the effects due to buoyant forces, temperature distribution, salinity distribution, tides, wind and boundary geometry. Different numerical schemes that could be used in the solution of the governing equations have been considered and given serious study. The three-dimensional extension of the Marker and Cell method developed by the Los Alamos group (Harlow, Welch, et al) is recommended to be used for the numerical calculation of the model. It has advantages for the treatment of free surface problems. It is concluded that, with the aid of the latest developments in numerical evaluation schemes, an analytical treatment of the proposed model study is feasible.

To provide input for the model development, the I.R. Scanner is recommended for use in measuring water surface temperature remotely and the 8-14 micron thermal band is considered to be the most suitable band for this purpose. The maximum emission of a blackbody corresponding to the sea surface temperatures falls into these wavelengths. In this region, the irradiation on the sea surface from the sun becomes negligible. Also, it is one of the few "windows" that is relatively transparent to the radiation. These I.R. Sensory Systems are available commercially and have been used by many researchers to remotely measure surface temperatures. The need of correction for non-blackness and atmospheric absorption effects have been considered. A few approaches for these corrections have been studied. The presently available equipment has been investigated and the alternates of using aircraft and/or spacecraft has been investigated carefully. It is felt that, initially, aircraft may be used to obtain more detailed and accurate results.

The satellites can provide large scale effects and eventual automatic surveillance, and the results from satellites can be tied in with the integrated results of the more detailed study. This means that the two surveys can be directly compared by convoluting the airplane results with those of the satellites. However, it should be noted that while the complementary use of these two systems (the spacecraft and the aircraft) are considered to be appropriate in the development stage of the proposed study, the ultimate goal is to evolve a system which utilizes spacecraft as the main instrument of remote data gathering. A NASA sponsored feasibility study using satellite I.R. data to determine sea surface temperature was conducted by Allied Research Association, Inc. in 1966. Since then, the resolution of I.R. Scanner in various satellite programs has been improved greatly. The proposed ERTS-B will be provided with a 10 to 12.6 micron thermal band with relatively good ground resolution. Before the ERTS-B data becomes available it is possible to obtain such data with 0.3 -mile resolution from the Air Force Data Acquisition and Processing Program (DAPP) satellites. It is believed that the use of a satellite for detecting sea surface temperatures with high accuracy should become practical in the near future.

In the remote sensing of turbidity, the Raman Pulsed Lidar effect has been considered and the University of Miami Optics Laboratory is capable of developing such a Turbidity Laser System. A controlled study will be needed in the early stage of development, but this system should be capable of going into field application in a relatively short period. For the remote sensing of vertical water temperature profile and salinity, laser beams have been considered. However, this concept may need some extensive research before it can be put to practical use.

For in-situ measurements, a thorough investigation of presently available field instruments has been carried out. Various data acquisition schemes have been considered. Special

consideration has been given to the interface between in-situ measurements and remote sensing and the manner in which this information can be incorporated to provide input for the model. It has been concluded that with the presently commercially available ocean instruments and logic system, such a Ground Truth and In-Situ Measuring System is not only feasible, but is practical.

Many sites of nuclear power plant units have been investigated for the utilization of the proposed model. The two FP&L Power Plant facilities at Turkey Point and on Hutchinson Island are most appealing to the project since they both are located in Florida, close to the University of Miami, as well as the Kennedy Space Center. Another interesting feature is their topographical contrast. The Turkey Point facility is located at a shallow lagoon type estuary, while the Hutchinson plant discharges onto the off-shore continental shelf. These two sites should provide a good test for the universal nature of the proposed three-dimensional model.

APPENDIX A

GENERAL LISTING OF GROUND TRUTH INSTRUMENTS

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GENERAL LISTING OF GROUND TRUTH INSTRUMENTS

This list of instruments is the result of a general study of commercially available instruments for the measure of parameters related to the ground truth requirements. The list is not meant to be a complete listing of all such instruments, but instead, an extensive enough list to show the large number and various types of commercially available instruments. The important aspects of each instrument are mentioned, including the approximate price, when given by the manufacturer.

The instruments are grouped by manufacturer (see Section IV for listing by type), in the following order:

<u>Section No.</u>	<u>Manufacturer</u>
1	Aanduraa
2	Beckman-Beckman Instruments, Inc.
3	Bissett-Berman
4	Endeco-Environmental Devices Corp.
5	Fisher-Porter
6	I.B.R.-International Business & Research Inc.
7	Kahlsico-Kahl Scientific Instrument Corp.
8	Martek
9	Plessy
10	Prodelin

1) Aanduraa Meter (Model 4)

- parameters - current speed and direction
- water temperature
- conductivity
- depth (of instrument)
- installation - surface buoy
- sub-surface buoy
- recording - magnetic tape (converted to computer tape)
- accuracy - current-speed; 1.5 to 250^{cm}/sec.
- direction; 0-360° ± 5°
- temperature-range choice i) -246-21.40°C
- ii) 10.08-36.00°C
- iii) -0.34-32.17°C
- (all ± .01°C)

- conductivity - 0-60 milliohm
- pressure-range choice i) 0-200 psi
 - ii) 0-500 psi
 - iii) 0-1000 psi
 - iv) 0-5000 psi(all accurate to better than $\pm 1\%$ of range)

price - \$4000.

2. Beckman

a) Beckman-Enviroline Model EV3 Enviroeye Electronic Secchi Disc

- parameter - amount of sunlight at a depth
- installation - hand held
- data recording - read off ammeter
 - depth read by marks on cable
- accuracy - range, % transmission - 1 to 100
 - sensitivity, % transmission - 2
 - accuracy, % transmission - 5
- price - \$140.

b) Beckman-Enviroline Model EV4 Envirotrans Underwater Turbidimeter

- parameter - measures water transparency
- installation - hand held
- data recording - read off ammeter
 - depth read by marks on cable
- accuracy - range, % transmission - 1-100
 - sensitivity - % transmission - 2
 - accuracy - % transmission - 5
- price - \$180.

c) Beckman-Enviroline Model EV5 Envirobridge, Salinity-Temperature Bridge

- parameters - temperature
 - salinity
- installation - hand held
- data recording - manually operated bridge
 - ammeter nulling
- accuracy - temperature - range; - 5 to 35°C
 - accuracy - 2°C
 - salinity - range - 1 to 40 ppt
 - accuracy - 2ppt
- price - \$190.

d) Beckman - Enviroline Model EV6 Envirometer
Conductivity - Temperature Meter

- parameters - temperature
- conductivity
- installation - hand held
- data recording - read off ohmmeter
- accuracy - temperature - range; - 10 to 40°C
- accuracy; 2°C
- conductivity - range; 50 to 2000 micromhs/cm
- accuracy: 50 micromhs/cm
- price - \$190.

3. Bissett - Berman Model 660T Thermosalinograph

- parameters - temperature
- salinity
- transect data, i.e. surface temperature
and salinity
- installation - permanent on board a boat
- utilizes flow-thru system, monitoring
water salinity/temperature on the
surface
- data recording - recorded on ship
- pen on strip chart
- time & locations monitored by operator
- accuracy - temperature - range choice: i) -2.-8°C
ii) 5-15°C
iii) 12-22°C
iv) 19-29°C
v) 26-36°C
(these are all settings
with accuracy of $\pm 0.1^\circ\text{C}$)
- salinity - range choice:
i) 20.0-30.0 ppt
ii) 28.0-38.0 ppt
iii) 28.0-30.0 ppt
iv) 29.5-31.5 ppt
v) 31.0-33.0 ppt
vi) 32.5-34.5 ppt
vii) 34.0-36.0 ppt
viii) 35.5-37.5 ppt
(these are all settings, the
accuracy for settings i & ii
is ± 0.15 ppt, for iii) to
viii); ± 0.03 ppt)
- price - approximately \$8000.

4. Endeco - Environmental Devices Corp.

a. Endico - Type 110 Remote Reading Current Meter

- parameters - current speed and direction
- depth
- temperature

installation - buoy - surface or sub-surface
- shipboard

data recording - data is telemetered via cable to the
remote meter

accuracy - current - speed - 0-5 knots
accuracy - $\pm 3\%$ of full scale
threshold - $\pm 1.9\text{cm/sec}$
- direction - 0.360°
accuracy - $\pm 2\%$ full scale
- depth - range-0-100 feet
accuracy - $\pm 2\%$ full scale
- temperature - range - 0-40°C
accuracy - $\pm 0.5^\circ\text{C}$

price - \$3000.

b. Endeco - Type 137 Temperature Data Buoy System

parameter - temperature - at the buoy (can be expanded
to several at a buoy)

installation - system of six buoys and either a data
receiving buoy or data receiving station

data recording - data is transmitted periodically from each
buoy to the central receiving station,
information is decoded and recorded on
a digital printer, or may be fed to a
teletype terminal

accuracy - temperature; 0 to 40°C $\pm 0.2^\circ\text{C}$

price - receiving station w/digital printer-\$6000 each
- buoy-single thermistor - \$3000 each
-three thermistor - \$4500 each

c. Endeco Type 138 Remote Reading/recording Current &
Temperature Recorder

parameters - current speed
- temperature

installation - fixed on bottom or other object

data recording - data recorded in the meter on strip chart

accuracy - current speed - 0 to ± 4 knots
accuracy - $\pm 3\%$ of full scale

temperature - range - 0 to 40°C
accuracy $\pm 0.25^\circ\text{C}$

price - single axis - bidirectional output,
includes tower - \$6000.
- extra speed sensor - \$1500.

d. Endeco - Type 146 Environmental Monitoring System

parameters - possible system parameters; underwater;
current speed and direction
water temperature

wave height and period
tide height
salinity
dissolved Oxygen
pH
turbidity

- meteorological; wind speed and direction
- air temperature
- relative humidity
- barometric pressure
- incident solar radiation
- net solar radiation
- rainfall

(This is a very versatile system, with accuracies, installation, and data processing subject to design criteria. Close cooperation with the manufacturer will provide the most satisfactory results.)

price - \$40,000.

5. Fischer-Porter - ADR - Electronic Timer - Tide Guage

- parameter - water level vs. time
- installation - fixed - rigid piling, etc.
- data recovery - records data, recover after 2 weeks
- need data reader
- convert to graphs, or computer tape
- accuracy - water level - reads to 0.01 ft
- accuracy to 0.1 ft
- price - ADR - \$1500
- display recorder - \$1000
- recorder-computer tape translator \$8000

6. I.B.R. - International Business & Research, Inc.

(NOTE: These I.B.R. instruments are air-deployed instruments, which are dropped from aircraft, transmitting the desired information to recorders on the plane.)

a. I.B.R. - Air-Deployed Expandable Bathythermograph Model AXBT-2500U

- parameters - temperature vs depth (vertical profile)
- installation - air-deployed by aircraft
- data recording - data telemetered by UHF radio to recorder on board the aircraft
- accuracy - temperature; 28°F to 95°F, accuracy: $\pm 1.0\%$
- depth; to 2500 meters
- descent rate (in water); $6.25^m/sec \pm 2\%$
- price - \$150 each per 100

b. I.B.R. - Expendable Shallow-Water Surface Current
Probe-Model XSSC

- parameters - average surface current
average surface wind
- installation - air-deployed from aircraft
- data recording - the data obtained is essentially in
the form of photographs of dye
patterns, as dye is emitted from
the floating section of the unit.
Analysis of the series of photo-
graphs is necessary in order to
gain knowledge about the currents
and winds.
- accuracy - general accuracy is stated as $\pm 2\%$
- price - \$20 each per 100

c. I.B.R. - Expendable Depth/Mass
Transport/and Surface Current
Probe - Model XDTC

- parameters - depth
mass transport
surface current
subsurface current
- installation - air-deployed from aircraft
- data recovery - The data received by the use of this
system is in the form of photographs
of various dye patterns at various
depths and times. Analysis of the
dye patterns knowing the times of
deployment result in the knowledge
of the parameters mentioned.
- price - \$100 each per 100

7. Kahlsico - Kahl Scientific Instrument Corp.

a. Kahlsico Deep Sea Reversing Thermometer - #295WA100
(protected) and #295WA200 (unprotected)

- parameter - temperature (at one depth)
- installation - shipboard
- data recording - thermometers are lowered by cable, de-
ployed by messenger, and data is ob-
tained by reading mercury levels in
the thermometers.
- accuracy - six range choices: i)-2-30°C in 0.1°C
ii)-2-20°C in 0.1°C
iii)-2-15°C in 0.05°C
iv)-2-35°C in 0.1°C
v)-2-8°C in 0.05°C
vi)-2-5°C in 0.05°C

- accuracy: $\pm 0.01^{\circ}\text{C}$ or $\pm 0.001^{\circ}\text{C}$, depending on scale range
- b. Kahlsico #202WA125 Bathythermograph
 - parameter - temperature vs depth - profile
 - installation - shipboard deploying
 - data recording - the BT is launched off the ship or towed. The graph of temperature vs depth is scribed on a slide and the information logged upon reading of the slide after recovery of the BT.
 - accuracy: temperatures: ranges: i)-2 to 30°C
ii)+2 to 90°F
 - accuracy: $\pm 0.1^{\circ}\text{C}$
 - depth: ranges: i) $30\text{m} \pm 0.4\text{m}$
ii) $60\text{m} \pm 0.4\text{m}$
iii) $135\text{m} \pm 1.5\text{m}$
- c. Kahlsico - Current Meter Model #232WA060
Gemware Mechanical Contact Current Meter
 - parameter - current speed
 - installation - suspended from ship
 - data recording - current speed recorded by earphones, digital printer or strip charts
 - accuracy - speed: $0.2-5.0^{\text{m}}/\text{sec} \pm 2\%$
direction: dependent on operator - not necessarily accurate
- d. Kahlsico - Cup-type Current Meter - Gemware Model #232WA080
 - parameter - current speed
 - installation - suspended from ship
 - data recording - earphones, digital recorder
 - accuracy - current speed: 0.1 to $11 \text{ ft}^{\text{ft}}/\text{sec} \pm 1\%$
current direction: dependent on operator, not necessarily accurate
 - price - relatively inexpensive
- e. Kahlsico - Hydrolab Comprehensive System
 - parameters
 - conductivity
 - depth
 - dissolved oxygen
 - oxidation-reduction potential
 - pH
 - specific ion activity
 - temperature
 - (This is a system which must be designed according to the needs and requirements of the purchaser. Data configurations, accuracies and data recording are dependent on the system design.)

8. Martek Instruments

- a. Martek-Model HMS In-situ pH Monitor
 - parameter - pH
 - installation - hand held, portable
 - data recording - direct readout of meter
 - accuracy - ± 0.1 pH
 - price - \$750.
- b. Martek - Model XMS In-situ Transmissometer
 - parameter - measures turbidity & particle quantity by measuring the optical properties of the water
 - installation - hand held, portable
 - data recording - direct readout of meter
 - accuracy - $\pm 1.0\%$
 - price - \$3000.
- c. Martek - Model DOA In-situ Dissolved Oxygen Monitor
 - parameter - dissolved oxygen level
 - installation - hand held, portable
 - data recording - direct readout of meter
 - accuracy - ranges: i) 0-20ppm
ii) 0-10ppm
iii) 0-2ppm
(All accuracies - $\pm 1\%$ of full scale)
 - price - \$750.
- d. Martek - Mark II Water Quality Analyzer
 - parameter - temperature
depth
conductivity
dissolved oxygen
pH level
 - installation - hand held, portable
 - data recording - direct readout from meter, only one transducer being in operation at any one time
 - accuracy - temperature - $\pm 0.5^{\circ}\text{C}$
depth - ± 1.5 meters or feet
dissolved oxygen - ± 0.1 ppm
pH level - ± 0.05 pH
 - price - \$2800 plus \$1.00 per foot of cable

e. Martek - Mark III Water Quality Analyzer

- parameters - temperature
depth
conductivity
dissolved oxygen
pH level
- installation - portable, yet may be adapted for more permanent type installation
- data recording - readout on meters, may be modified for in-situ recording or data telemetry, possible simultaneous monitoring of all variables
- accuracy - temperature - $\pm 0.5^{\circ}\text{C}$
depth - ± 1.5 meters or feet
dissolved oxygen - ± 0.1 ppm
pH level - ± 0.05 pH
- price - \$4950 plus \$1.00 per foot of cable, (\$4250 without pH monitor)

f. Martek - Model EDR Environmental Data Recorder

- parameters - records data from many sources
- installation - either fixed or portable
- data recording - accepts DC voltages, from up to ten individual data sources
- displays in original measured units
- display is printed on tape
- will scan at variable time intervals (1-60 minutes)
- accuracy - 0.1%
- price - \$2800.

g. Martek - Advance Product Bulletin

1. Series DAS Data Acquisition and Telemetry System

- data logging, reading, telemetry system
- specifies as to operation not stated in bulletin
- seems to be a complete data acquisition system with data available in several forms

2. Model DAL Data Logger

- logs, records and displays data
- records on magnetic tape - various timing options
- reads and translates data through reader

price - \$2500.

9. Plessey Instruments

a. Plessey Submersible Water Quality System - MM4

- parameters - temperature
- pH
- depth
- suspended solids
- dissolved oxygen
- conductivity
- installation - buoy type - self contained
- operational temperature - 0-30°C
- operational depth - 33m maximum
- data recording - recorded on magnetic tape
- may be translated from magnetic tape to computer tape by use of Model M092 Tape Translator
- may be left unattended for up to three weeks
- accuracy - time - cumulative - ± 5 min/month
- temperature - 0-30°C $\pm 0.3^\circ\text{C}$
- depth - $\pm 2\%$ FSD
- pH - ± 0.2 pH
- solids - $\pm 1\text{mg}/1$ at $0\text{mg}/1$, $\pm 10\text{mg}/1$ at $100\text{mg}/1$
- dissolved oxygen - $\pm 5\%$ within 20° temp. range
- conductivity - detailed options
- price - 4000 to 5000 £ (English Pounds)

b. Tape Translator Model M091/1

- for use with Water Quality System #MM4

c. Plessey Recording Current Meter Model M021

- parameter - current
- bulletin states that "other sensors may be added"
- installation - self contained buoy
- data recording - recorded on magnetic tape
- extended service to 80 days
- telemetry possible up to 500m by use of hydrophone
- extended service to 60 days when recording 4 parameters
- accuracy - current - $\pm 20\text{mm}/\text{sec}$, or 2%, whichever is greater
- price - 1500 £

d. Plessey Tuned Hydrophone Receiver, Model M024/2

- for use as telemetry receiver with the Recording Current Meter Model M021

- e. Plessey Direct Reading Current Meter - Model M027/2M
 - parameter - current
 - installation - hand held, portable
 - data recording - via cable to shipboard meter
 - appears that an operator is needed
 - accuracy - $\pm 30^{\text{mm}}$ /sec. or 3%, whichever is greater
 - price - less than 1000 (english pounds)
- f. Plessey Temperature Sensor - Model 4005
 - parameter - temperature
 - installation - buoy - fixed
 - data recording - signal is to a recorder
 - may be long distance by fm signal
 - accuracy - temperature - $\pm 0.02^{\circ}\text{C}$
- g. Plessey - Pressure Sensor - Models 4006, 4026
 - parameter - pressure
 - installation - buoy - fixed
 - data recording - signal is to a recorder
 - may be long distance by fm signal
 - accuracy - pressure - $\pm 0.25\%$ full scale - on 4006
 - $\pm 0.03\%$ full scale - on 4026
- h. Plessey - Sound Velocity Sensor - Model 4031
 - parameter - sound velocity
 - installation - buoy - fixed
 - data recording - signal is to a recorder
 - may be long distance by fm signal
 - accuracy - sound velocity - $\pm 0.3^{\text{m}}$ /sec (RSS)
- i. Plessey - Conductivity Sensor - Model 6015
 - parameter - water conductivity
 - installation - buoy - fixed
 - data recording - signal is to a recorder
 - may be long distance by fm signal
 - accuracy - conductivity - $\pm 0.03^{\text{mmho}}$ /cm (RSS)
- j. Plessey - Thermosalinograph - Model 6600T
 - parameters - temperature
 - salinity
 - horizontal transect
 - installation - permanent on board boat
 - utilizes flow-thru system
 - monitoring water salinity and temperature on the surface

data recording - recorded on ship
- pen on strip chart
- time & locations monitored by operator

accuracy - temperature - range choice: i) -2-8°C
ii) 5-15°C
iii) 13-22°C
iv) 19-29°C
v) 26-36°C

(These are all settings
with accuracy of $\pm 0.1^\circ\text{C}$)

- salinity-range choice: i) 20.0-30.0ppt
ii) 28.0-38.0ppt
iii) 28.0-30.0ppt
iv) 29.5-31.5ppt
v) 31.0-33.0ppt
vi) 32.5-34.5ppt
vii) 34.0-36.0ppt
viii) 35.5-37.5ppt

(These are all settings, the
accuracy for settings i) & ii)
is ± 0.15 ppt, for iii) to
viii) ± 0.03 ppt)

k. Plessey - Telemetering STD - Model 9040

parameters - temperature vs depth
- salinity vs depth
- vertical profiling

installation - shipboard - winch, adaptable to buoy

data recording - versatile system
- data recorded on magnetic tape, binary
form, DC analog, fm analog

accuracy - temperature - range choice: i) -2-3°C
ii) 2-7°C
iii) 6-11°C
iv) 10-15°C
v) 14-19°C
vi) 18-23°C
vii) 22-27°C
viii) 26-31°C
ix) 30-35°C
x) 34-39°C
xi) -10-40°C

- accuracy; $\pm 0.02^\circ\text{C}$ for i) to x), $\pm 0.15^\circ\text{C}$
for #xi)

- salinity-range choice: i) 30-32 ppt
ii) 31.5-33.5ppt
iii) 33.0-35.0ppt
iv) 34.5-36.5ppt
v) 36-38ppt
vi) 37.5-39.5ppt
vii) 30-40 ppt

- accuracy; ± 0.02 ppt on i) to vi), ± 0.06 ppt
on #vii

- depth - $\pm 0.25\%$ full scale

10. Prodelin Data Acquisition System

- sensors
 - water, current and direction
 - wind direction
 - conductivity
 - chlorinity
 - dissolved oxygen
 - rainfall
 - water turbidity
 - wave height
- installation
 - buoy system
- data recording
 - system consists of master station with telemetered buoys
 - master station, interrogates buoys - data is printed out at the master station
- accuracy
 - dependent on transducer
- price
 - determined by the extent of the system, depending on the number of buoys, transducers, etc.

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Appendix B.

Supplementary Information on Site Studies

A. GEOGRAPHICAL REGION: FLORIDA

1. The Turkey Point Power Plant Facility of Florida Power and Light Company

The Turkey Point site is located on the western shore of Biscayne Bay approximately 25 miles south of Miami. Figure 1 is a map of the local area. The Turkey Point power plant is composed of four independent electric generating units as follows:

<u>Unit</u>	<u>Fuel</u>	<u>Start-up</u>	<u>Gross</u> <u>Capa</u> <u>MWe</u>	<u>Cooling</u> <u>Water</u> <u>cfs</u>
1	oil	Spring 1967	432	635
2	oil	Spring 1968	432	635
3	Nuclear	Summer 1972	728	1490
4	Nuclear	Late 1972	728	4250
Combined			2320	4250

The cooling water for units 1 and 2 has been taken from Biscayne Bay through an inlet canal, and was originally discharged back into Biscayne Bay principally through Grand Canal, about one mile south of the plant as shown in Figure 2. With the later completion of the large canal running south to Card Sound, the discharge water was then split in two directions, part through Grand Canal and part through the large canal as shown in Figure 3. When units 3 and 4 were brought into operation in later years, the cooling water for all 4 units were to flow once-through with the discharge split into the two canals. Due to the increased concern over the thermal effects from these power plants, the FP&L Company later adapted a complicated canal system aimed at the recirculation of the cooling water. The construction of the cooling system began in November 1971 and was scheduled for completion by November 1975. This recirculating cooling reservoir is shown in Figure 4.

A thermal study of lower Biscayne Bay was conducted by the Federal Water Pollution Control Administration from April to

August 1968 to investigate the effect of units 1 and 2 on the temperature regime of the Bay. In that study, continuous temperature recording instruments were used to obtain a record of water temperature at selected locations in the bay. The instrument used consisted of a spring wound, clock driven, 15 day chart with a bimetallic sensing element enclosed in a water-proof stainless steel case. The thermographs were suspended approximately 14 inches under the water surface below a 12"x12"x17" block of styrofoam which was anchored by means of stainless steel cable to a 5/8" steel rod driven into the bottom of the bay. Sufficient data for analysis was obtained from ten stations as shown in Figure 5. Station H13A had two monitors; one at a depth of 14 inches and one approximately one foot from the bottom. In that investigation, intensive studies of water temperature in the area around Turkey Point were also conducted. Transects extending approximately perpendicular to the shoreline were established between Turtle Point and Homestead Bayfront Park. Vertical profiles of temperature were taken at 100 yard intervals along the transects. One of the results of the transect studies is shown in Figure

On February 15, 1972, Florida Power and Light Company opened the Card Sound Cooling Canal. A weir was constructed in the canal to Biscayne Bay (Grand Canal) to adjust the mean flow rates to approximately 1800 cfs to Card Sound and 1200 cfs to Biscayne Bay. However, due to a 40-minute tidal phase lag, the discharge to Card Sound varies from a peak of 2450 cfs at the time of high tide at Turkey Point to a minimum of 1970 cfs at low tide. The discharge temperature at the two locations varies from 1 to 3°C above ambient. This mode of discharge was to be continued until nuclear units three and four were put on line. Mapping of surface temperature and salinity was conducted by a team from the Rosenstiel School of Marine and Atmospheric Science, University of Miami, just prior to the initial discharge into Card Sound, three days later and then one week after the canal was opened. Since then detailed mapping of the discharge plume has been conducted on a semi-monthly

basis. The results show that the plume is clearly distinguishable both in temperature and salinity due to plant heating and the ambient temperature and salinity contrasts which develop between south Biscayne Bay and Card Sound. The low mean discharge of 1800 cfs to Card Sound produces a relatively small thermal plume with approximately 600 acres above 1°C. However, the observation suggests that even at these small discharge rates there is a tendency for the area east of the cooling canal to stratify, as can be seen in Figures I-15, and II-10.

86

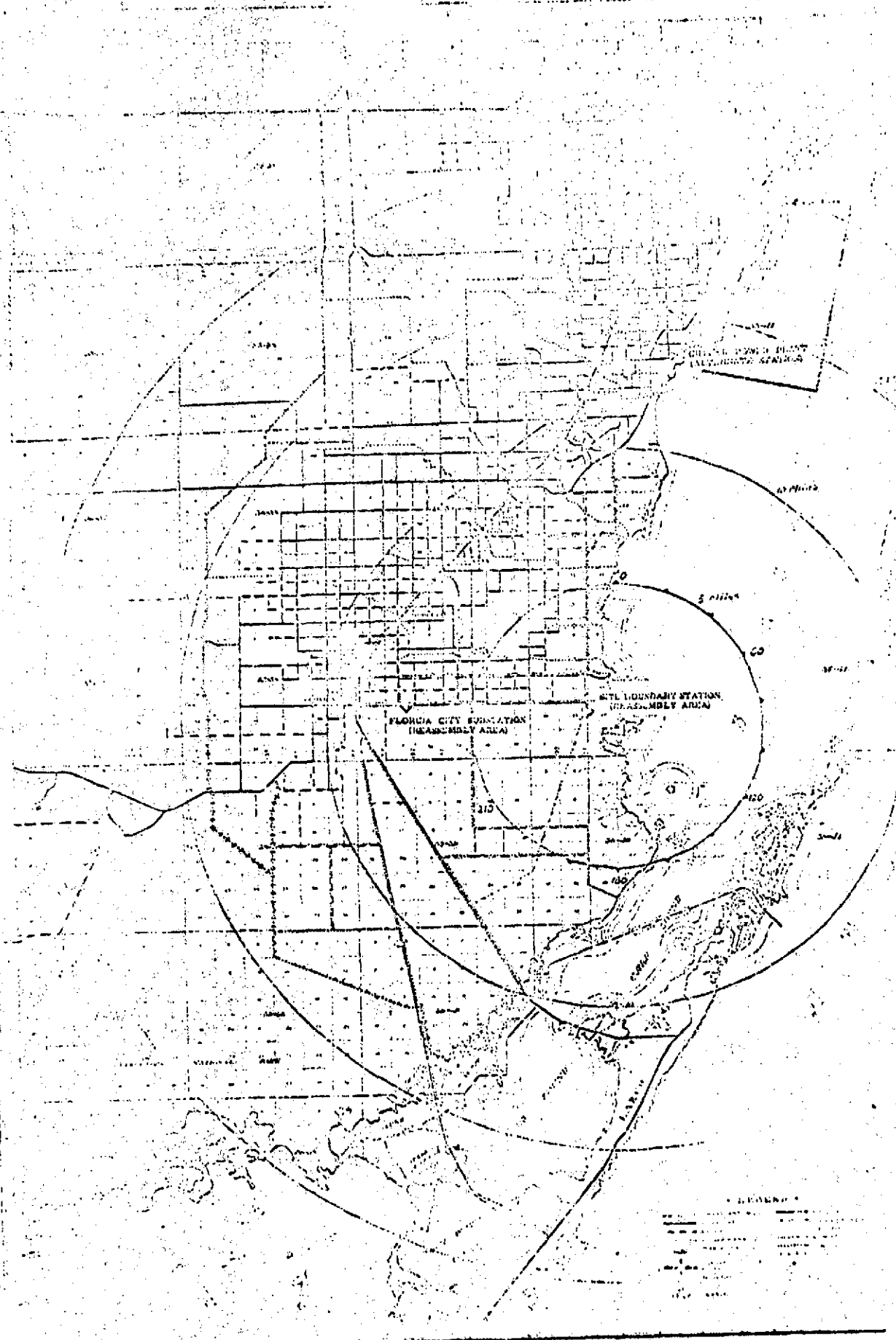


Figure 1.
Map showing
Area Surrounding
Turkey Point.

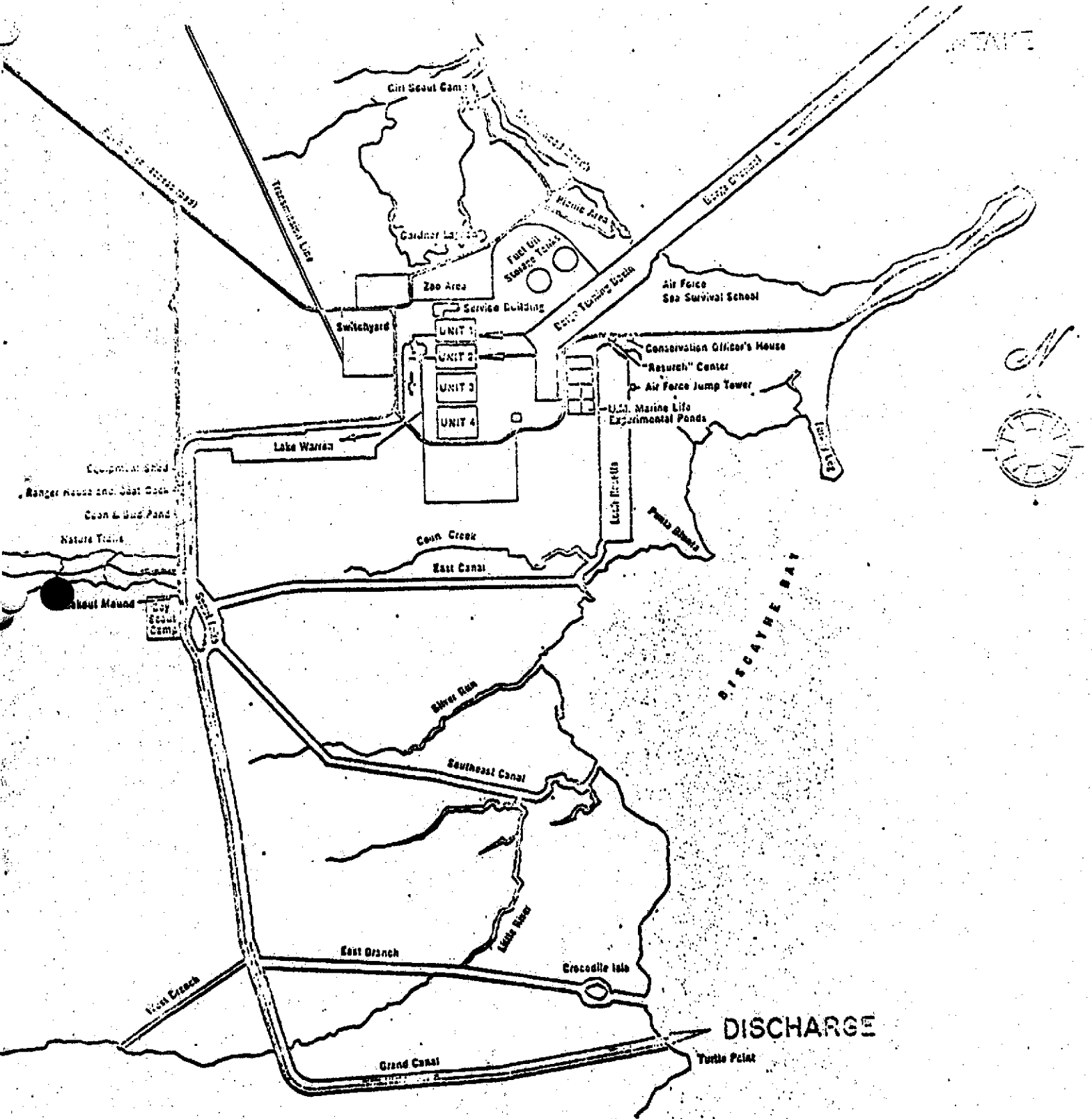


Figure 2. Once-Through Cooling Flow for Units 1 & 2.

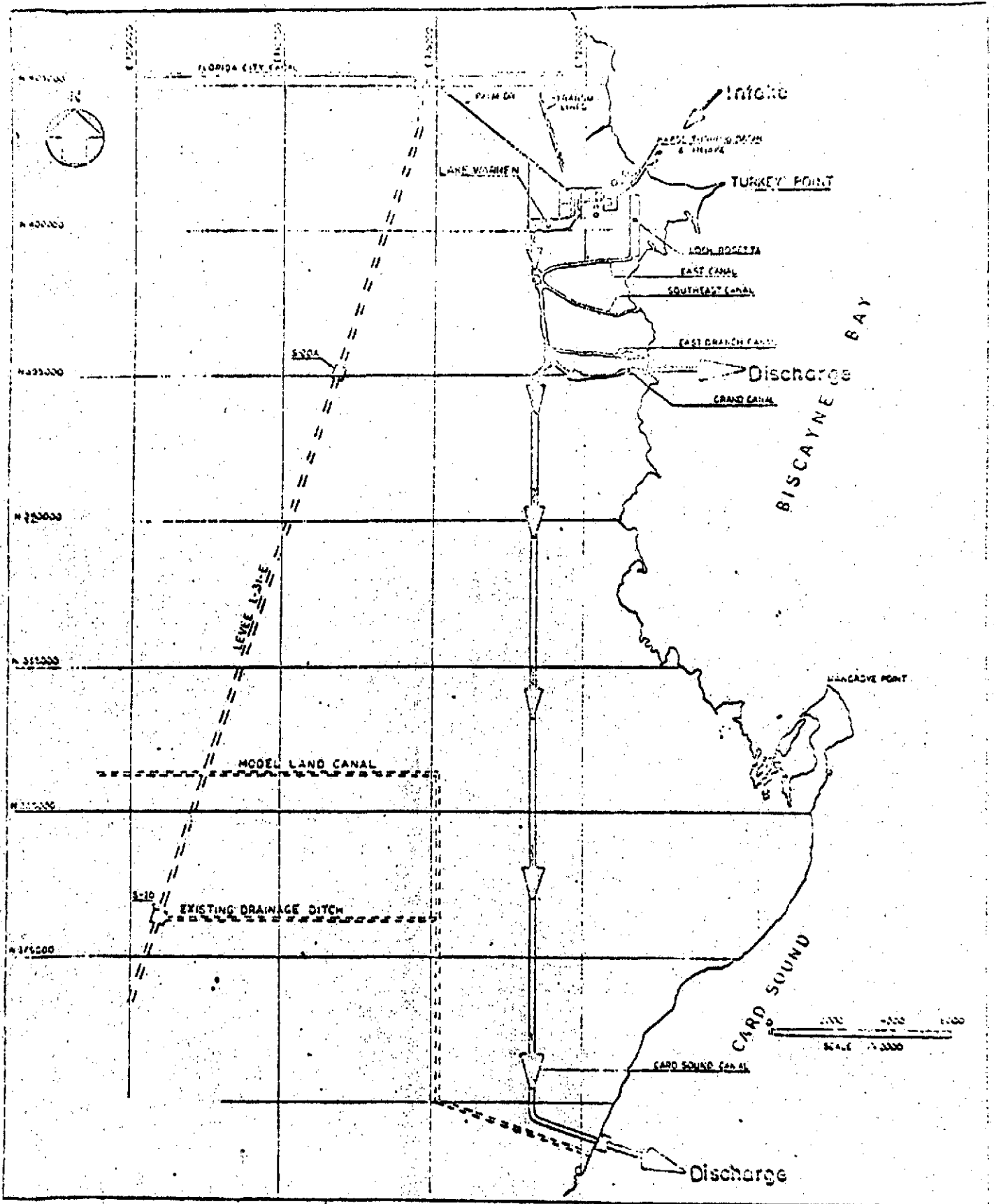


Figure 3. Once-Through Cooling Flow Circuit for all 4 Units.

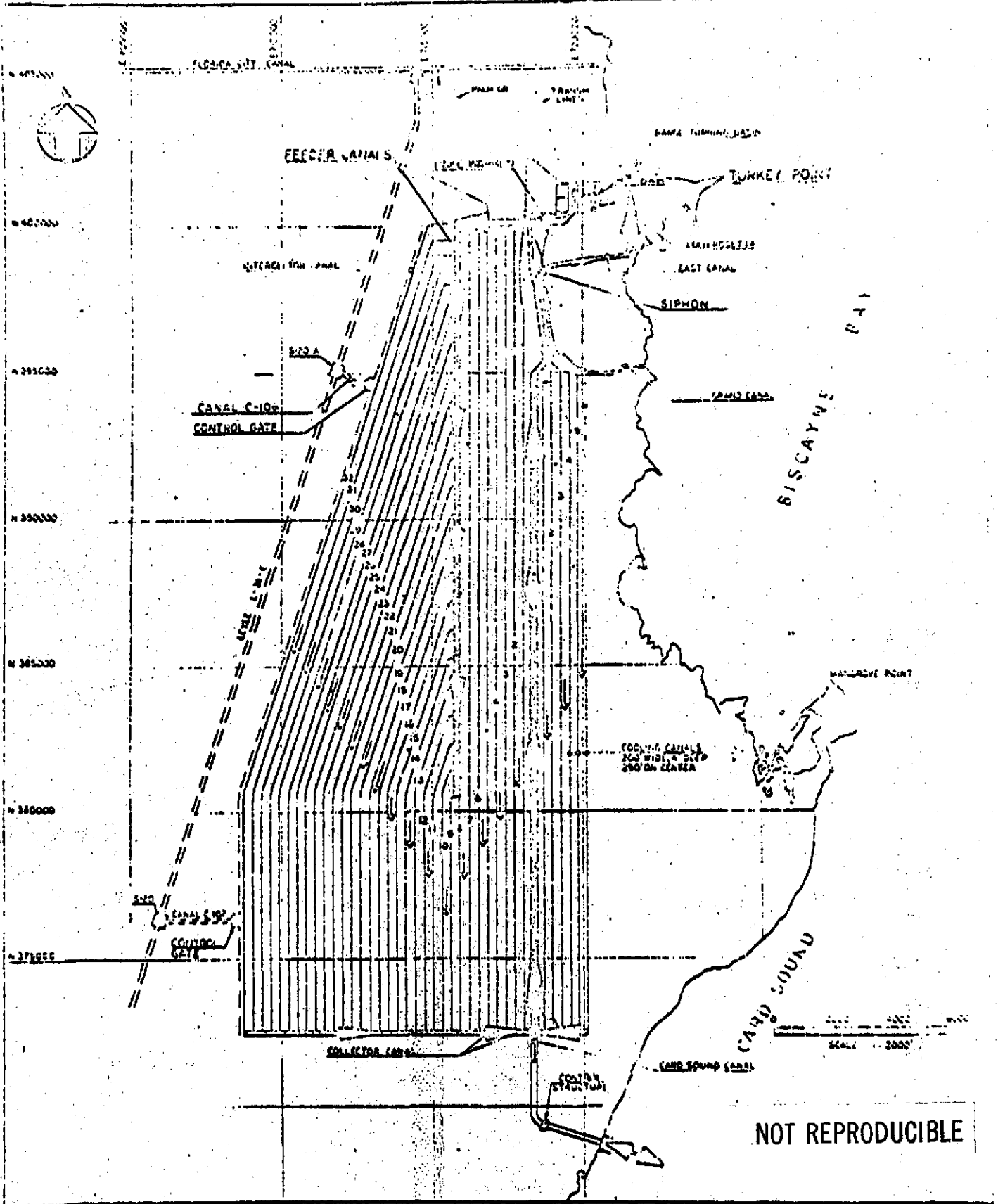


Figure 4. Completed, Closed-Loop, Recirculating Cooling Reservoir for all 4 Units.

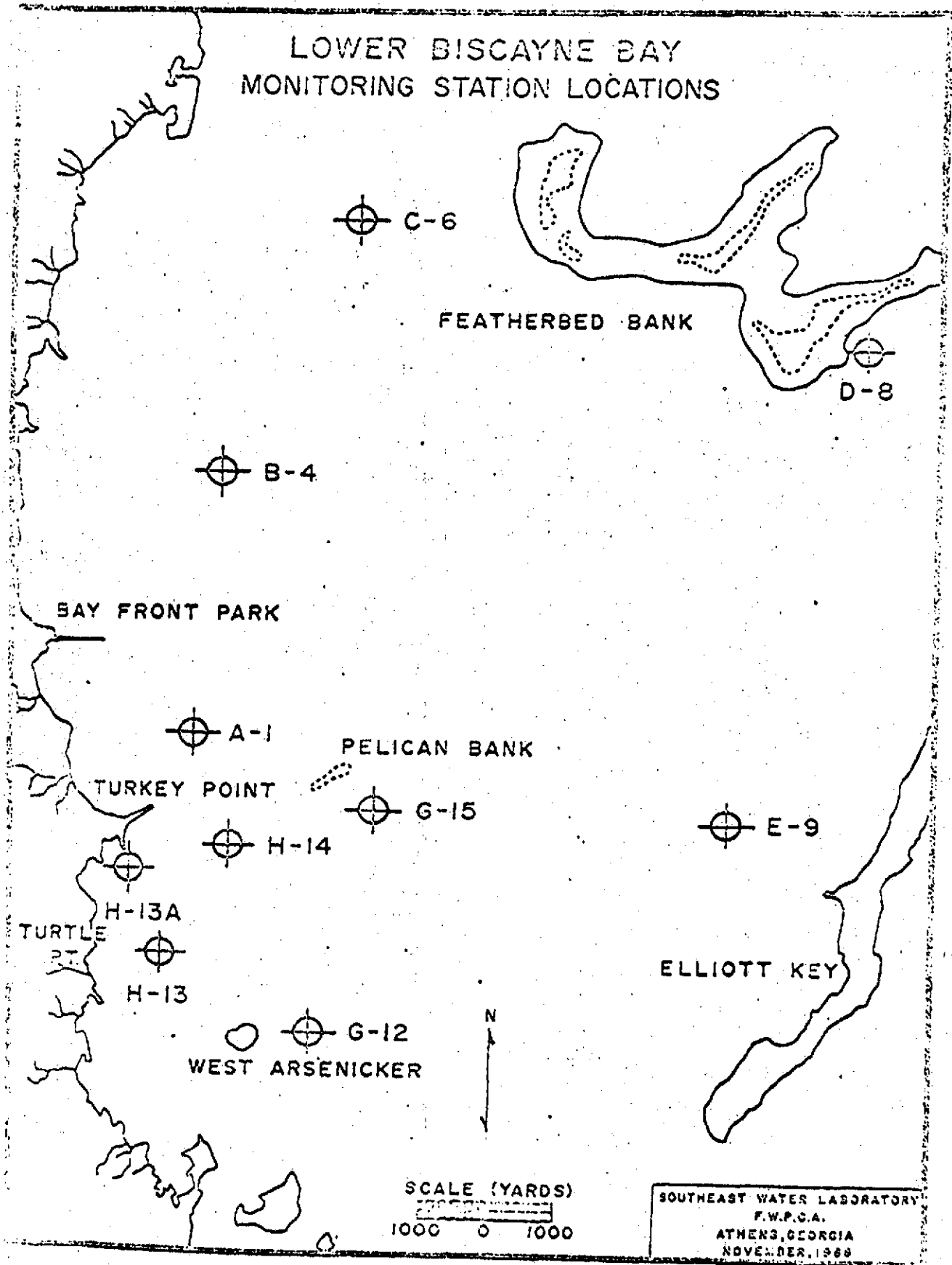
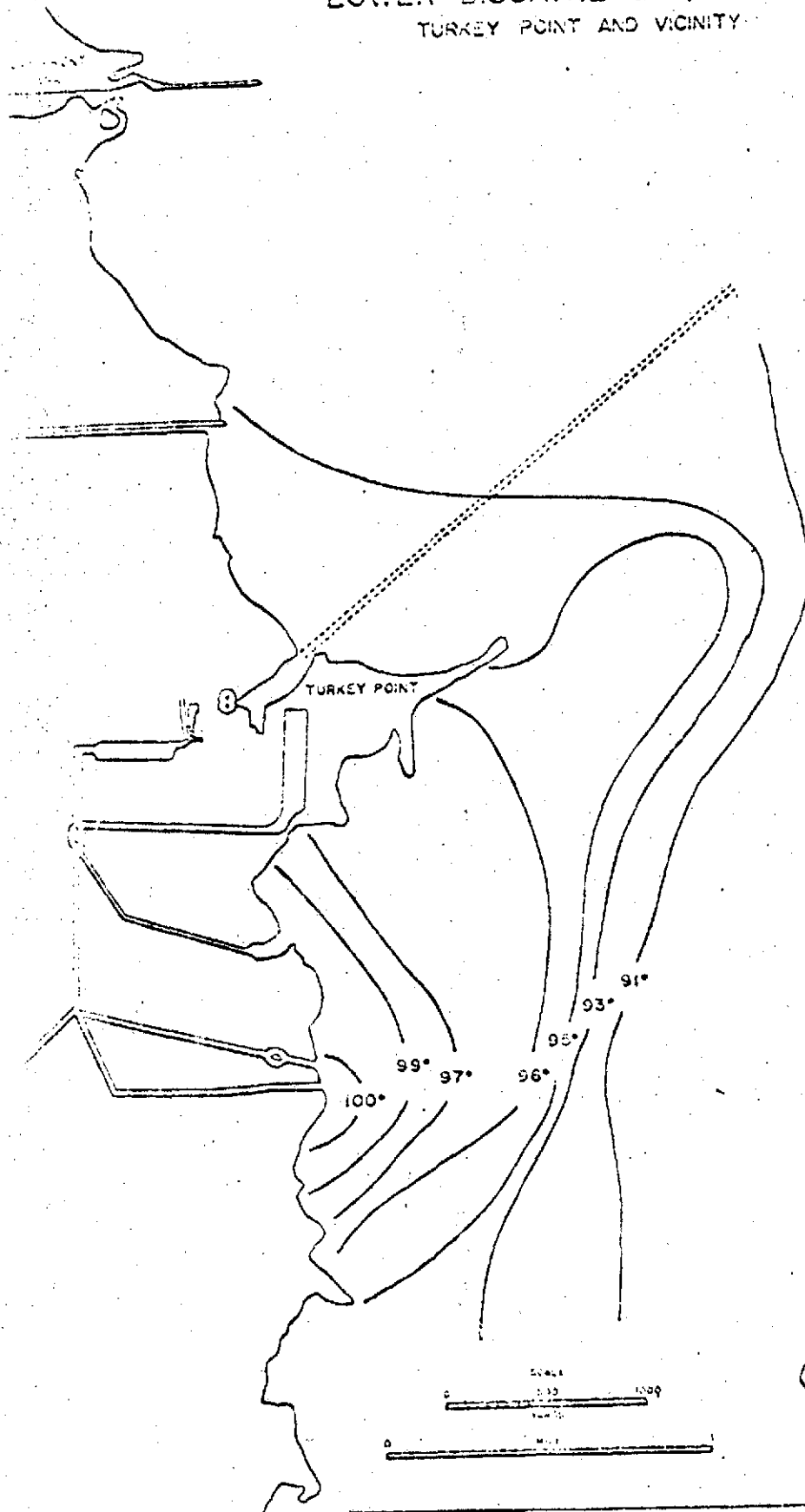


Figure 5.

Figure 6.

-92-

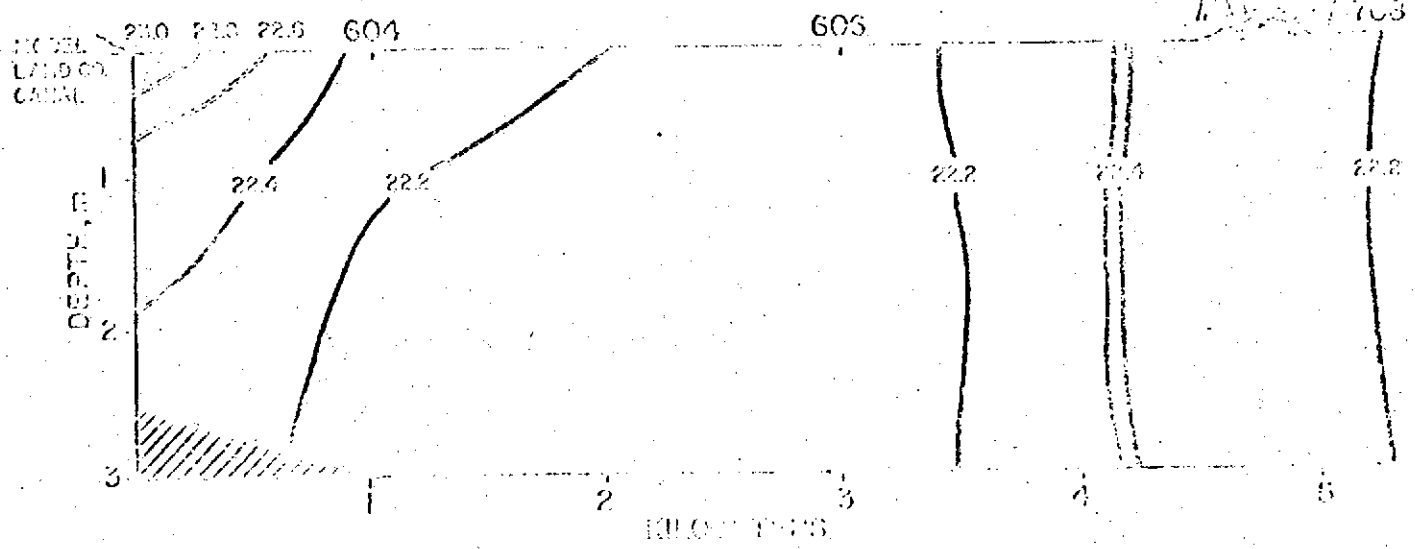
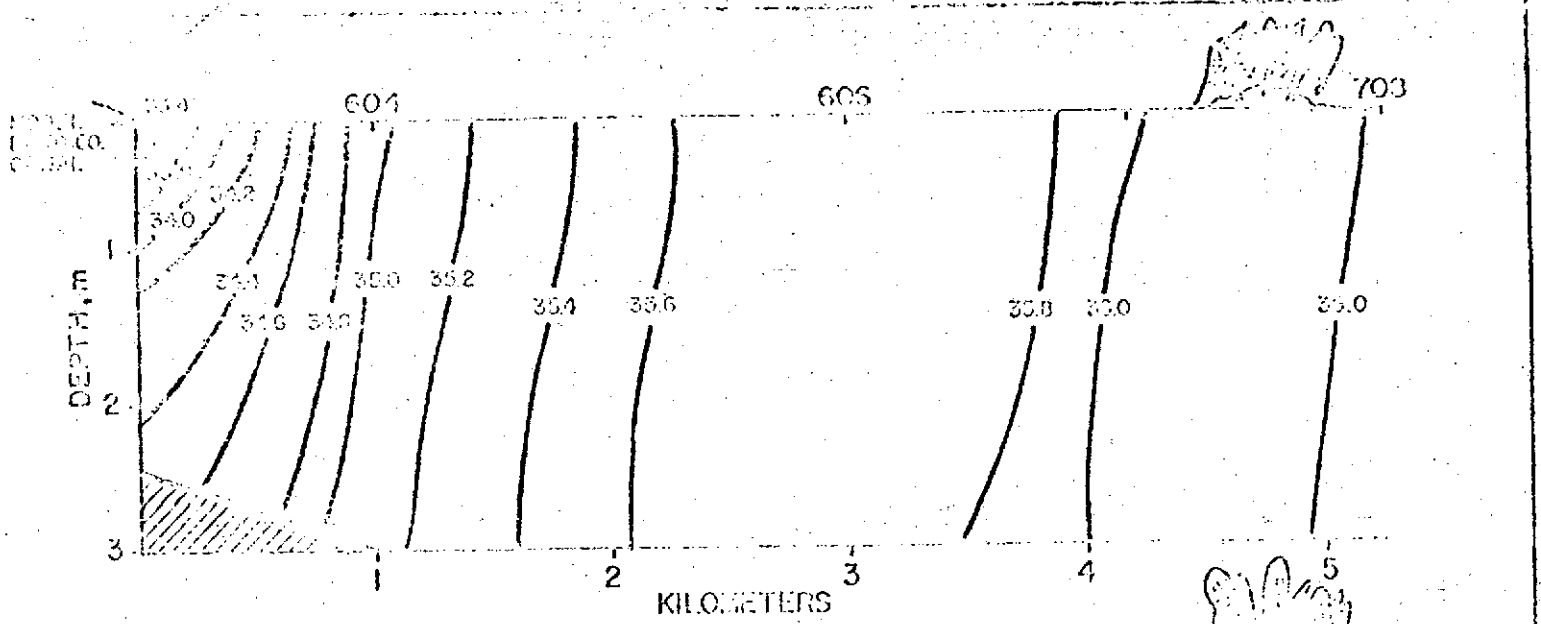
LOWER DISCAYNE BAY, FLORIDA
TURKEY POINT AND VICINITY



7/26/65
TIME 1740 - 1900
HIGH TIDE 254
LOW TIDE 1906

WEST
ARDENCKER

NAVY
ATLANTA, GEORGIA
NOVEMBER, 1965



7.

(C) 1970-1971 (6-1) 11/10/71

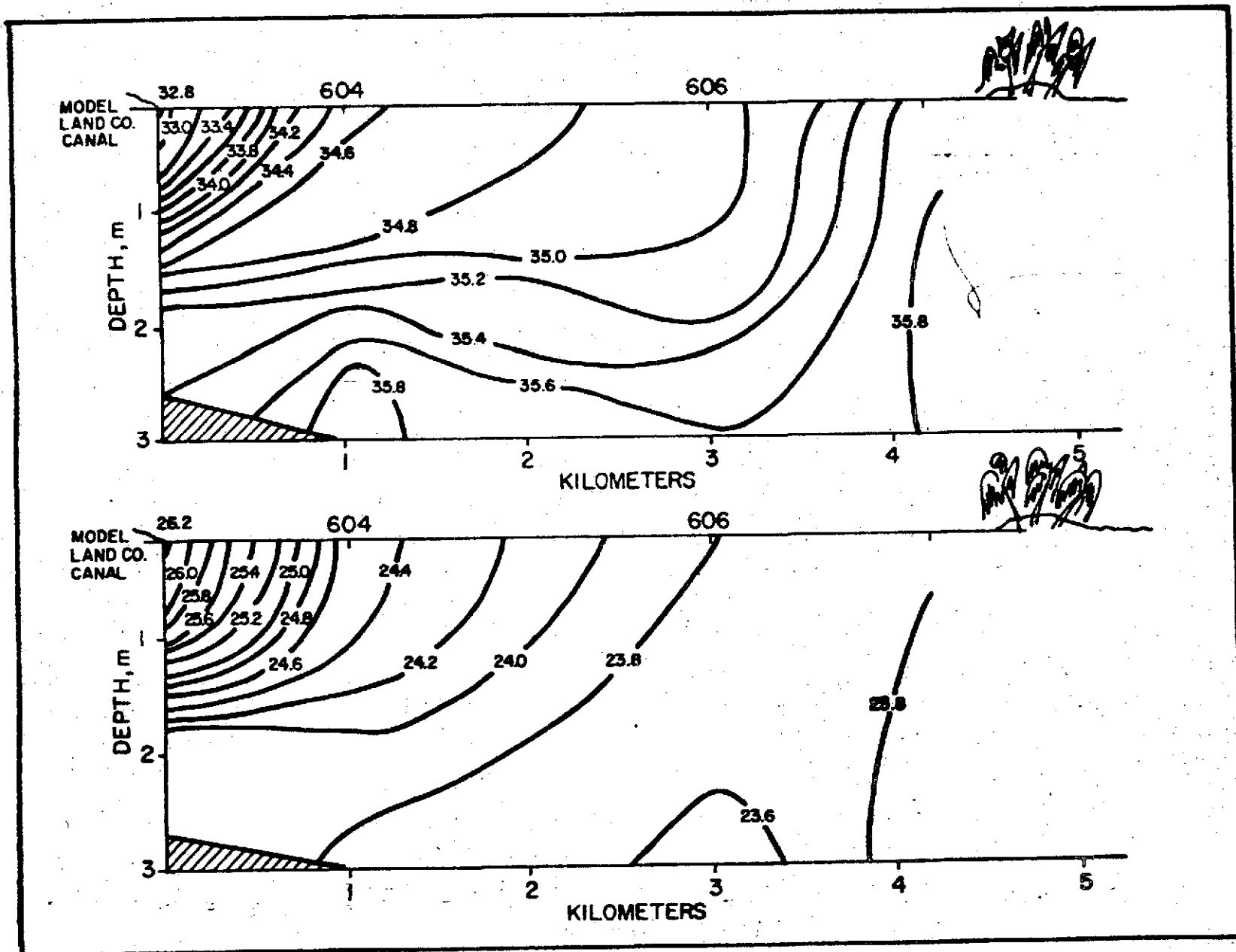


FIGURE 8. Temperature ($^{\circ}\text{C}$) and salinity (ppt) sections across Card Sound 2/18/72.

REFERENCES

1. "Report on Thermal Pollution of Interstate Waters of Biscayne Bay, Florida", U.S. Dept. of the Interior Federal Water Pollution Control Administration., Feb. 1972.
2. "Temperature Predictions at Mouth of Planned Discharge Canal in Card Sound, Turkey Point Facility", Dept. of Coastal and Oceanographic Engineering, University of Florida, Nov. 1970.
3. "Addendum to Turkey Point Water Temperature Study: Prediction of Water Temperature Resulting from Plant Discharge, August, 1968, Meteorological Conditions", Dept. of Coastal and Oceanographic Engineering, University of Florida, March 1970.
4. "Recirculation and Temperature Field Consideration: Turkey Point Facility", Dept. of Coastal and Oceanographic Engineering, University of Florida, April, 1969.
5. "An Ecological Study of South Biscayne Bay and Card Sound, Florida". Rosenstiel School of Marine and Atmospheric Science, University of Miami, June 1972.
6. "The Engineering Design of the Turkey Point Cooling Reservoir", Florida Power & Light Company, Environmental Engineering Technical Report No. 72-8, June 1972.
7. "Temperature Studies Lower Biscayne Bay, Florida", L.B. Tebo, Jr., et al., U.S. Dept. of the Interior Federal Water Pollution Control Administration, Oct. 1968.

2. The Hutchinson Island Nuclear Power Plant of the Florida Power and Light Company

The Hutchinson Island Nuclear Power Plant site consists of approximately 1,132 acres on Hutchinson Island in St. Lucie County about halfway between Fort Pierce and Stuart on the east coast of Florida. The site is generally flat, covered with water and has a dense vegetation characteristic of Florida coastal mangrove swamps. Two identical units will provide 850 MWe each at full load. The pressurized water reactors will be supplied by Combustion Engineering Incorporated. The first unit is presently scheduled to enter service by September 1975. The second will follow suit by September 1979.

The circulating water system consists of intake and discharge pipes in the ocean with canals to the plant. Pumps at the intake structure provide 1180 cfs of flow. The maximum design temperature rise of the condenser cooling water, at 850 MWe, will be approximately 24°F. However, the temperature rise for normal full load operation (745 MWe) will be 21°F. The temperature rise averaged over a day will be less than 21°F because of the daily cyclic loading of the plant. The condenser cooling water will be withdrawn from the Atlantic Ocean through two 10.5 ft. I.D. pipelines originating 1200 ft. offshore in about 18 feet of water. Because each intake pipe requires a vertical section to prevent sanding, and a velocity cap to minimize fish entrapment, there will be about 8 ft. of water over the top of each velocity cap. These caps will insure a horizontal velocity field in the vicinity of the pipes' inlets and limit the approach to about 2 fps.

The intake pipes will be located approximately 2300 ft. south of the discharge pipe. They will be buried from the intake points for a distance of about 1600 ft. beneath the ocean bottom and under the beach, terminating in a canal on the west side of the sand dunes. After passing through the intake pipes at about 6 fps, the circulating water will be conveyed in a canal about 900 ft. to State Road 41A and will pass under this road through culverts.

After passing under the road, the water will be conveyed in a canal at about 2 fps for approximately 4000 ft. to the plant intake structure.

From the turbine building, the discharged condenser cooling water will be transported approximately 500 ft. in a buried pipeline and then about 600 ft. in a canal to State Highway 1A. The water will be carried under 1A in culverts. Once past 1A, the cooling water will travel about 1200 ft. in a canal to an outfall structure, located on the western side of the sand dune line. From the canal outfall structure, the cooling water discharge will be carried in a 12 ft. diameter pipeline about 1425 ft. long, buried under the dunes, the beach and beneath the ocean bottom. The pipeline will terminate at a depth of 18 ft. (MLW). At its termination, the 12 ft. diameter pipe will be modified with a short transition section and a two port Y-type discharge will be added. Approximately 20 ft. of water will be over the top of each port. Both ports in the Y will be 7.5 ft. in diameter and the discharge velocity from each port will be about 13 ft. per sec (fps.). A short sloping trench will be excavated from the invert of the ports, daylighting at the natural ocean bottom. The trench will be lined to prevent scour from the jet discharges.

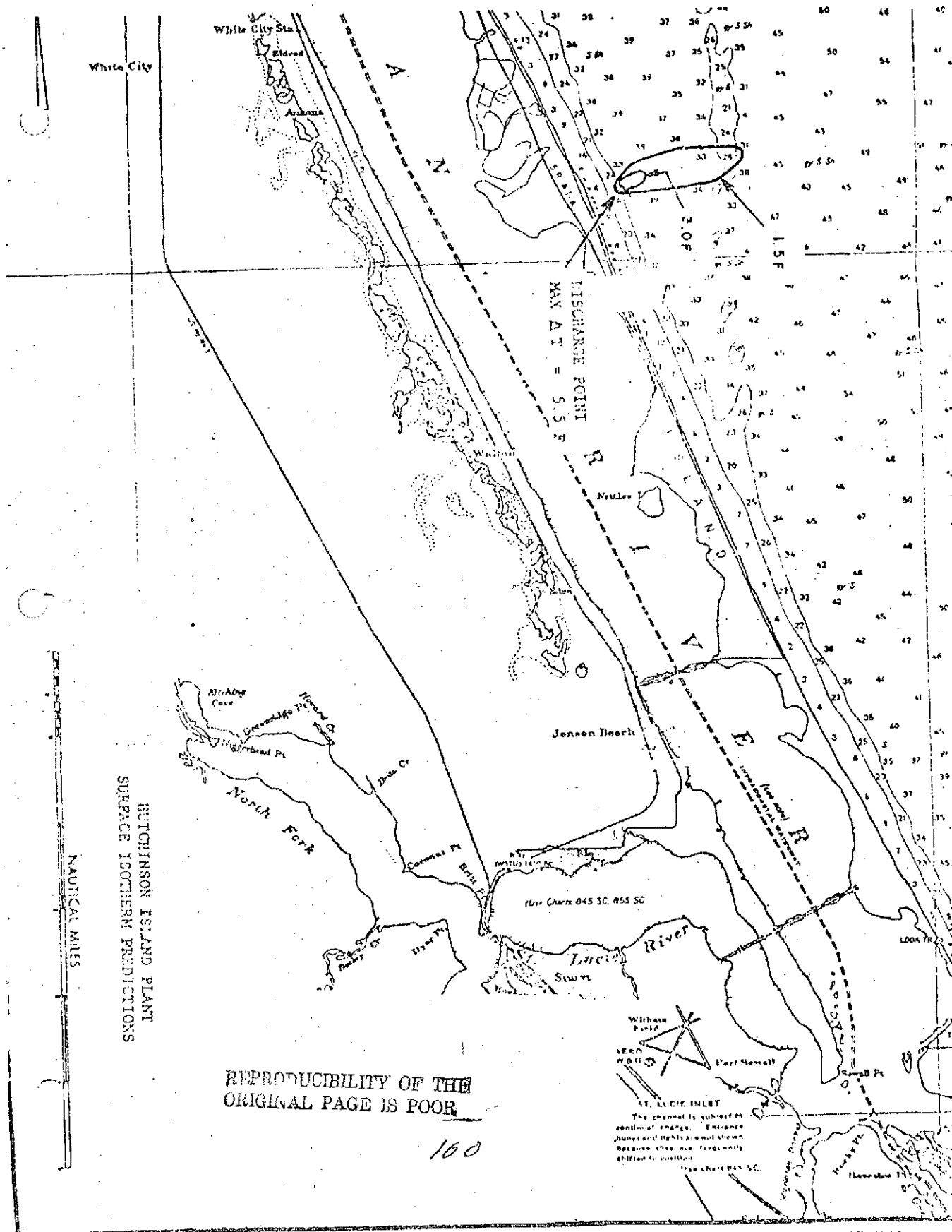
Florida Power & Light Company has sponsored some environmental studies offshore of Hutchinson Island. A summary of these studies is given below.

- a. During an 18 month period from early 1969 to the spring of 1970 the Department of Coastal and Oceanographic Engineering, of the University of Florida, Gainesville, Florida, conducted hydrographic measurements offshore of Hutchinson Island. A short term dye release study and current monitoring program was conducted by the University. This study determined that the littoral current is variable and weak, generally resulting in a net southerly drift current of about 0.2 fps. About 55 percent of the time the current went to the south, at a

velocity of up to 1.2³ fps and typically 0.6 fps or less. During 25% of the time, the current flowed northward at a velocity up to 6 fps and at an average of 0.2 fps. Results of the short dye release program, conducted during this study, yielded a lateral dispersion coefficient of about 1.1 ft²/sec.

- b. A biological survey by James B. Laskey included physical sampling and analysis of plankton and benthos in both the Indian River and the ocean offshore Hutchinson Island. Surveys were conducted in February and June of 1969 and April 1970. Results of the ocean sampling indicated a scarcity of bottom biota in the ocean offshore Hutchinson Island. The nutrient levels in the ocean were found to be low. No organic silt interface was found on the ocean bottom and phosphate levels in the upper waters were low. Plankton was diverse in species but very sparse in number.
- c. A 28-day dye release program was conducted in the ocean offshore of Hutchinson Island during July and August 1970. The study was conducted by Dr. J. H. Carpenter of the Chesapeake Bay Institute. Temperature and salinity measurements indicated that no well defined thermocline or holocline existed in the water off Hutchinson Island during the survey period. This confirmed the results of the previous studies.
- d. On August 24, 1970, FPL initiated a long term temperature monitoring program in the ocean offshore Hutchinson Island. Two Ryan recording thermographs were installed approximately 2000 feet offshore in a depth of 30 ft. The Thermographs were placed at the top and bottom of the water column and were used to determine maximum water temperature, and the existence of a thermocline. Data so far obtained confirms the lack of a thermocline.
- e. FPL is sponsoring a hydraulic model study of subaqueous

buoyant jet discharges. The model study is being conducted by the Coastal and Oceanographic Engineering School of the University of Florida under the supervision of Ebasco's Environmental Engineers. The results of this study are included in the plants' environmental report.



White City

White City Sta

Golden

Anchor

5.5 F
2.0 F
1.5 F

DISCHARGE POINT
MAX Δ T = 5.5 F

Jonson Beach

HITCHINSON ISLAND PLANT
SURFACE ISOTHERM PREDICTIONS

NAUTICAL MILES

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160

Witham Field

SEAS 4.0 FT

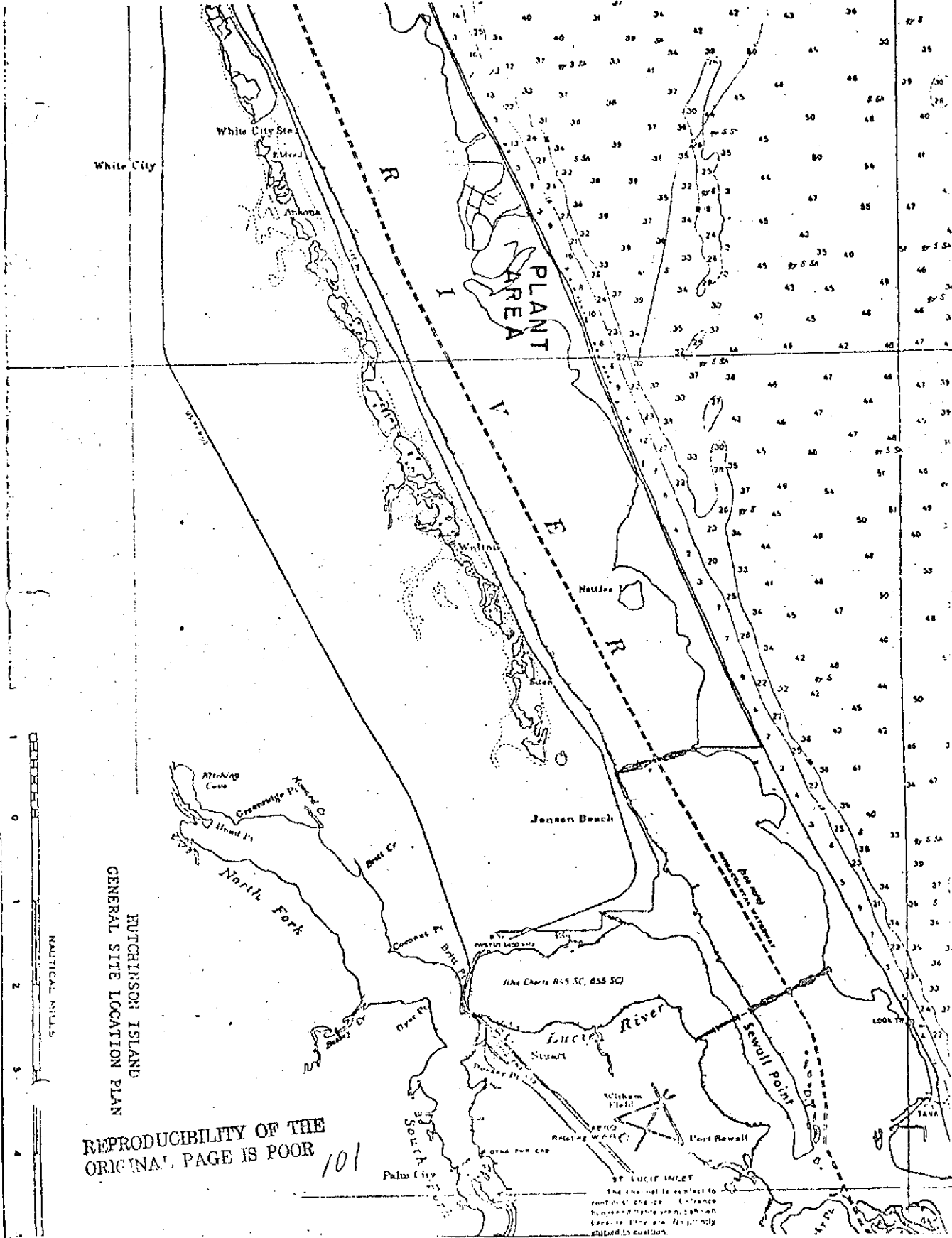
Port Howell

ST. LUCIE INLET
The channel is subject to continual change. Entrance points and lights are not shown because they are frequently shifted to maintain

Light Chart 685 SC.

Light Chart 685 SC.

Light Chart 685 SC.

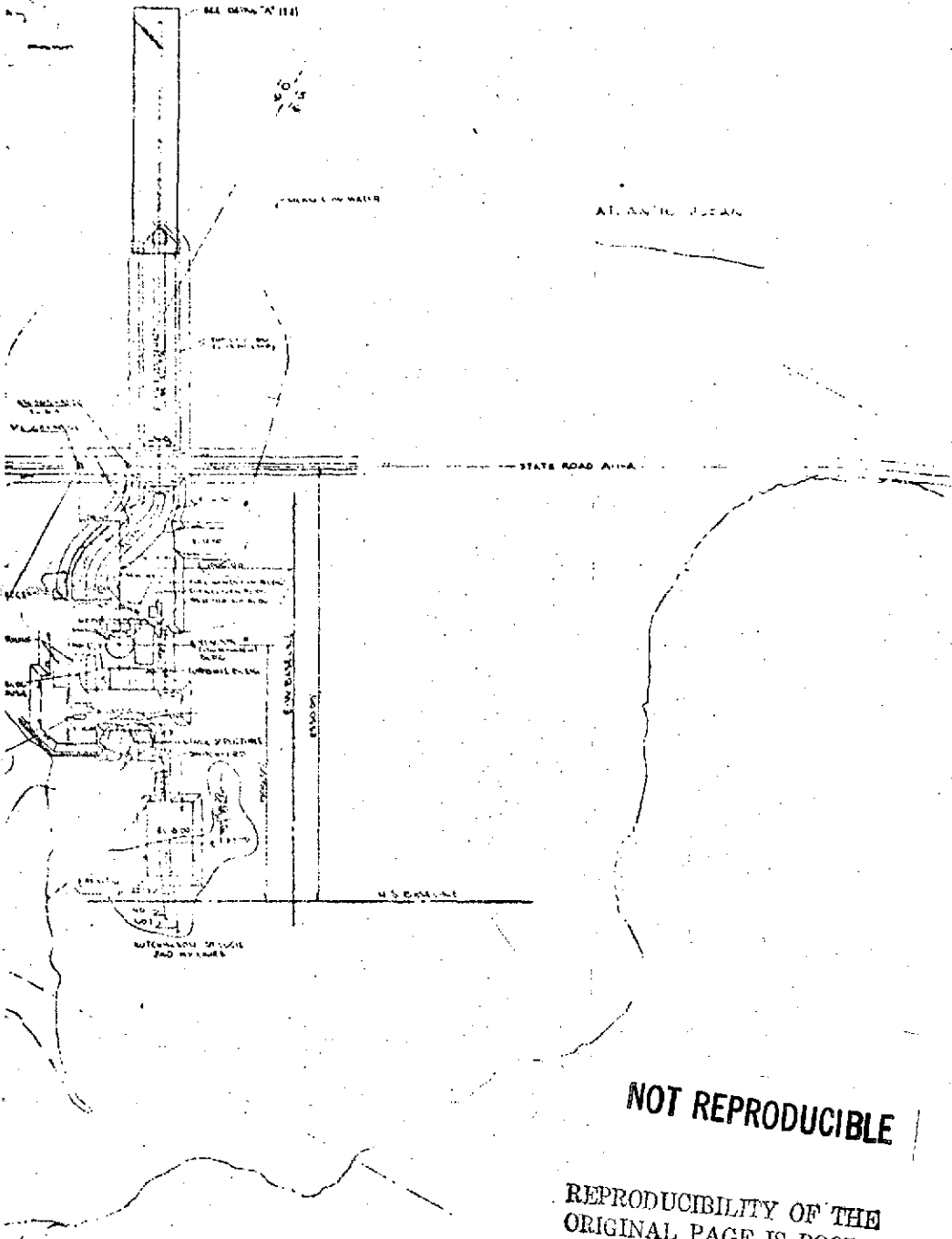


HUTCHINSON ISLAND
GENERAL SITE LOCATION PLAN

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101

9 10 11 12 13 14 15 16 17 18 19



NOTE
 1- PLANT DATA SHALL BE KEPT UNLIMITED
 IN ATLANTIC OCEAN EL. 0.00'
 2- COORDINATES ARE BASED ON STATE PLANNING
 COORDINATE SYSTEM, EAST ZONE

NOT REPRODUCIBLE

REPRODUCIBILITY OF THE
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102

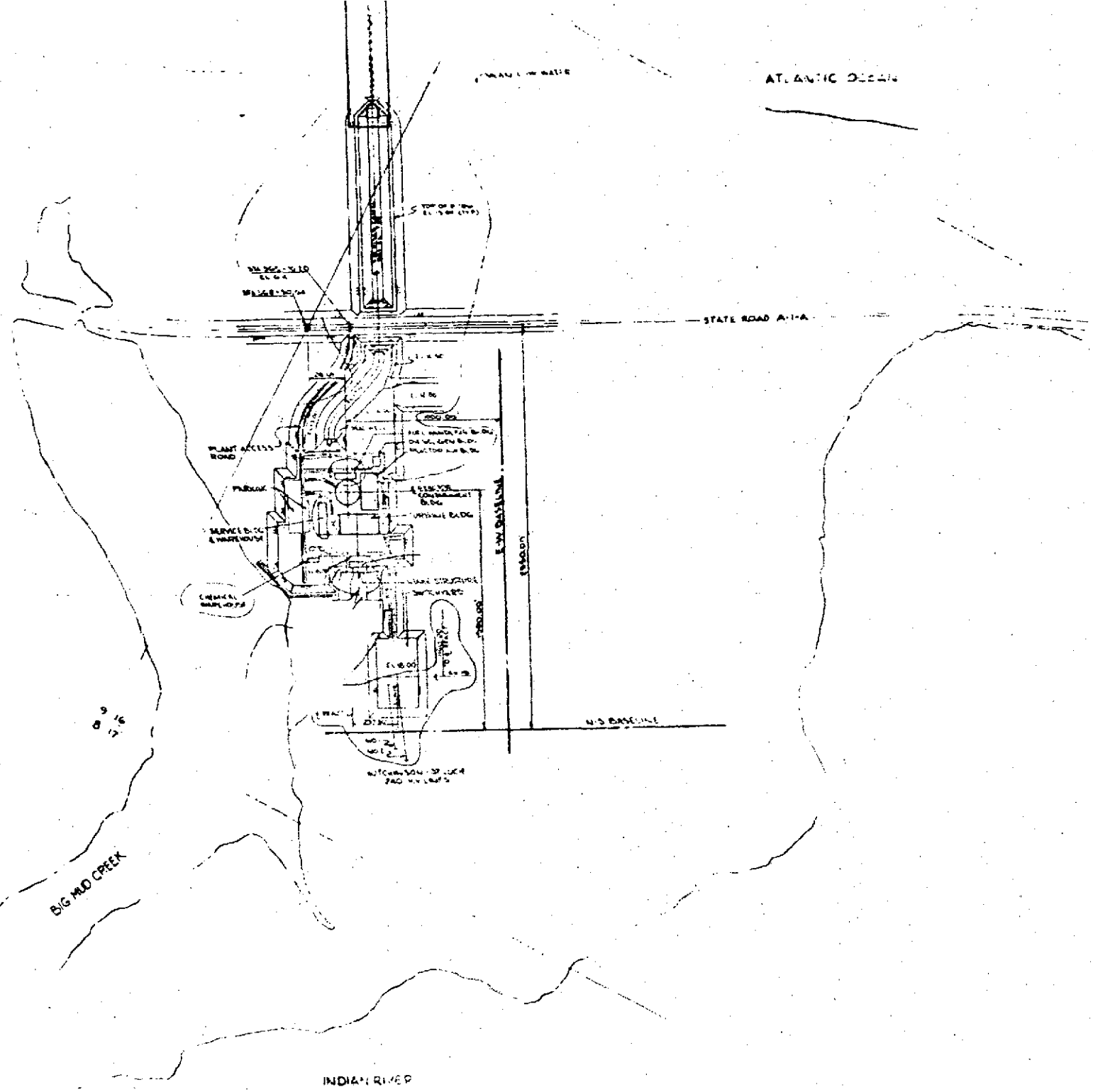
0 100 200 300 400 500

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FLORIDA POWER & LIGHT COMPANY
 HUTCHINSON ISLAND UNIT NO. 1
 CIRCULATING WATER DISCHARGE SYSTEM

INVERTED

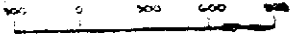
9 10 11 12 13 14 15 16 17 18



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-103-

NOTE
1. PLANT DETAILS SHALL BE WITH LOW WATER
IN ATLANTIC OCEAN EL. 0.00
2. COORDINATES ARE BASED ON STATE
COORDINATE SYSTEM, EAST ZONE.



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FLORIDA POWER & LIGHT COMPANY
MUTCHINSON ISLAND UNIT NO. 1
2ND WATER DISCHARGE STRUCTURE

B. GEOGRAPHICAL REGION: ATLANTIC COAST

1. Brunswick Steam Electric Plant of Carolina Power and Light Company.

The Brunswick Plant is located near Southport, North Carolina at the Cape Fear estuary. The geography of the plant site is shown in the map attached below. The plant consists of two units, each with 821 MWe capacity. The reactor is of boiling water type, supplied by the General Electric Company. It is expected to be operated by December of 1974. A brief description of the plant's circulatory water system is given below.

The circulatory water is conveyed by a system of canals to a pumping station located near the beach. The water is then pumped to the outfall area through two 13 foot diameter pipes where it is released as a high momentum jet stream approximately 2000 feet offshore. A copy of the outfall topography is attached.

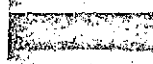
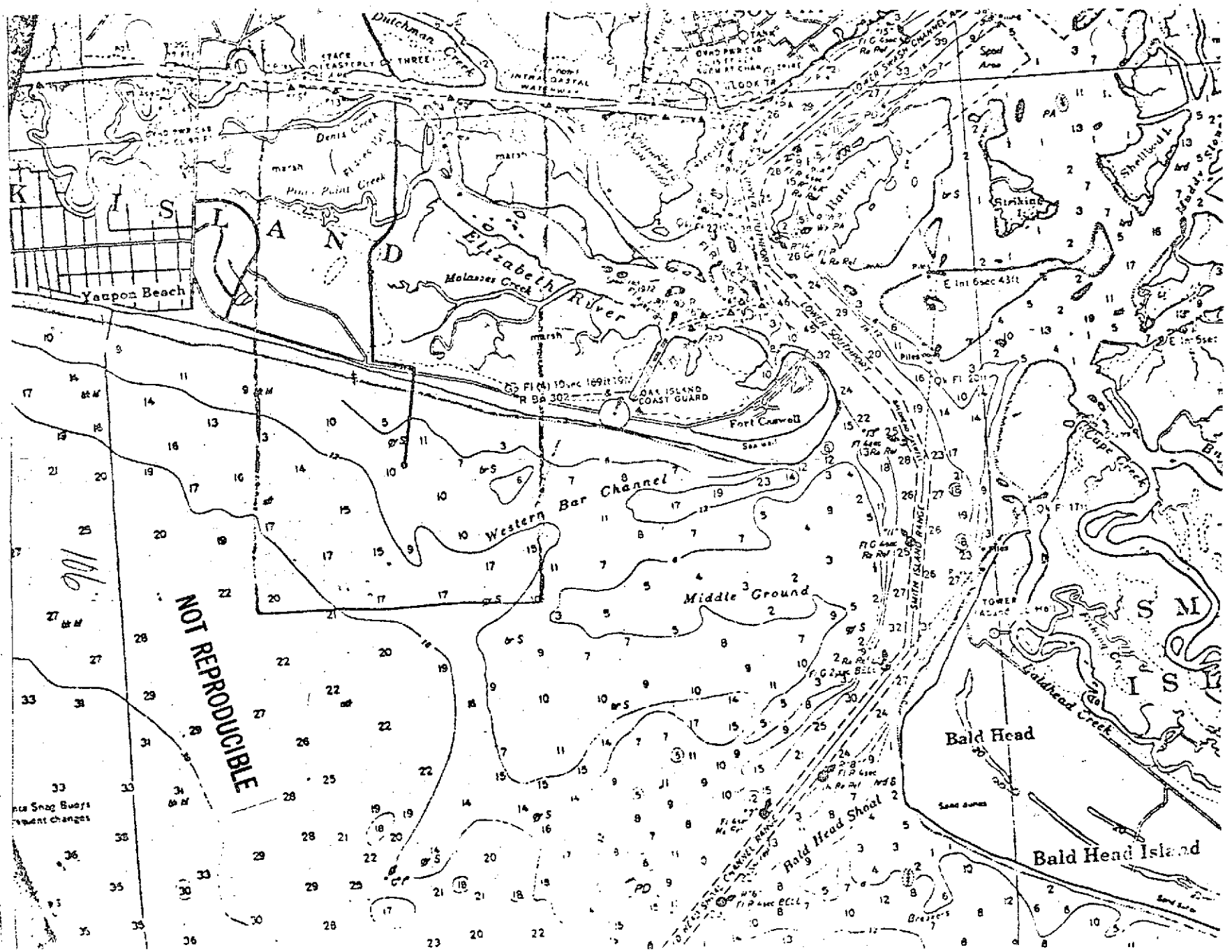
The plant has been designed for a circulating water flow of 2750 cfs and a discharge velocity into the ocean of 10 fps.

The temperature of the circulating water at the outfall will be about 18 degrees Farenheit above ambient water temperature as a result of plant operation. Typical surface ambient temperatures observed in the area of discharge are given below.

January	11.0°C	(51.8°F)
April	10.2°C	(61.2°F)
June	20.2°C	(79.2°F)
August	28.5°C	(83.3°F)
October	21.7°C	(71.1°F)

A field study on the discharge area was undertaken during July 1969 by Dr. James H. Carpenter. The field program consisted of (a) continuous discharge of a tracer material (30% rhadamine B solution) at the proposed outfall and measurements of its distribution, and (b) temperature and salinity measurements at stations

along transects through the outfall area. The salinity measurements showed that significant quantities of the waters discharged from the Cape Fear estuary move westward along the shore off Oak Island. As a result, there was strong vertical density stratification in the discharge area. Figure 1 shows the location of the observation positions. The distribution of temperature and salinity of one experiment is given in figure 2 to illustrate the horizontal and vertical variations.



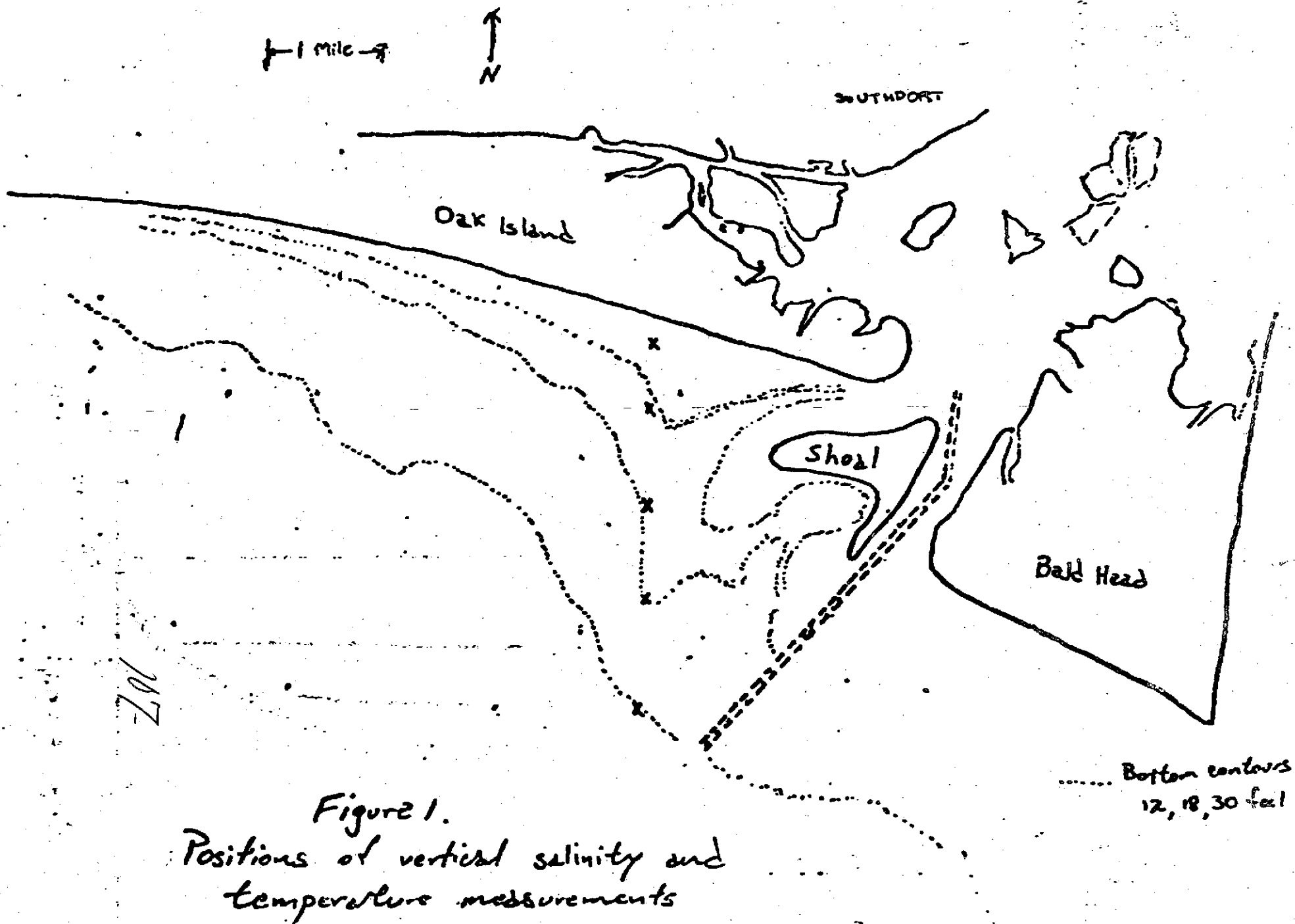


Figure 1.
Positions of vertical salinity and
temperature measurements

19 July, 1969 OBZ. - 7922 Wind 10kts SW

Distance offshore - miles

1 2 3 4

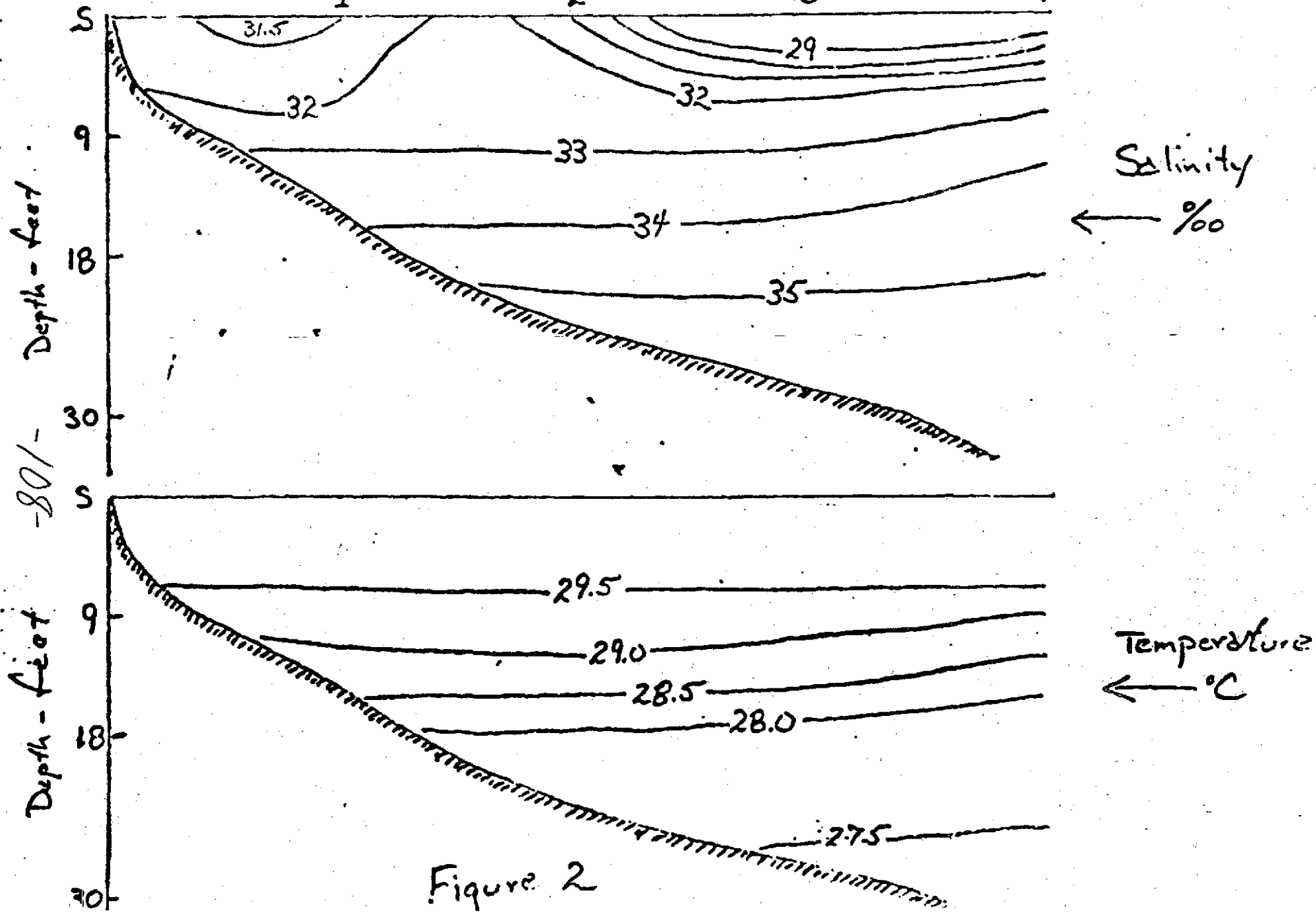


Figure 2

2. Long Island Lighting Co.

The Shoreham Nuclear Power Station of the Long Island Lighting Co. is located near Brookhaven, New York. The Boiling Water Reactors will be supplied by General Electric Co. The plant will produce 819 MWe and will begin commercial operation by June, 1973.

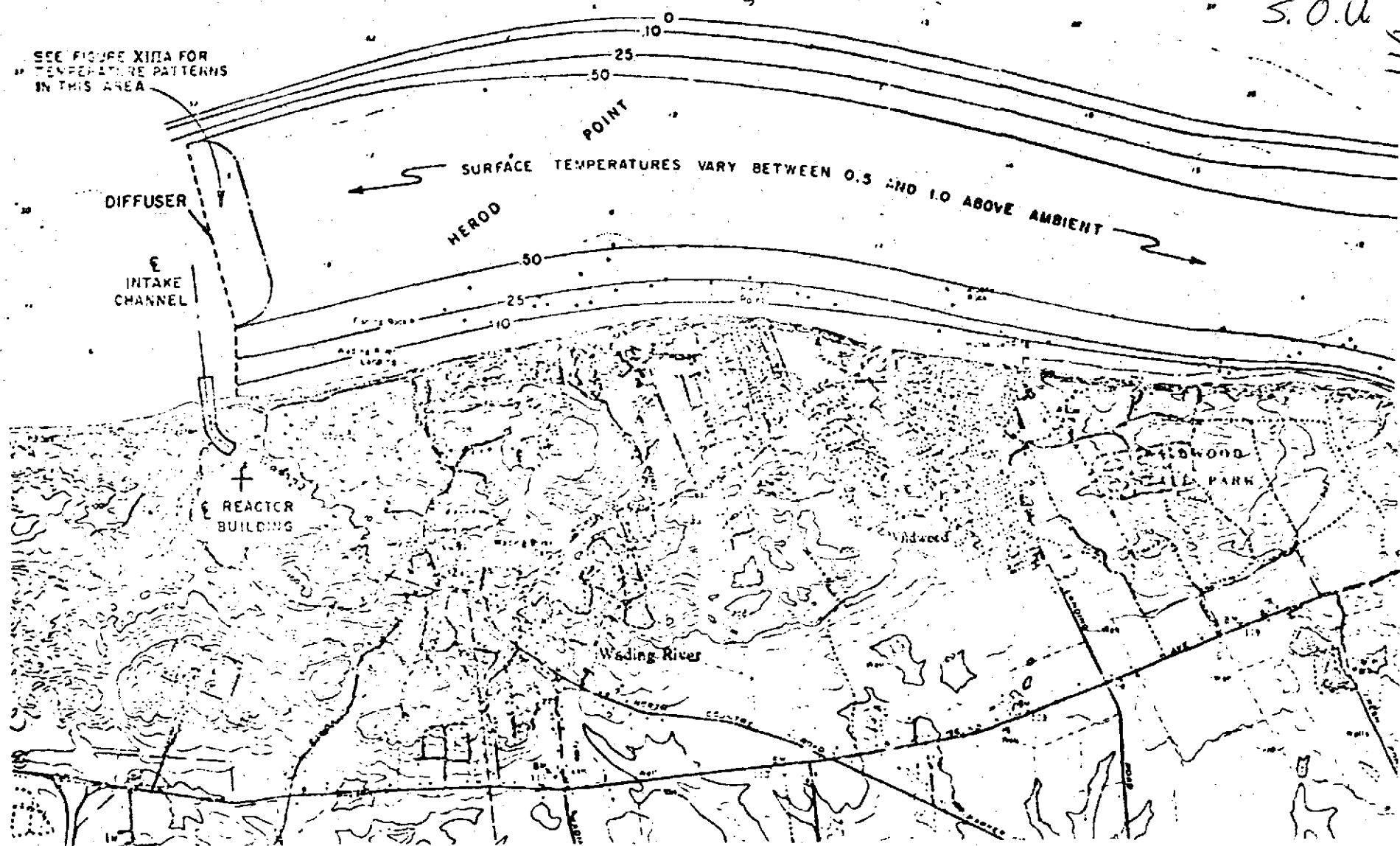
The circulating water system has been designed to meet the New York State criteria governing thermal discharges. A multiport diffuser has been selected as the discharge system to be employed. Mathematical and hydraulic modeling were undertaken to aid in the design process. Dynamic and dispersion characteristics of a three-dimensional and time dependent thermal discharge flow in an open body of water was considered. Accurate hydraulic modeling proved to be impractical and solution of the mathematical model could not be rigorous. A limited mathematical analysis coupled with distorted hydraulic modeling and field measurements were executed to estimate diffuser performance.

Analysis of the resulting data was used to predict the thermal field of the power plant discharge. The temperature rise of the discharge was assumed to be 19.7°F at full load discharge of 1320 cfs. Details and general topography of the discharge region may be found in the attached map.

L O N G S H O A L I S L A N D

S.O.U.
-110-

SEE FIGURE XIII A FOR TEMPERATURE PATTERNS IN THIS AREA



Predicted Isotherms at Shoreham Plant

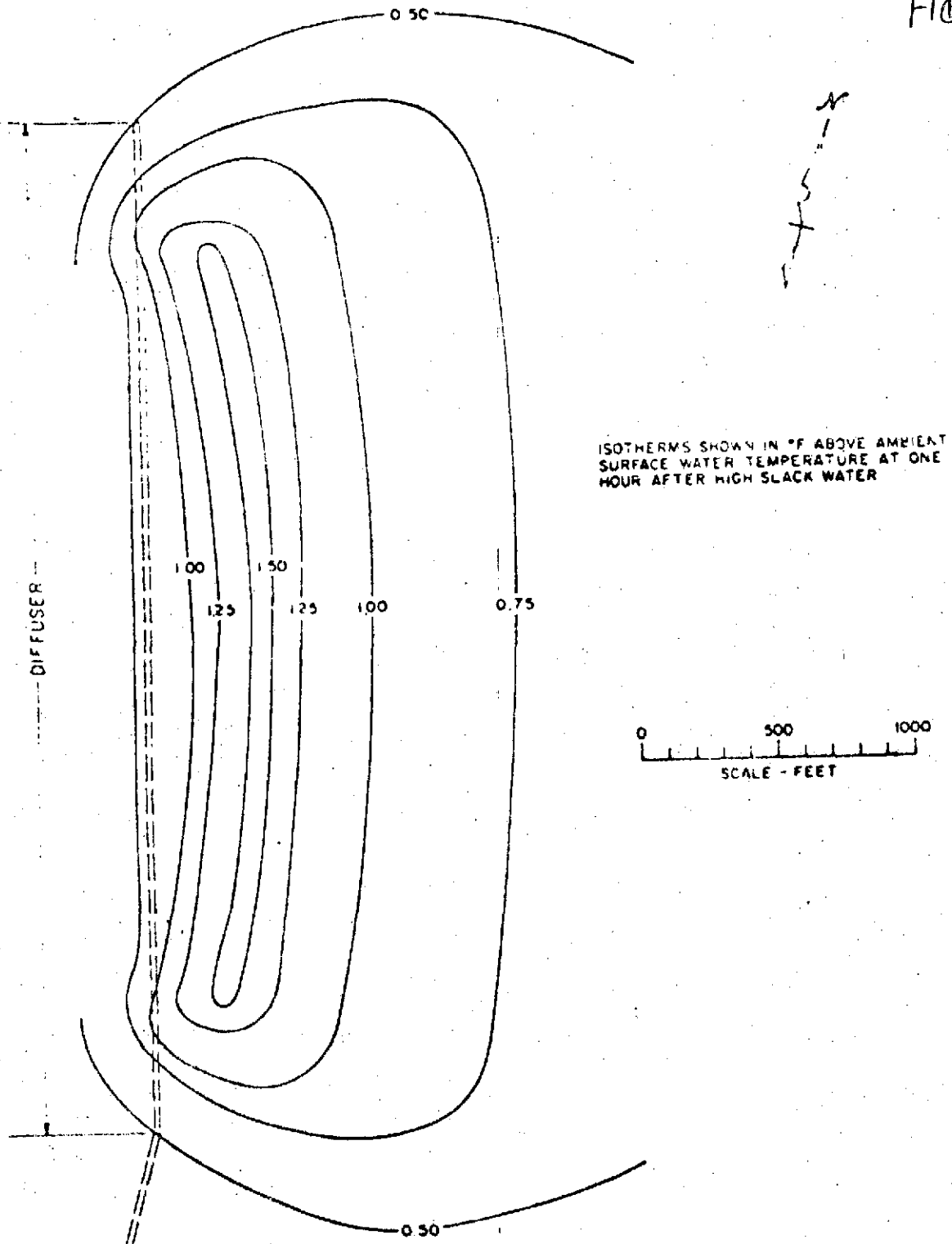
0 5000 10,000

SCALE - FEET

0 1 2

SCALE - NAUTICAL MILES

FIG IIIA



ISOTHERMS SHOWN IN °F ABOVE AMBIENT
SURFACE WATER TEMPERATURE AT ONE
HOUR AFTER HIGH SLACK WATER

**PREDICTED MAXIMUM SURFACE TEMPERATURE
IN NEAR FIELD FOR SEPTEMBER**

ENGINEERING REPORT ON
CIRCULATING WATER DISCHARGE SYSTEM
SHOREHAM NUCLEAR POWER STATION
LONG ISLAND LIGHTING COMPANY
STONE & WEBSTER ENGINEERING CORPORATION

FEBRUARY, 1971

-111-

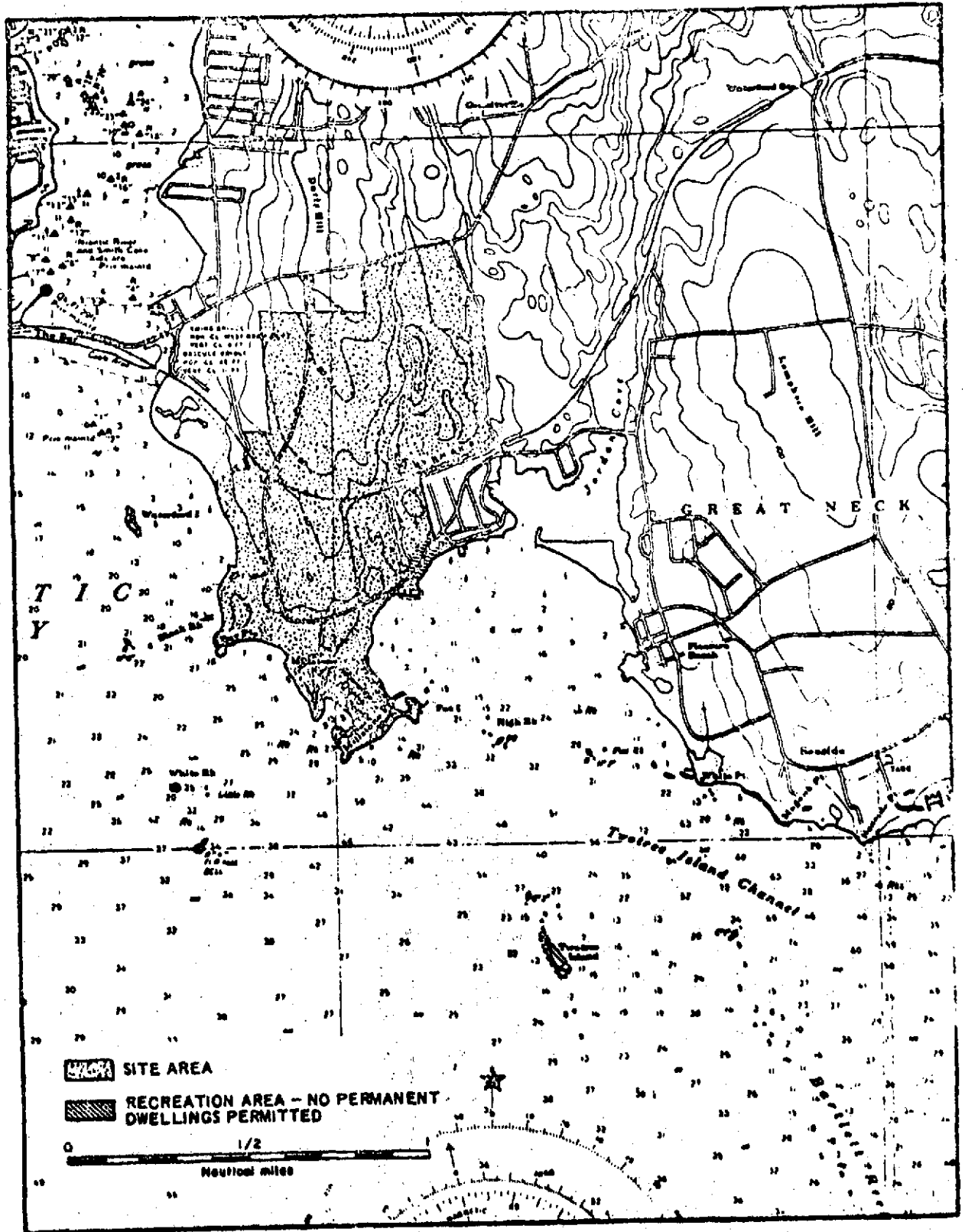
3. Northeast Utilities

The Millstone site of the Northeast Utilities Association is located near Waterford, Connecticut. The site will eventually contain three nuclear generating units with a total output of 2630 MWe.

Unit 1, which began commercial operation in December 1970 is a BWR supplied by G.E., with an output of 652 MWe. Millstone unit 2 will be a PWR, supplied by Westinghouse Electric Co. Unit 3 will produce 1150 MWe and is expected to enter service by October 1979. Maps showing the plant and its geographical situation may be found attached.

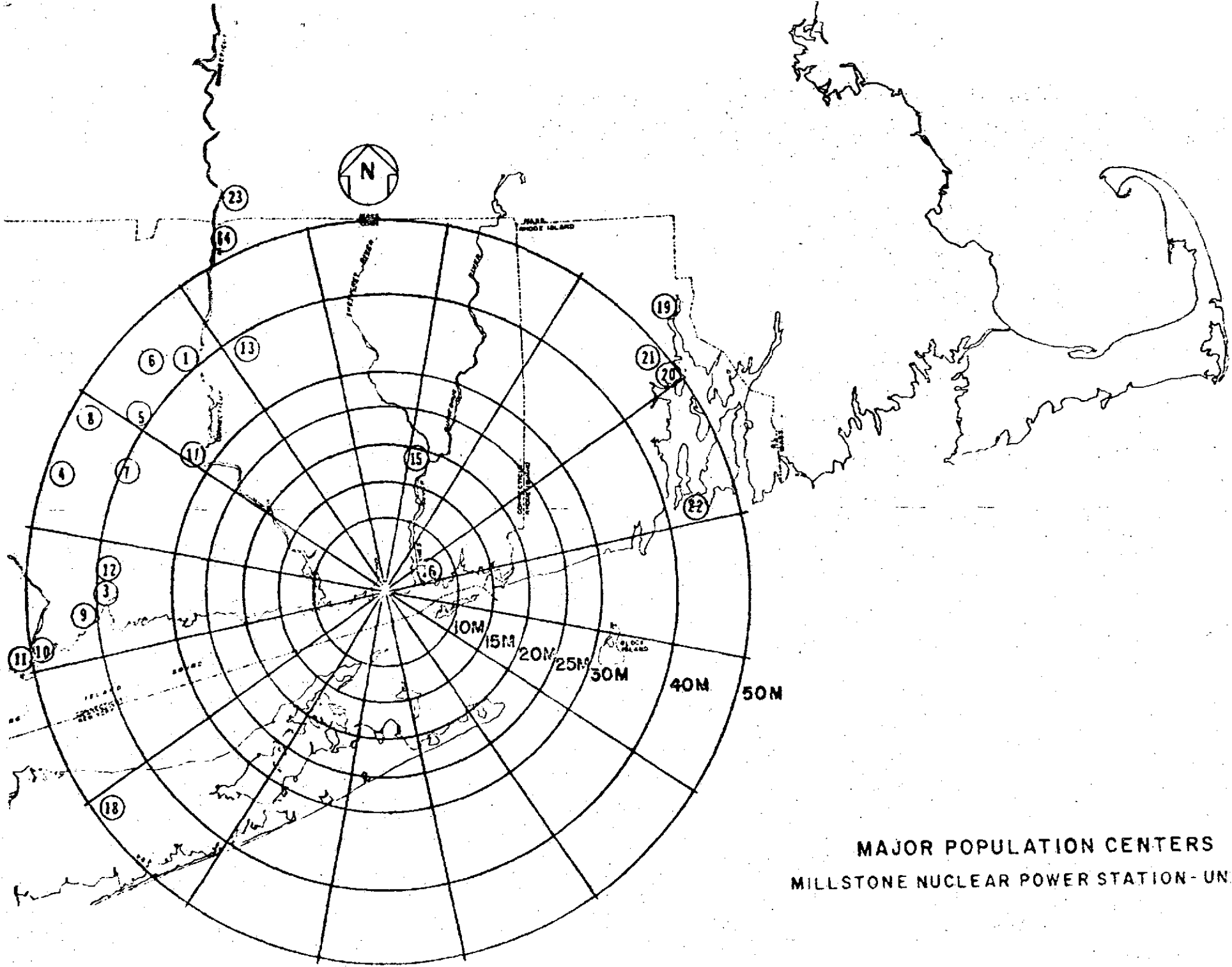
The cooling water system of Millstone units 1 through 3 are discharged by separate structures into an old quarry lake which drains into Two Trees Island Channel in Long Island Sound. The intake structures are on the southwest side of the peninsula. Unit 1 uses 935 cfs with a maximum temperature rise of 23°F. Unit 2 uses 1560 cfs with a maximum 20°F temperature rise. Unit 3 uses 2000 cfs heated to 18°F above ambient. The combined flow at the discharge channel will be approximately 4155 cfs with a maximum full load temperature rise of 20°F.

Studies of the discharge for unit 1 have been conducted by the contractors for the company since it commenced operation. These studies included dye dispersion studies of the plant discharge water.

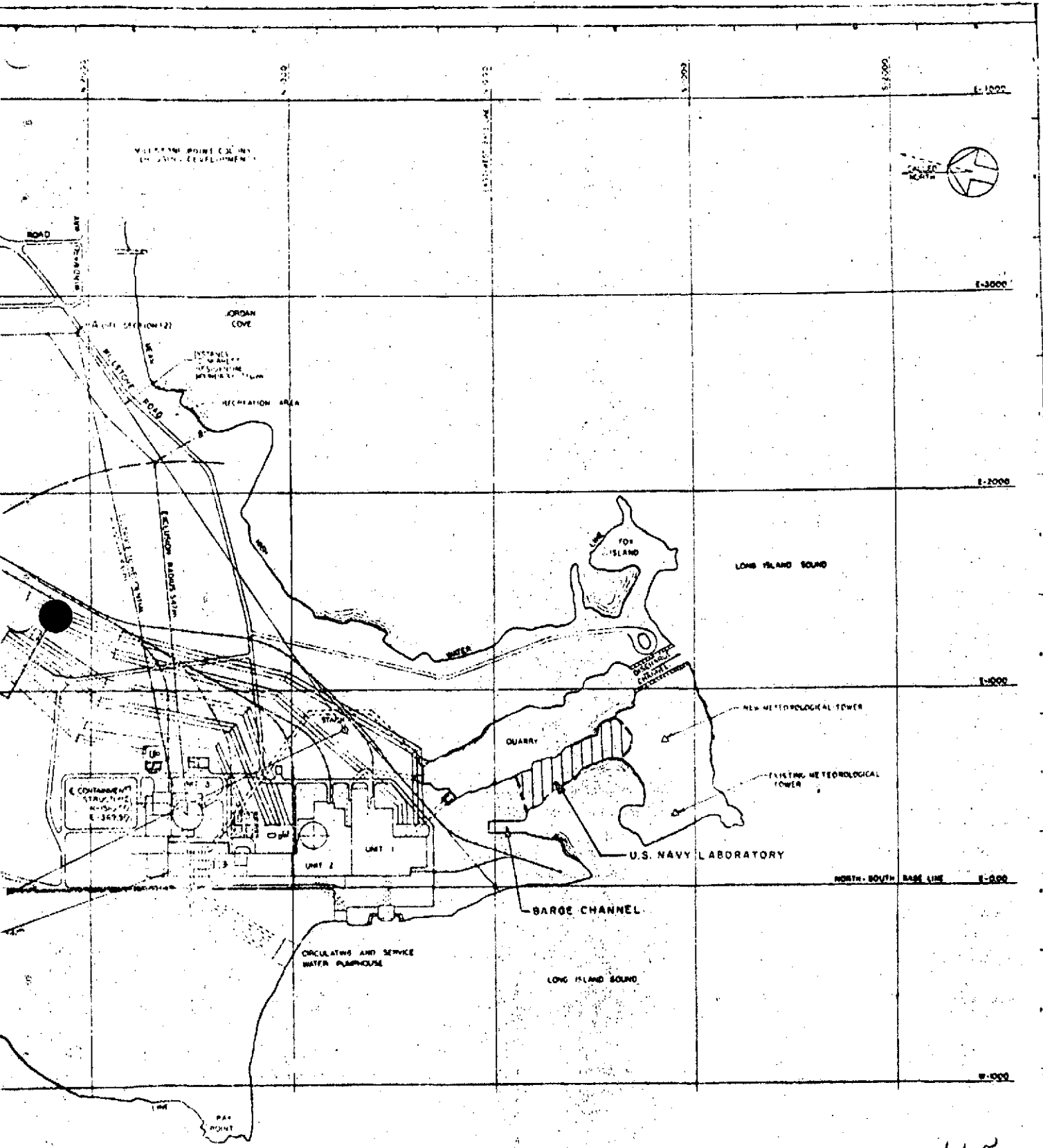


LOCATION OF MILLSTONE NUCLEAR POWER STATION
 WATERFORD, CONNECTICUT

713-



MAJOR POPULATION CENTERS
MILLSTONE NUCLEAR POWER STATION - UNIT 3



-115-

SITE PLAN
MILLSTONE NUCLEAR POWER STATION
UNIT 3

4. Baltimore Gas and Electric Co.

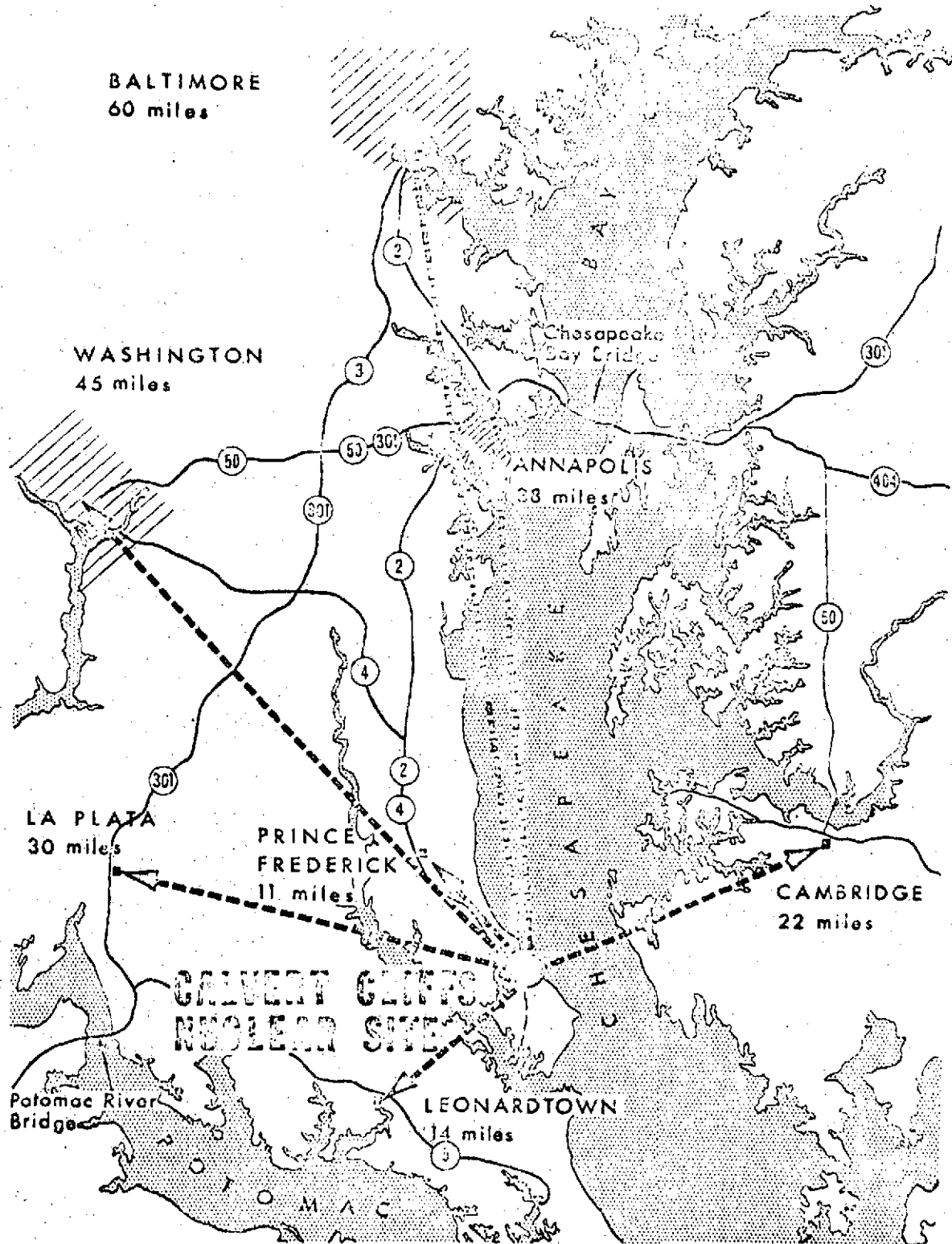
The Calvert Cliffs Nuclear Power Plant is located on the shore of Chesapeake Bay near the town of Lusby, Maryland. The plant will produce 845 MWe net in each of two identical units. The Pressurized Water Reactors have been supplied by Combustion Engineering Co. The first unit began commercial operation in early 1973, the second is scheduled to do so early in 1974.

The cooling water system will circulate 5400 cfs of Chesapeake Bay water through the condensers and return it to the Bay 10°F warmer than it entered. The intake water will be drawn from below a sharp thermocline which develops during the summer months. The temperature difference between the surface and underlying water ranged from 3 to 15°F.

A company supported study indicated that if the deep, cool, oxygen deficient, highly saline water was to be used as a coolant consideration should be given in the design of the discharge to provide for rapid mixing with oxygen rich waters to avoid possible harmful effects to aquatic life in surface waters.

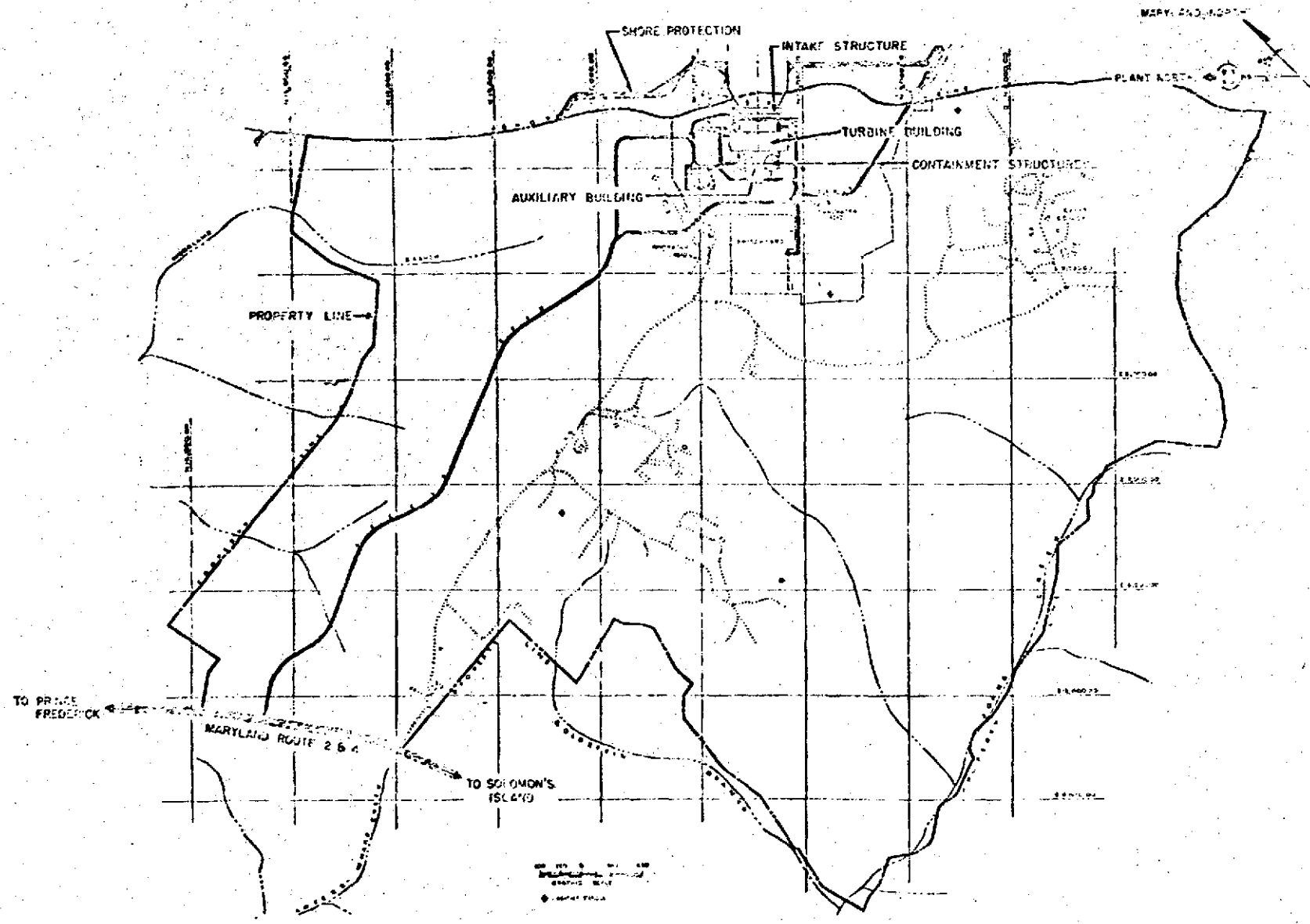
The site vicinity, the site plot plan and the circulating water system of this power plant facility are shown in the figures contained herein.

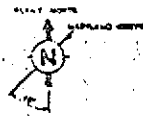
SITE VICINITY



SITE PLOT PLAN

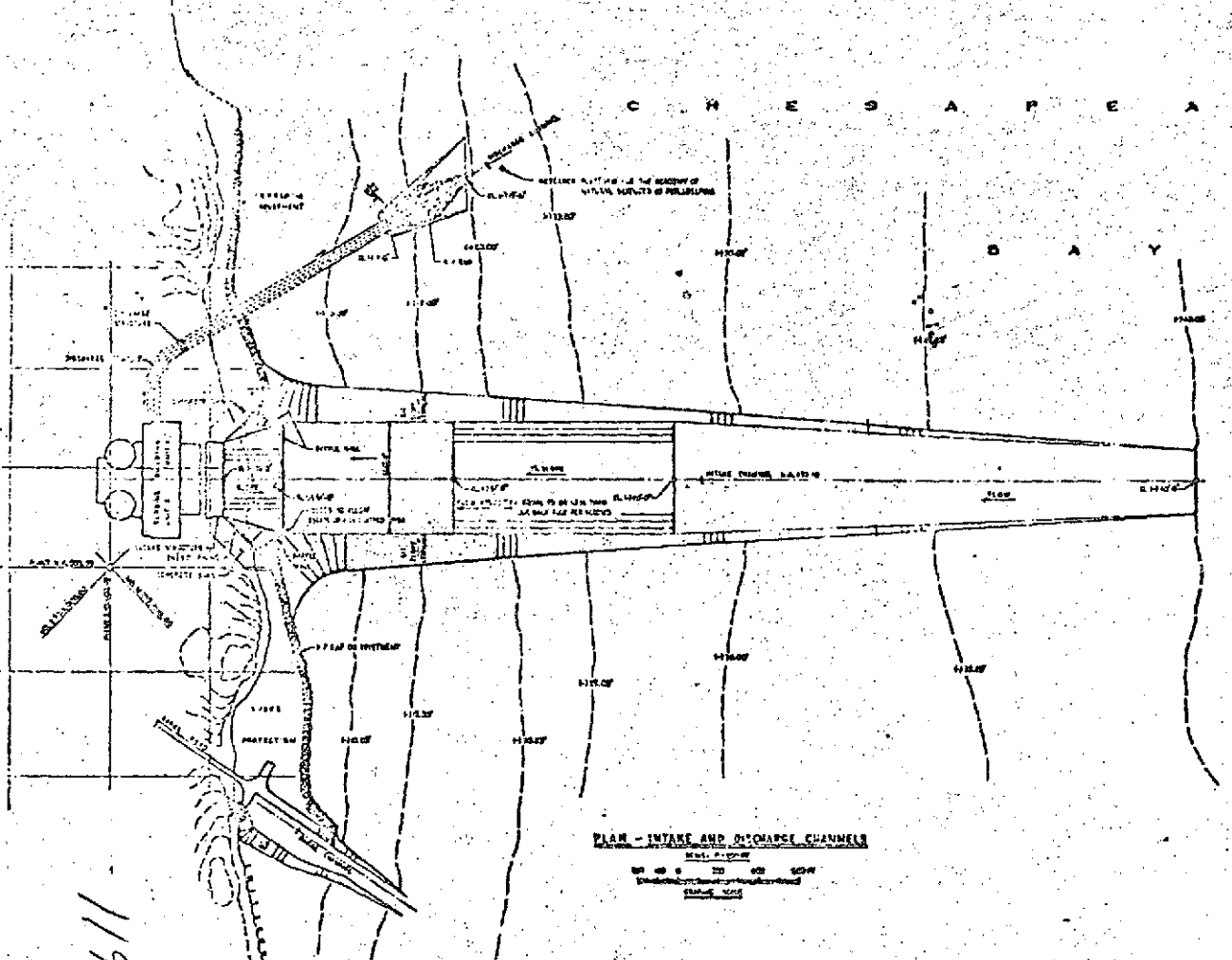
CHESAPEAKE BAY





C H E S A P E A K E

B A Y



PLAN - INTAKE AND DISCHARGE CHANNELS
Scale: 1" = 50'
NO. 100 200 300 400 500
Vertical Scale: 1" = 10'
Horizontal Scale: 1" = 50'

119-

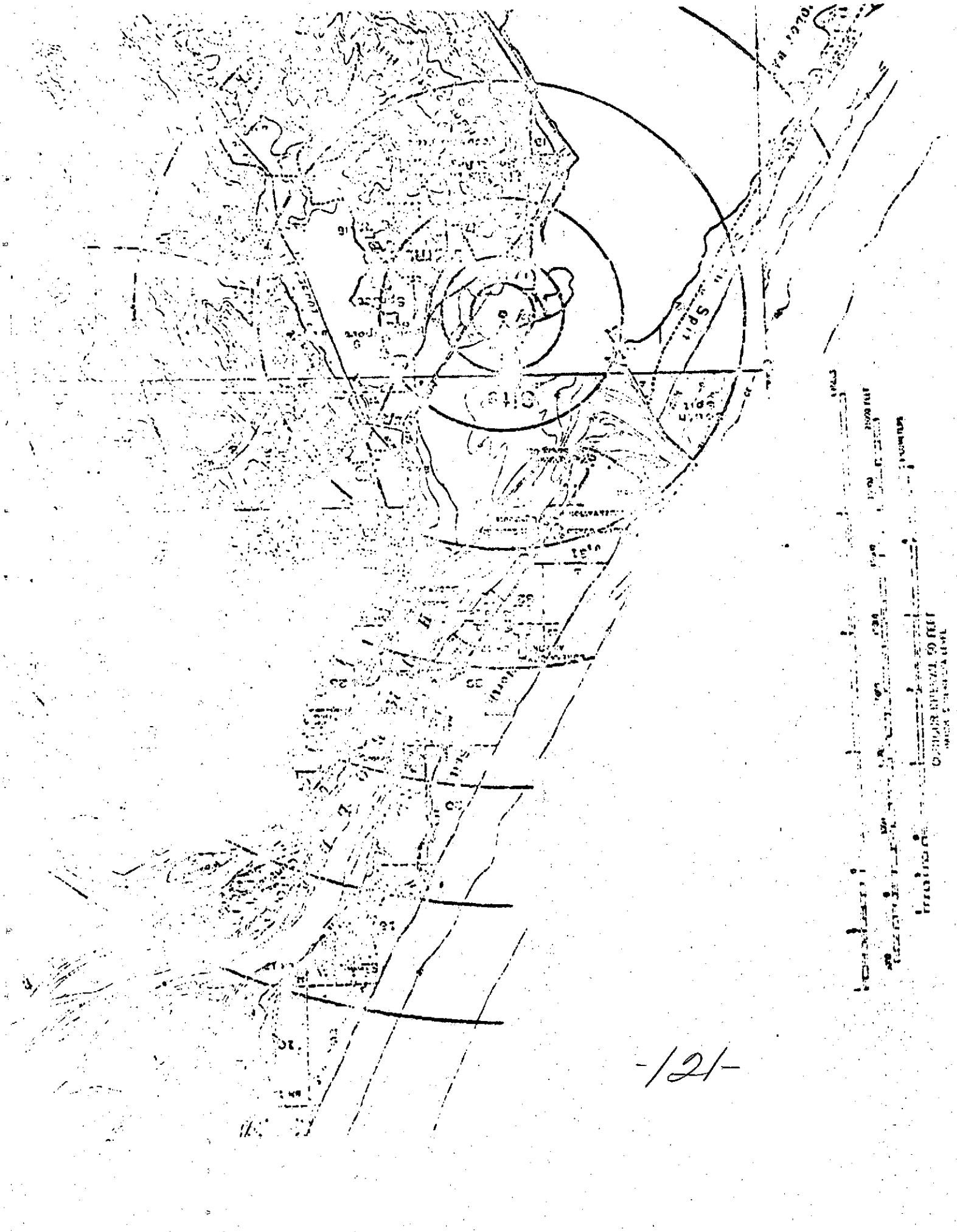
CIRCULATING WATER SYSTEM
Sheet 1
ELECTRIC PRODUCTION PLANT
CALVERT CLAYS UNIT # 2
WILMINGTON GAS & ELECTRIC CO.
ENGINEERS ASSOCIATES

C. GEOGRAPHICAL REGION: PACIFIC COAST

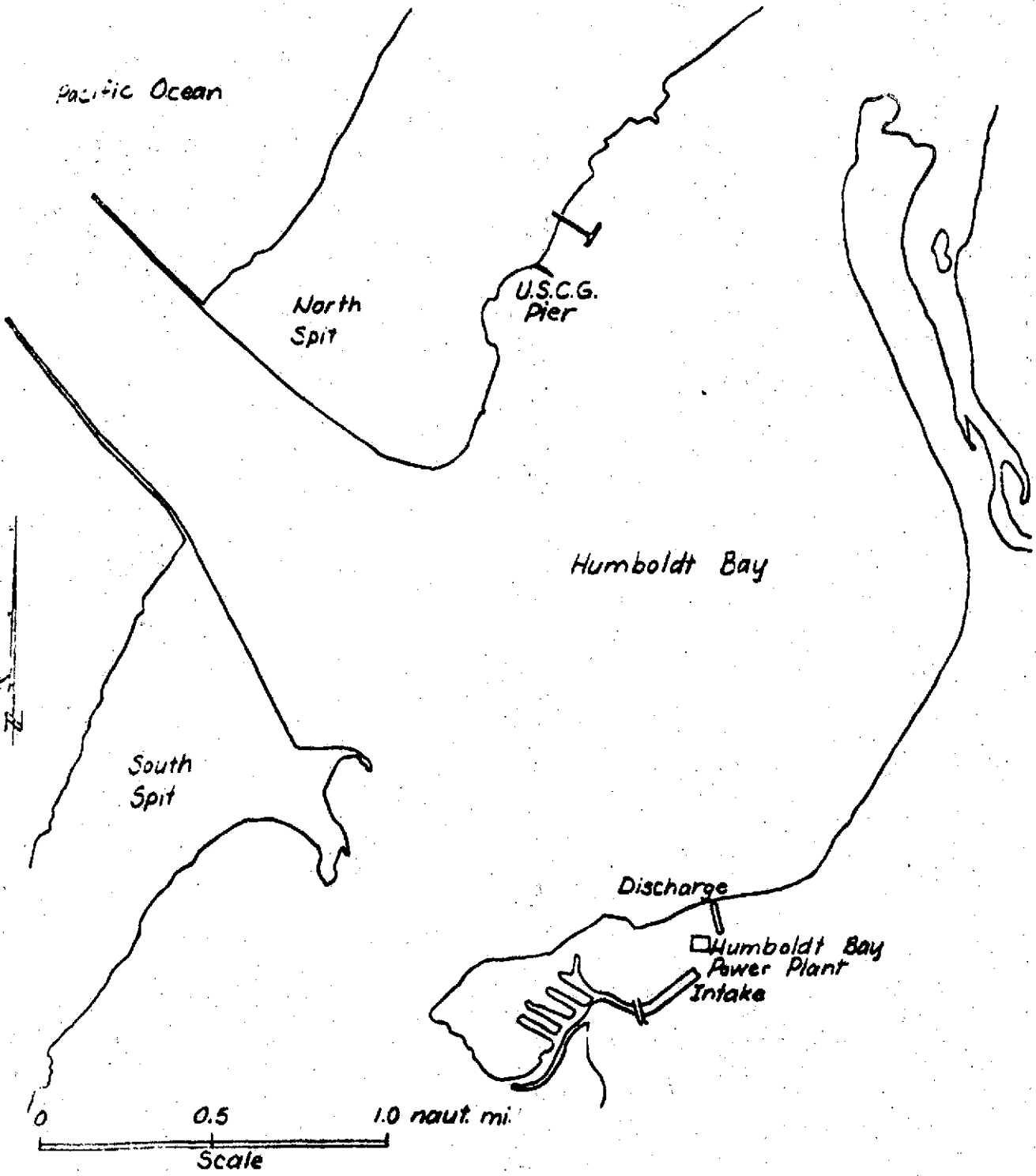
1. Pacific Gas and Electric Co.

The Humboldt Power Plant of the Pacific Gas and Electric Co. is located near Humboldt Bay, California. The plant produces 68 MWe by means of a Boiling Water Reactor supplied by the General Electric Co. The plant began commercial operation in August 1963. Cooling water discharge from three units, two fossil fueled and one nuclear, of a combined rating of 172 MWe is discharged at the shore of Humboldt Bay. The topography of the region is attached herein along with details related to the thermal discharge. The total flow is 230.4 cfs and has a discharge velocity of 7.3 fps into the Bay. The average temperature rise above ambient at the outfall is 18°F.

The company has conducted remote sensing and in-situ measurements at the site and some examples of the results are also attached herein.



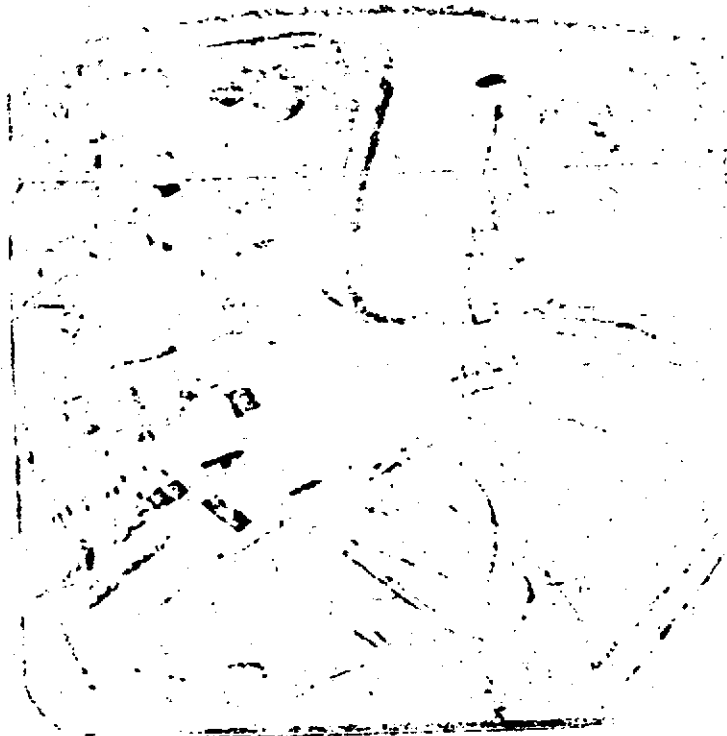
PROVIDED BY THE
OFFICE OF THE
CHIEF OF NAVAL OPERATIONS
WASHINGTON, D.C.



Location Map - Humboldt Bay Power Plant

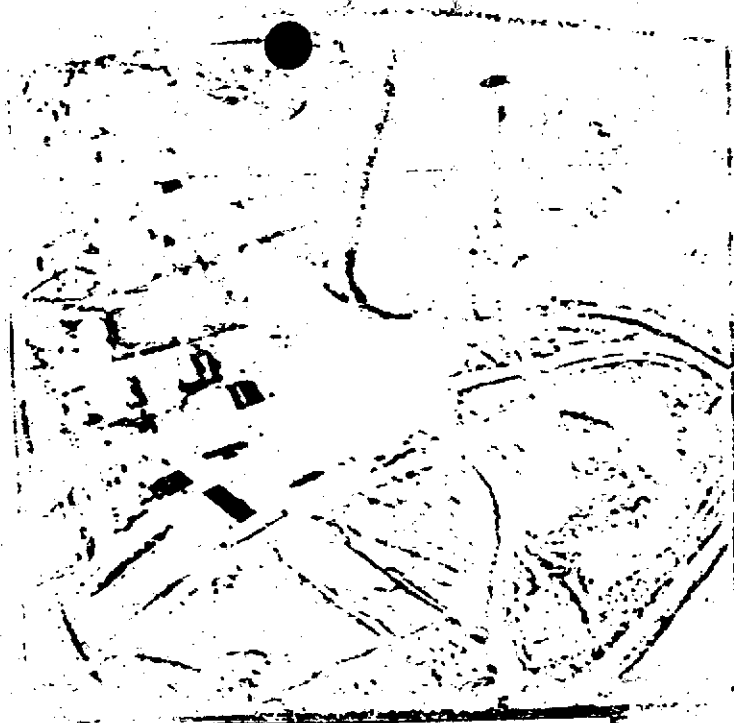
HUMBOLDT BAY

14μ INFRARED AND VISABLE IMAGES

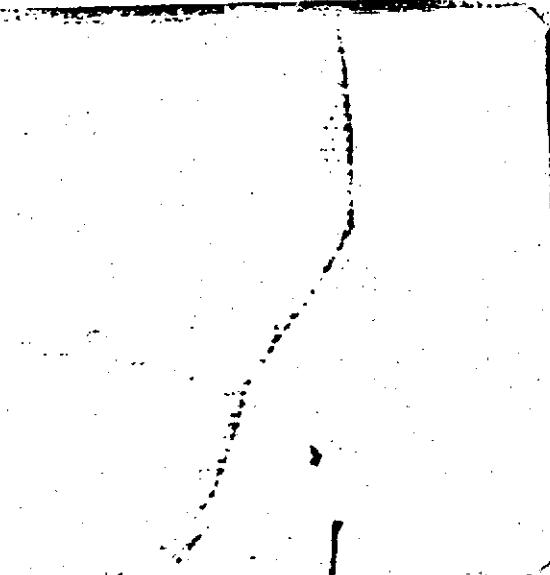


OCTOBER 12, 1971
TIME 1521 INFRARED

OCTOBER 12, 1971
TIME 1400
VISIBLE



OCTOBER 12, 1971
TIME 1521 INFRARED



OCTOBER 12, 1971
TIME 1513 INFRARED

OCTOB
TIM
VI

OCTOB
TIME 140

D. GEOGRAPHICAL REGION: GREAT LAKES

1. Zion Nuclear Power Station of Commonwealth Edison Company.

The Zion Power Station is located on the shore of Lake Michigan about midway between Chicago and Milwaukee. It is about 80 miles northeast of Dresden Nuclear Power Station where Edison's first nuclear unit was built. The reactor is of the boiling water type. The plant consists of two units of 1,100 Net MWe each. Unit 1 is scheduled to be operated in June, 1973 and Unit 2 is expected to be completed by December of the same year.

Cooling water for both Zion units is to be drawn from the lake at a point some 2000 feet from shore and 22 feet below the surface. Two discharge pipes, 760 feet from shore and 154 feet north and south of the intake line, discharge the water in a high-velocity jet at an angle 45 degrees from the shoreline and 90 degrees from the other jet. The discharge temperature will be limited to not more than 20°F above ambient.

2. Point Beach Nuclear Plant of Wisconsin Electric Power Co. and Wisconsin Michigan Power Co.

The Point Beach Nuclear Plant is located in Two Creeks, Wisconsin on the shore of Lake Michigan. The following three figures show the topology and location of the plant site. It consists of two units with a capacity of 497 MWe. It was first operated in December, 1970.

Cooling water is drawn from the Lake at a point 1750 feet perpendicular to shore and 5 feet above lake bed. It is then discharged to the lake through a pipe at 150 feet from the shore, about 18 feet below water level.

Flow and temperature characteristics are given below:

$$Q_{\max} = 700,000 \text{ gpm}$$

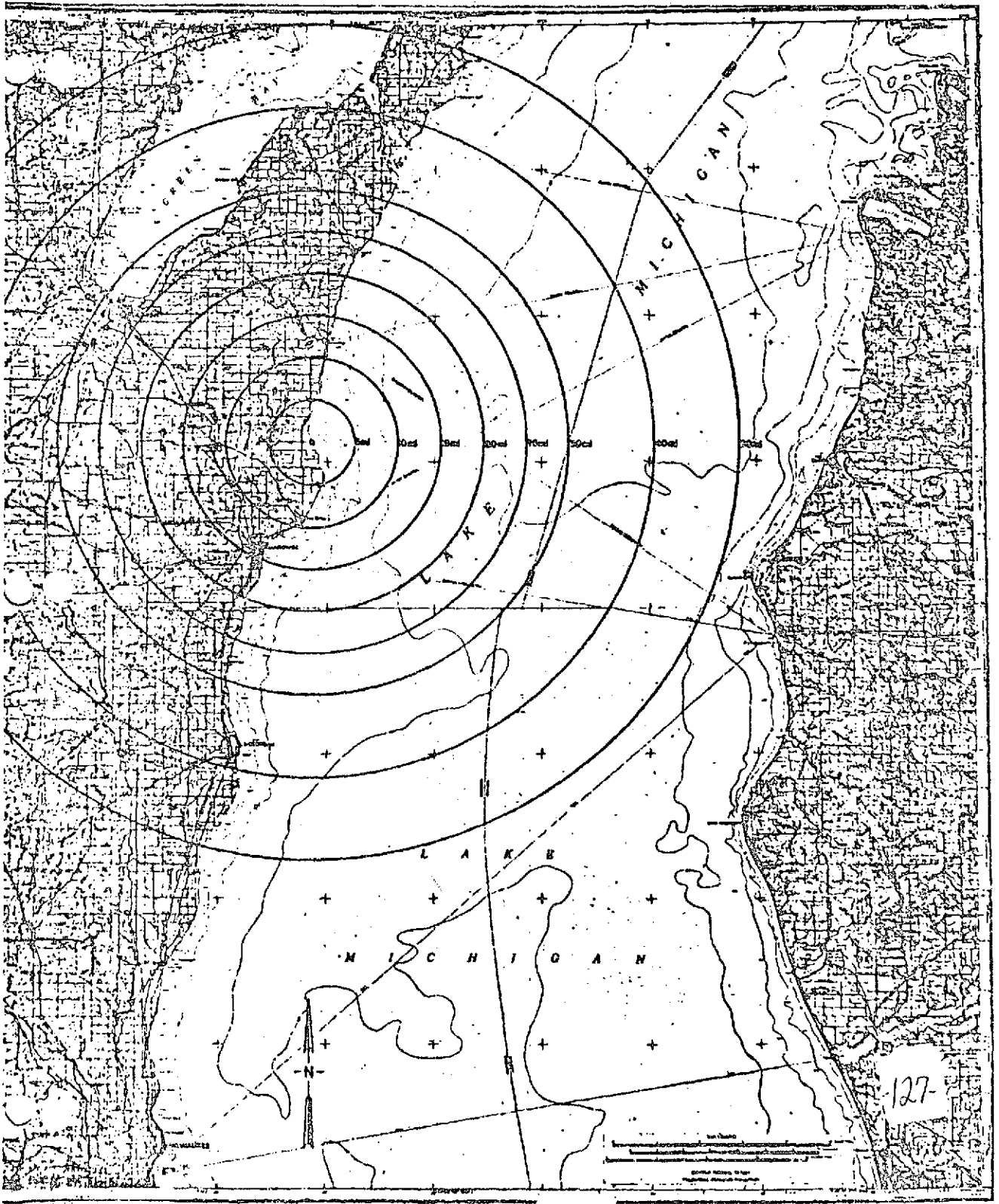
$$\Delta T_{\max} = 19.3^{\circ}\text{F}$$

when ambient temperatures are below 40°F

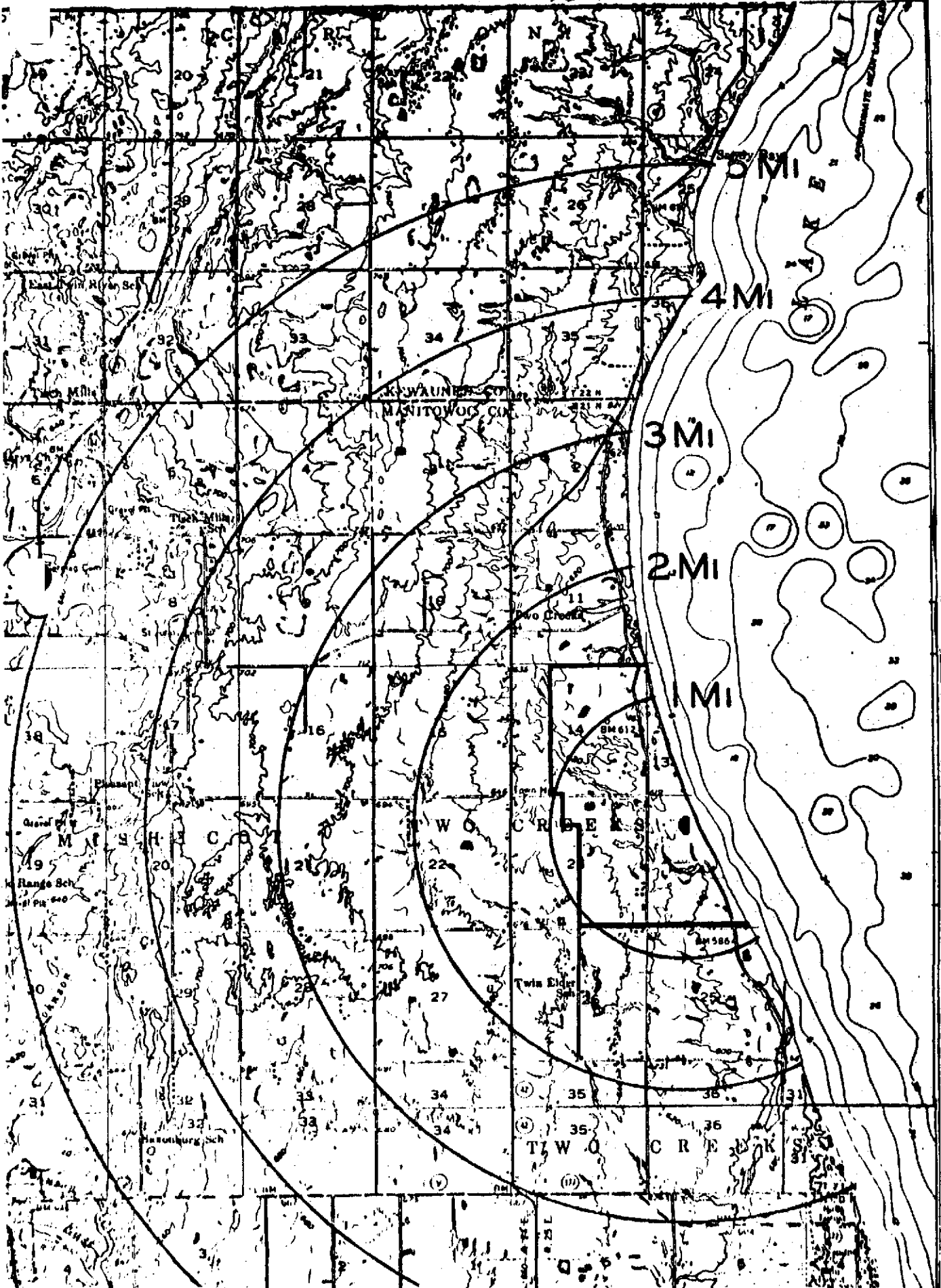
$$Q_{\max} = \text{Variable } 320,000 \text{ gpm to } 428,000 \text{ gpm}$$

$$\Delta T_{\max} = 31.5^{\circ}\text{F} \text{ Therefore outfall } T_{\max} = 71.5^{\circ}\text{F}$$

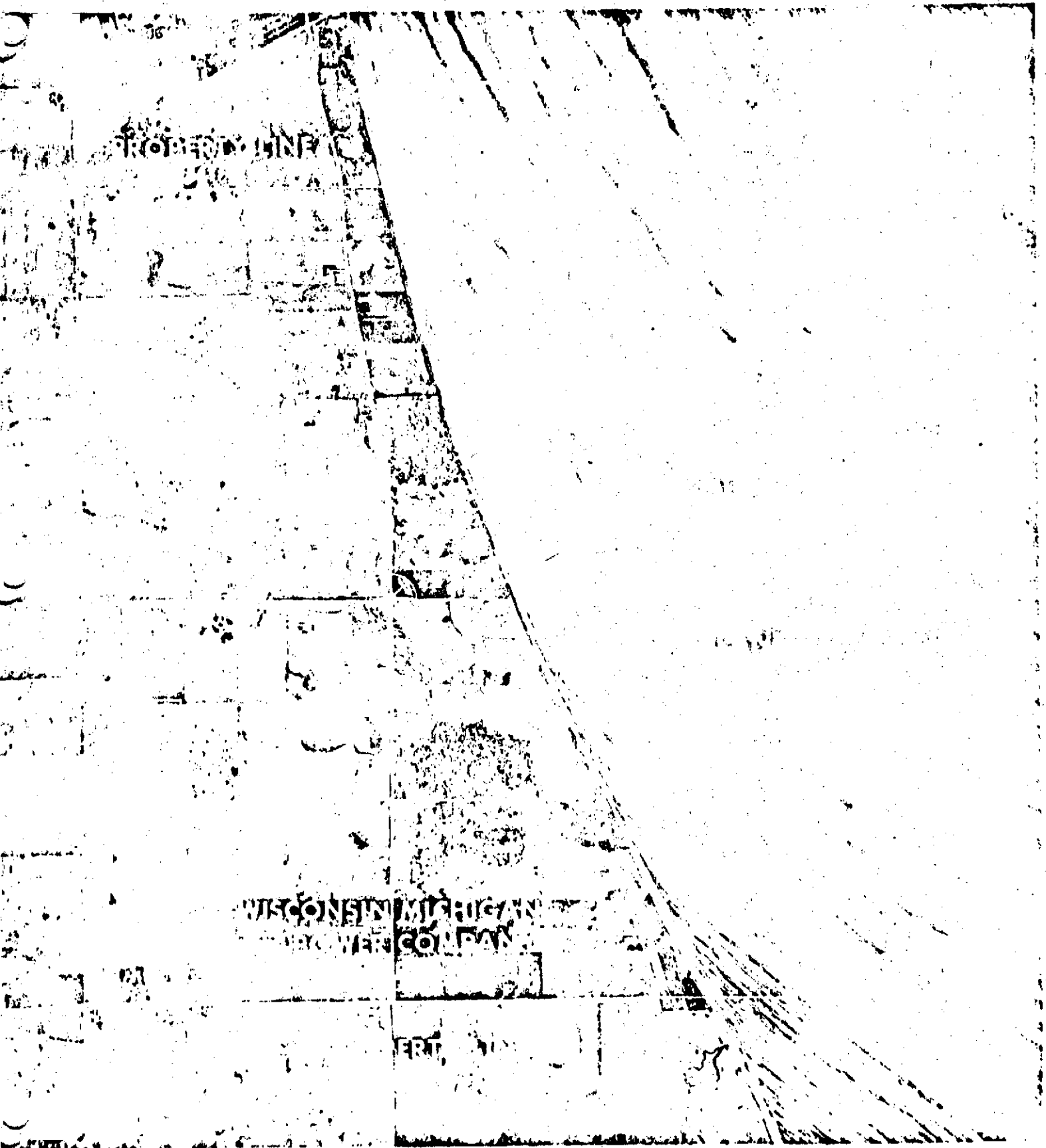
The location of the site is shown in the following attached maps.



GENERAL TOPOGRAPHY MAP



LAKE MICHIGAN



3. Wisconsin Public Service Co.

The Kewaunee Nuclear Power Plant of the Wisconsin Public Service Co. is located in Kewaunee County, Wisconsin. The Pressurized Water Reactor supplied by Westinghouse Electric Co. is expected to begin producing 540 MWe commercially in December 1973.

Cooling water will be provided by a circulating water system at a rate of 431,000 gpm, $\Delta T = 28^{\circ}F$ in the summer. The circulating water will be supplied from Lake Michigan via an intake structure located approximately 1570 feet on a line perpendicular to the shore. The water is pumped through the condensers and then to the discharge structure which is located at the shoreline. A copy of the topography of the area is included in this report along with a plot of the thermal plume from results of the company preliminary environmental study.



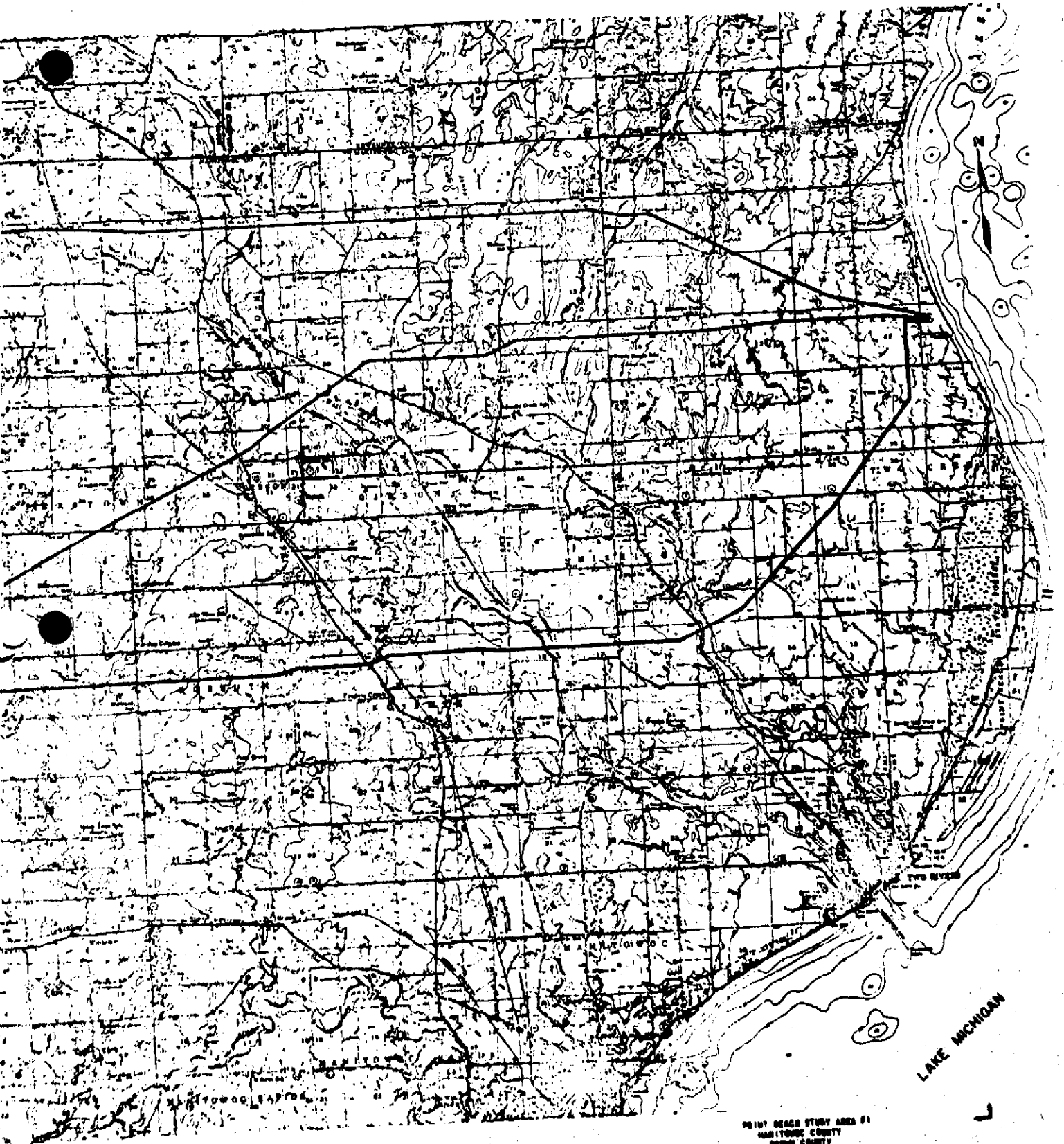
SCALE



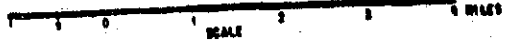
-131-

(POPULATION CENTERS OF 25,000 OR MORE (●))

GENERAL LOCATION MAP

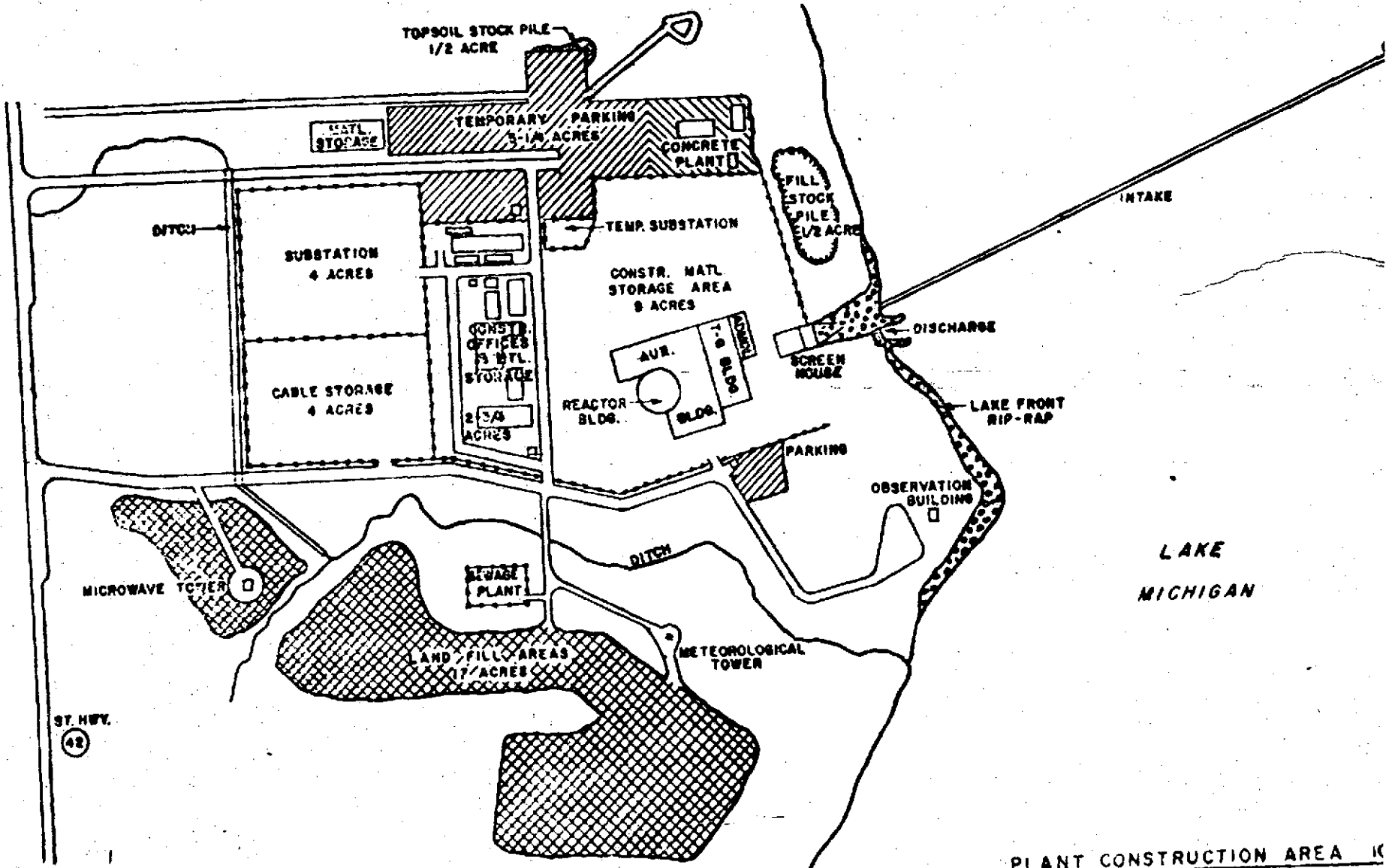


POINT BEACH STUDY AREA #1
MANITOWISH COUNTY
WISCONSIN

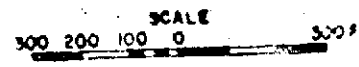


LAKE MICHIGAN

LEGEND
●
○
○



PLANT CONSTRUCTION AREA K



ST. HWY.
42

103

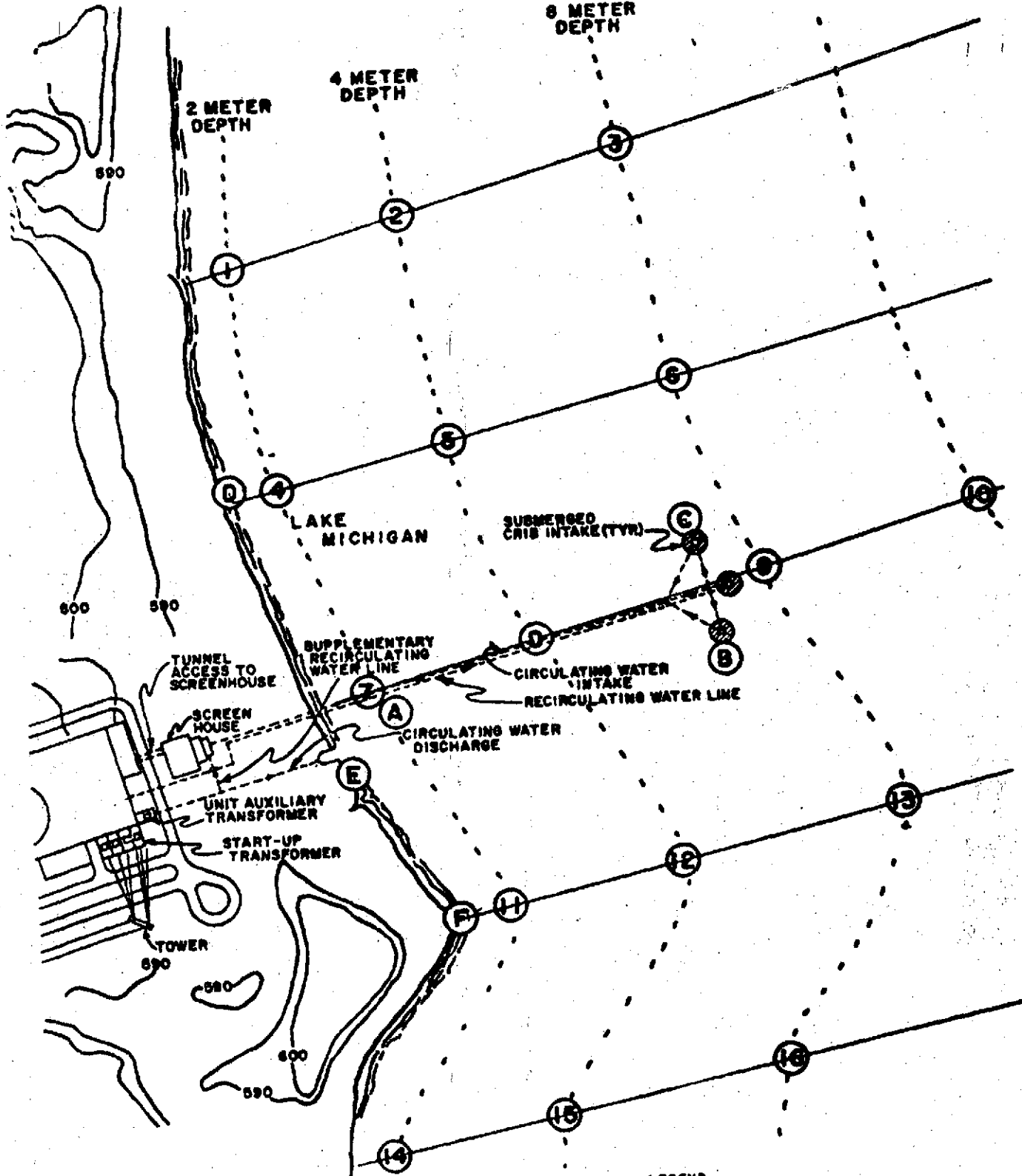
WATER QUALITY SAMPLING LOCATIONS

16 METER DEPTH

8 METER DEPTH

4 METER DEPTH

2 METER DEPTH



LIMNOLOGICAL LEGEND

Conductivity: 1, 14 Mid-depth; 3, 16 Top, Mid, Bottom Depth
 Temperature Each Meter and Secchi Disc 1-16
 D.O., pH, T. Alk., Mid-Depth (2M) : 1, 4, 7, 11, 14
 D.O., pH, T. Alk., Top and Bottom Depth : 2, 5, 8, 12, 15
 D.O., pH, T. Alk., Top, Mid, and Bottom Depths : 3, 6, 9, 13, 16, 10
 Water Quality, Bacteriology, Plankton (triplicate)
 A=Mid-Depth
 B=Top and Bottom of the Water Column
 Benthos (triplicate samples) A, B, C
 Zooplankton (six replicate vertical tows) B, C
 (triplicate samples): D, E, F

RESERVOIR SURFACE
ELEV 835-0'
850 ACRES

LAKE MICHIGAN

-18 -16 -20 -22 -24 -26 -28 -30

DIKE

ROAD

INTAKE FACILITY

POWER PLANT

INTAKE WELL

HIGHWAY 42

SPELLWAY

SWITCHYARD

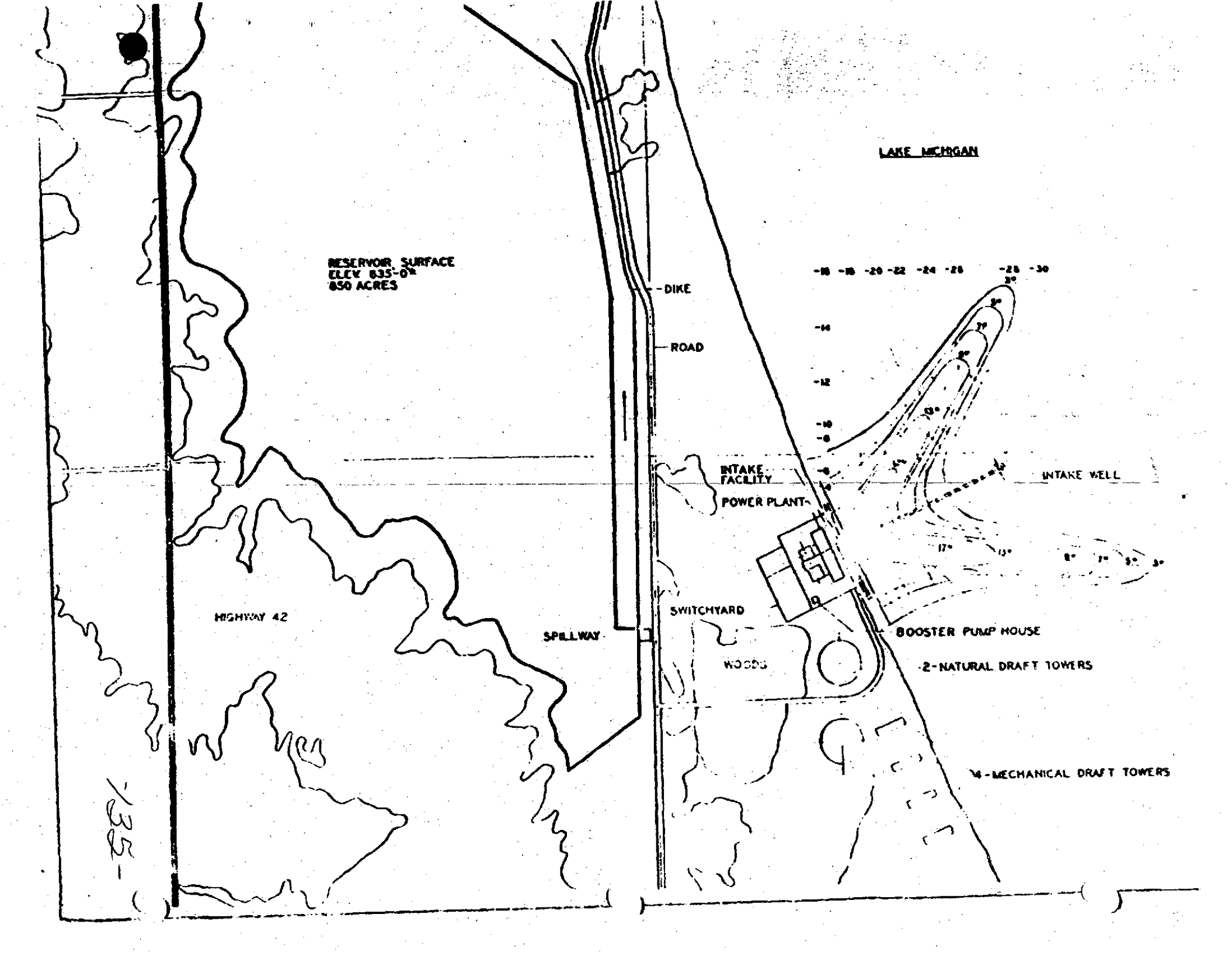
WOODS

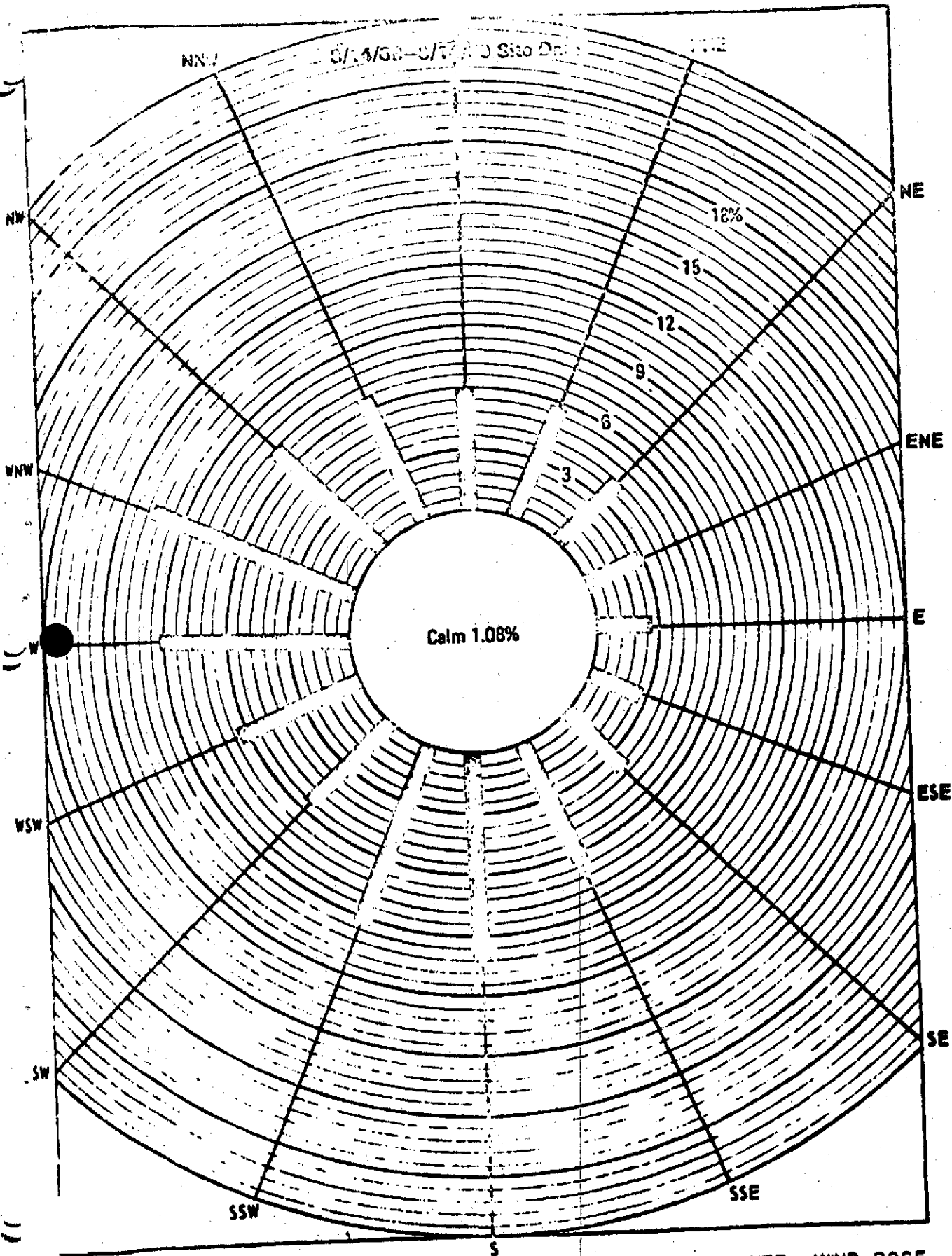
BOOSTER PUMP HOUSE

2-NATURAL DRAFT TOWERS

14-MECHANICAL DRAFT TOWERS

135-





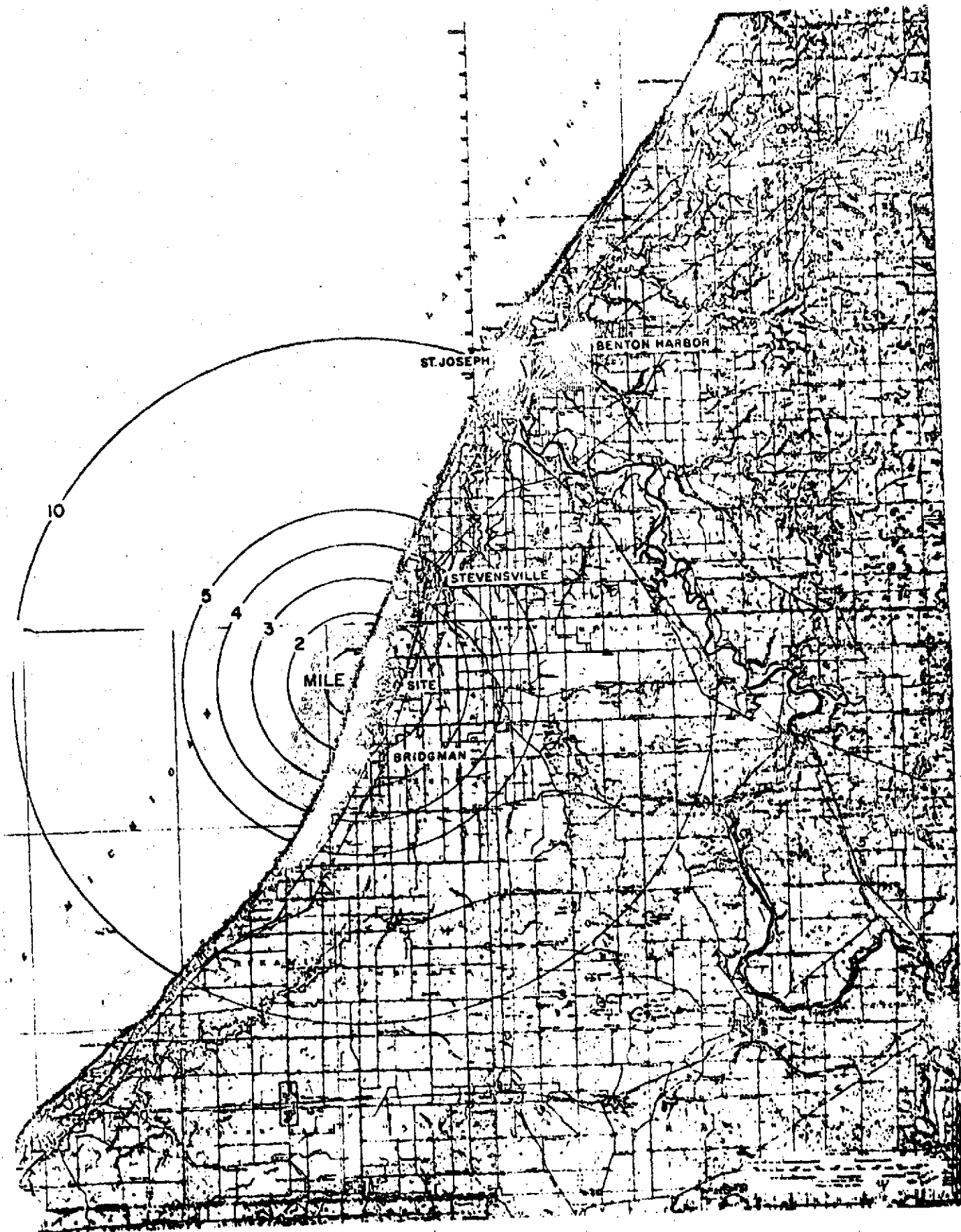
KEWAUNEE WIND ROSE
Annual Summary

4. Indiana and Michigan Electric Co.
American Electric Power System

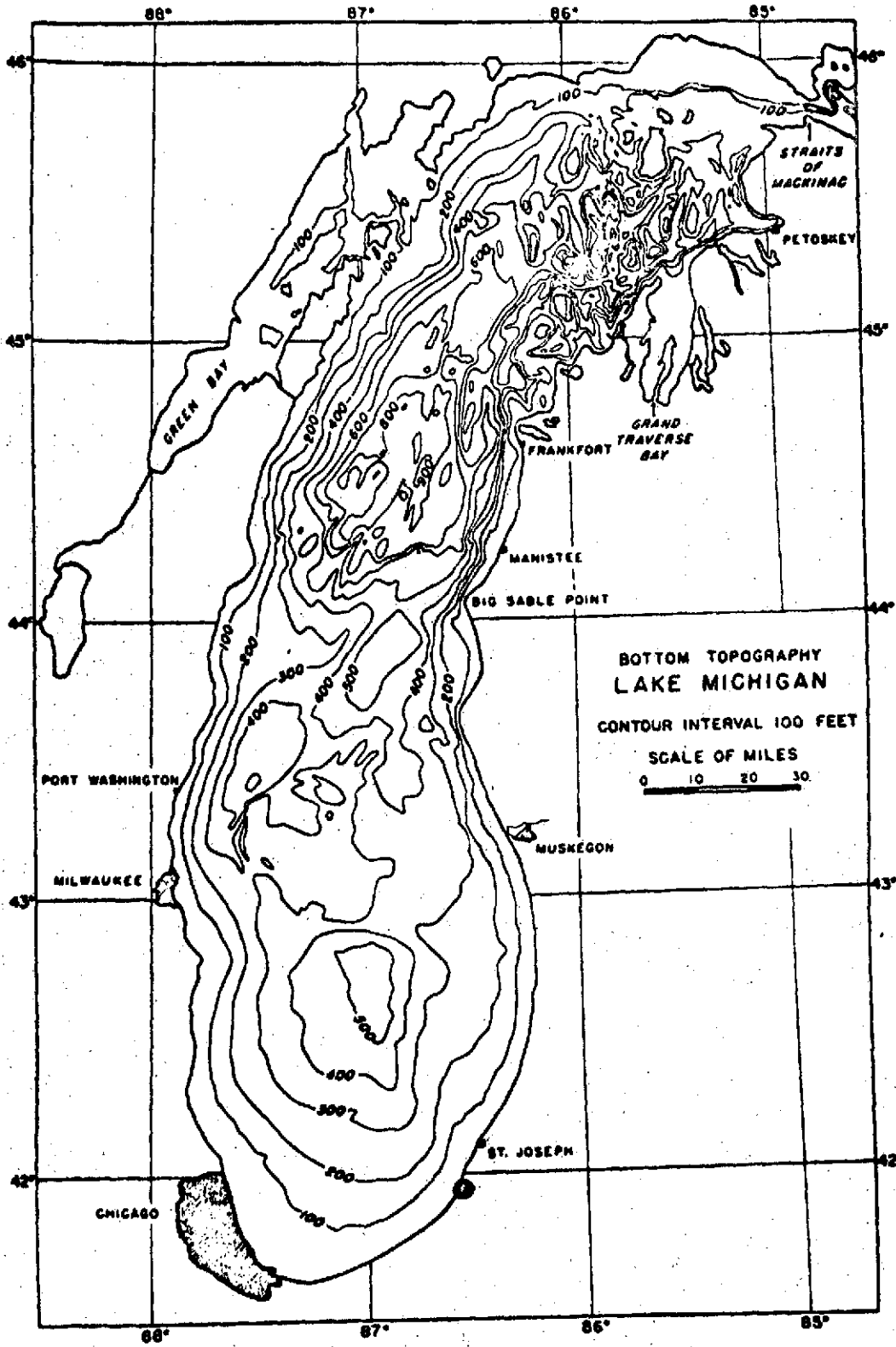
The Donald C. Cook Nuclear Plant Site is located in Lake Township, Berrien County, Michigan, about 11 miles south-southwest of the center of Benton Harbor. The site consists of about 650 acres/along the eastern shore of Lake Michigan.

Two identical systems employing pressurized water reactors provided by Westinghouse Electric Co. will produce 1054 MWe each. Unit one is expected to enter commercial service in 9/74, Unit two is expected to do so by 4/76. Lake Michigan water will be used to cool the condensers and will be returned to the lake. When the plant is operating with both units at full load 2,260 million gpd will be heated to 20°F above ambient temperatures. The intake structures will be located 2250 feet offshore. The smoothly rounded intake elbows will be set in the lake bottom and provided with barriers to prevent entrainment of foreign objects. The intake pipes will be 16 feet in diameter to allow low velocities for the same purpose.

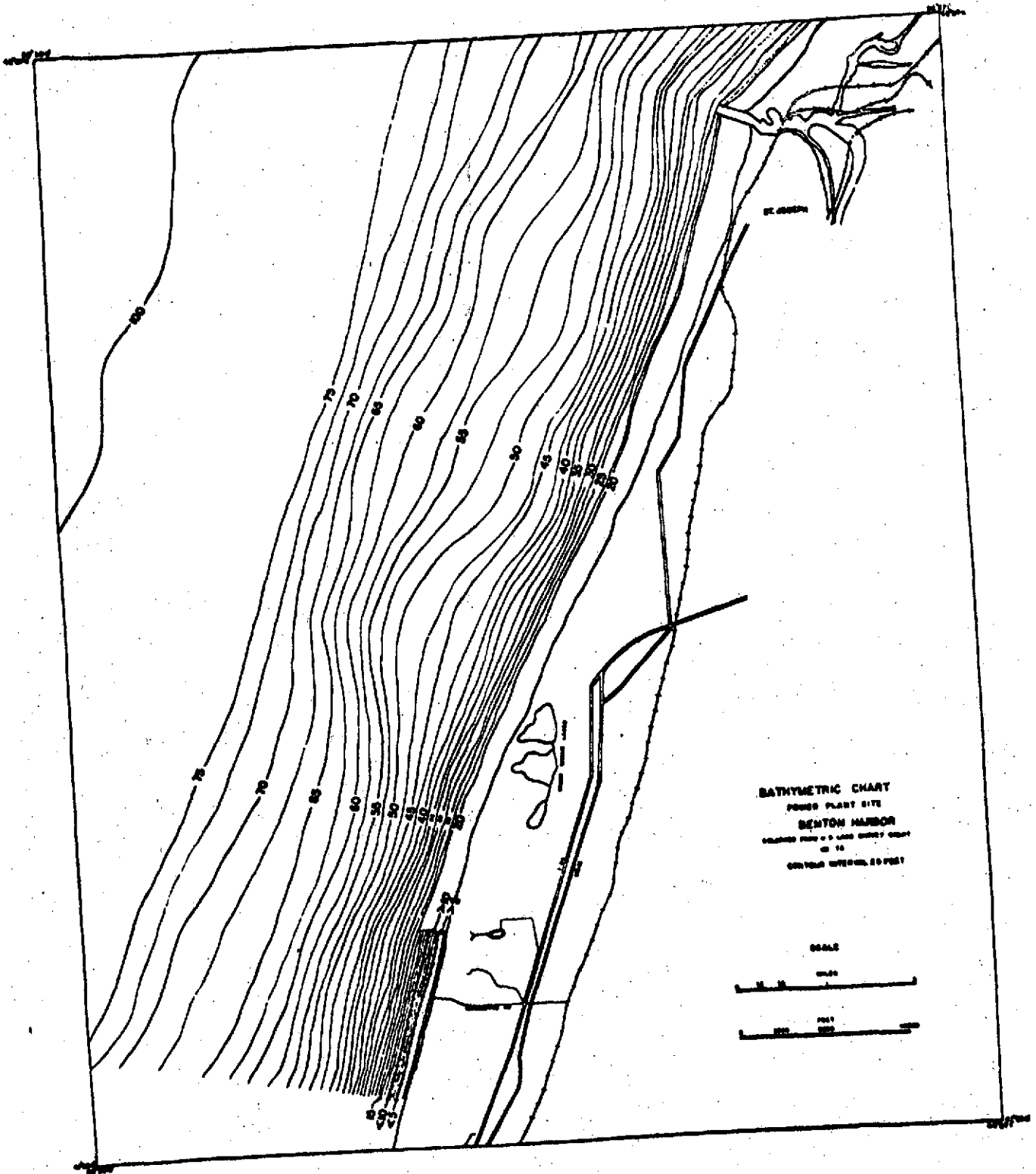
The discharge is divided into two discharge pipes. Each discharge pipe terminates in a discharge elbow about 1160 feet from the ordinary high water line. Each elbow designed on the basis of hydraulic model tests, to deliver the warm water to the lake surface without subsurface mixing, in order to minimize the area affected by the warm water discharge volume and to insure minimal disturbance of the lake bottom. Details of the lake, the plant, and its immediate surroundings may be found in the following attached maps.



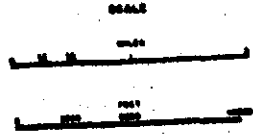
MAP SHOWING LOCAL FEATURES



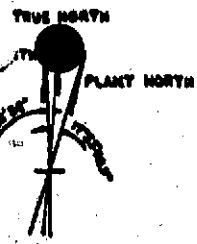
THE BOTTOM TOPOGRAPHY OF LAKE MICHIGAN (FROM HOUGH 1958)



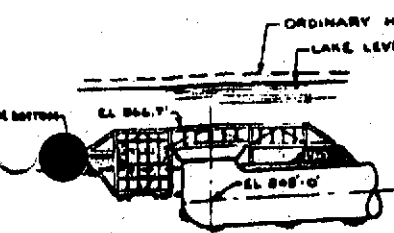
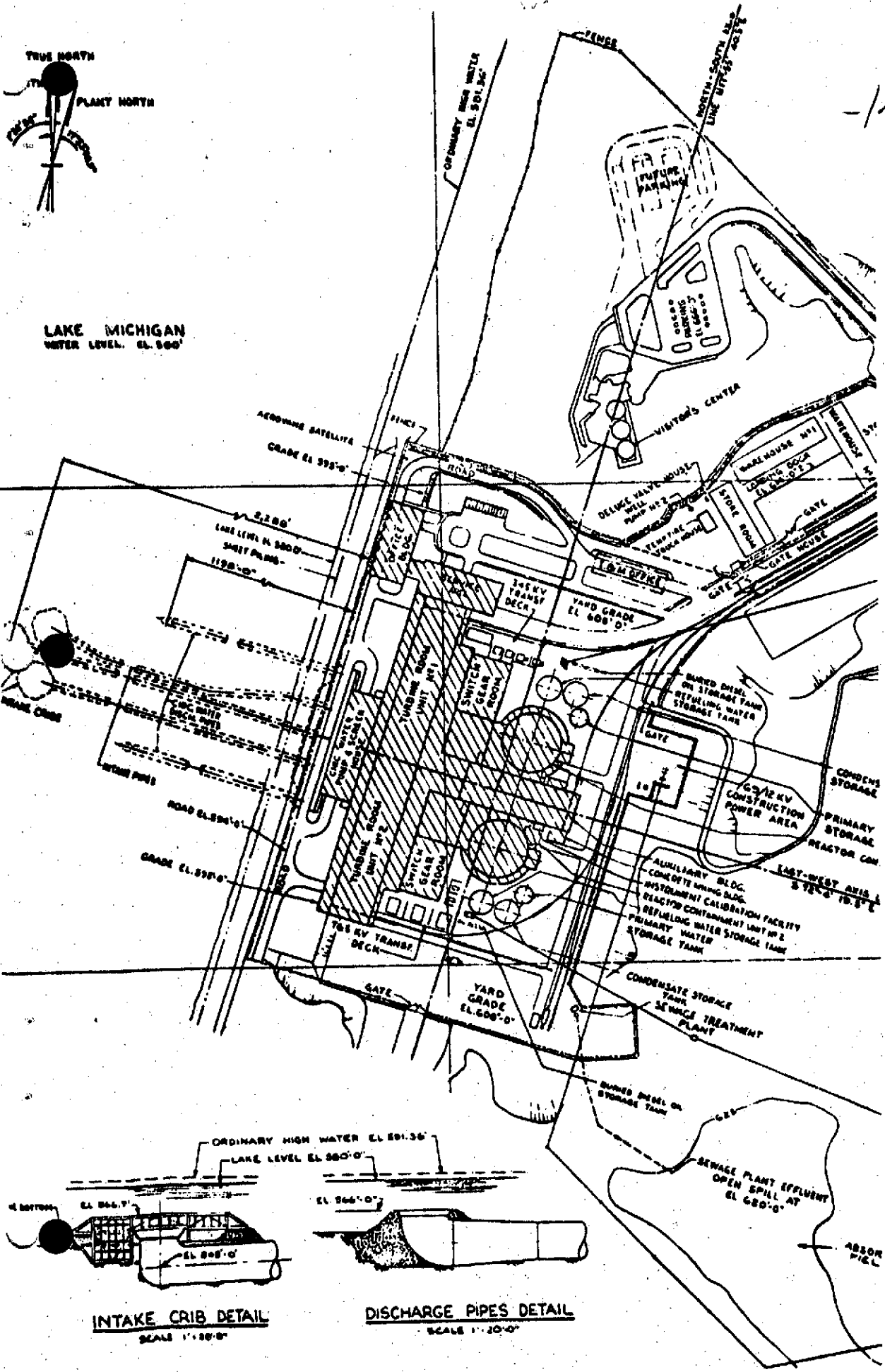
BATHYMETRIC CHART
POWER PLANT SITE
BENTON HARBOR
PUBLISHED FROM U.S. LAND SURVEY CHART
NO. 10
CONTAINING INFORMATION TO FOOT



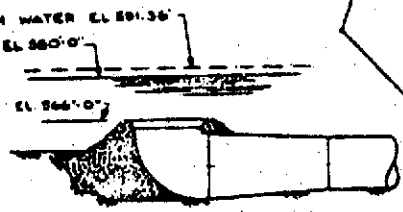
BATHYMETRIC CHART



LAKE MICHIGAN
WATER LEVEL EL. 580'



INTAKE CRIB DETAIL
SCALE 1"=20'-0"



DISCHARGE PIPES DETAIL
SCALE 1"=20'-0"

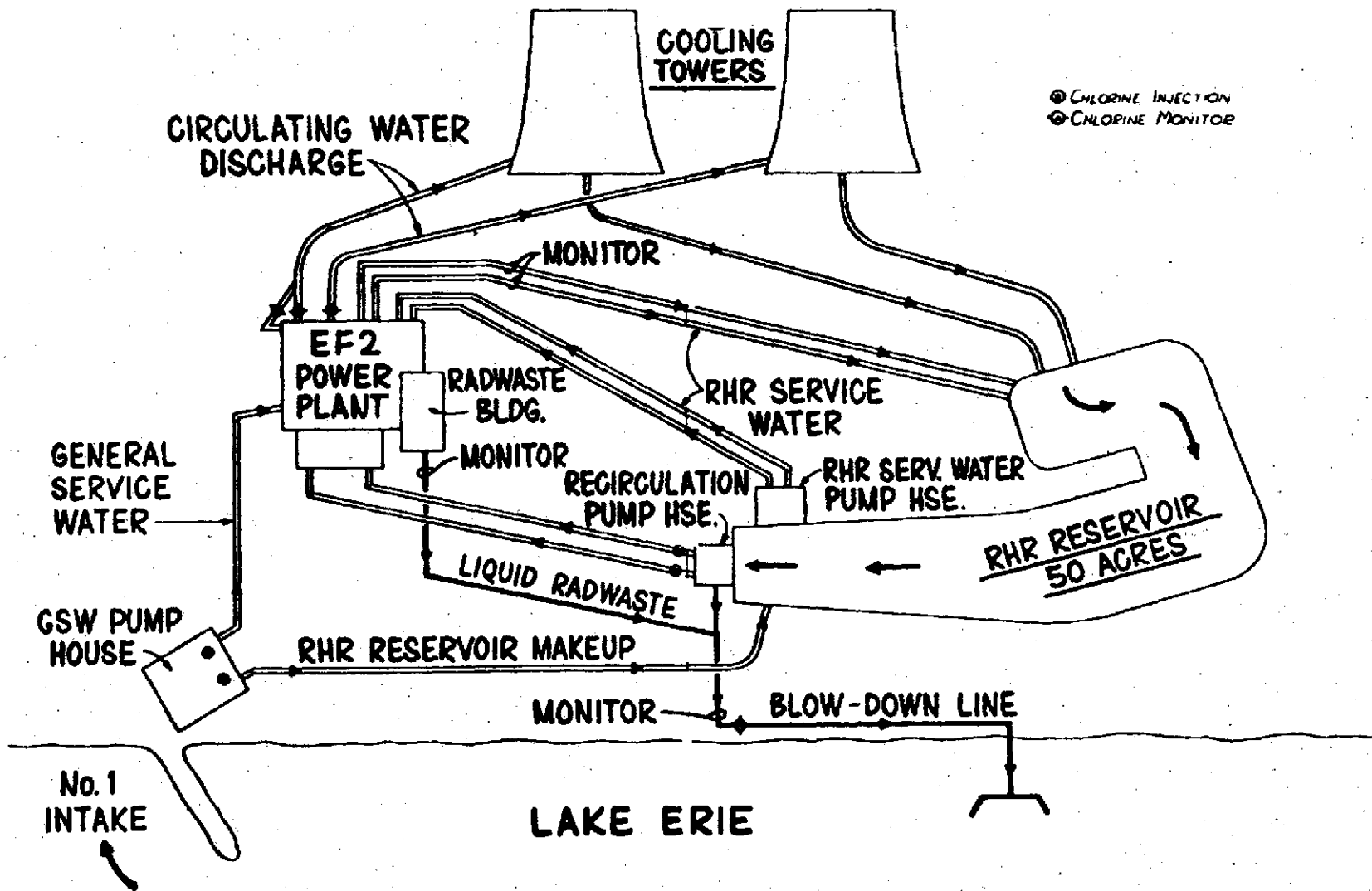
5. The Detroit Edison Co.

The Enrico Fermi Plant of the Detroit Edison Co. is located at Newport, Michigan. The Boiling Water Reactors will produce 150 MWe by April 1977 if construction continues on schedule. General Electric is supplying the reactors. The Fermi No. 2 plant will have a closed cycle cooling system. A cooling pond and natural convection cooling towers are its major features. Some water from the pond will be discharged into Lake Erie. Maximum discharge will be 12,000 gpm during July and half of that value in January. The maximum temperature differential will be 12°F in July and 23°F in January. These figures are based on 105% power production. The maximum heat flux discharged will be about 78.3 million Btu per hour. Maps of the region of the plant and other details of interest are attached.



Enrico Fermi Plant
General Location

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**ENRICO FERMI ATOMIC POWER PLANT UNIT 2
EF2-CONDENSER COOLING WATER AND RHR SYSTEM**

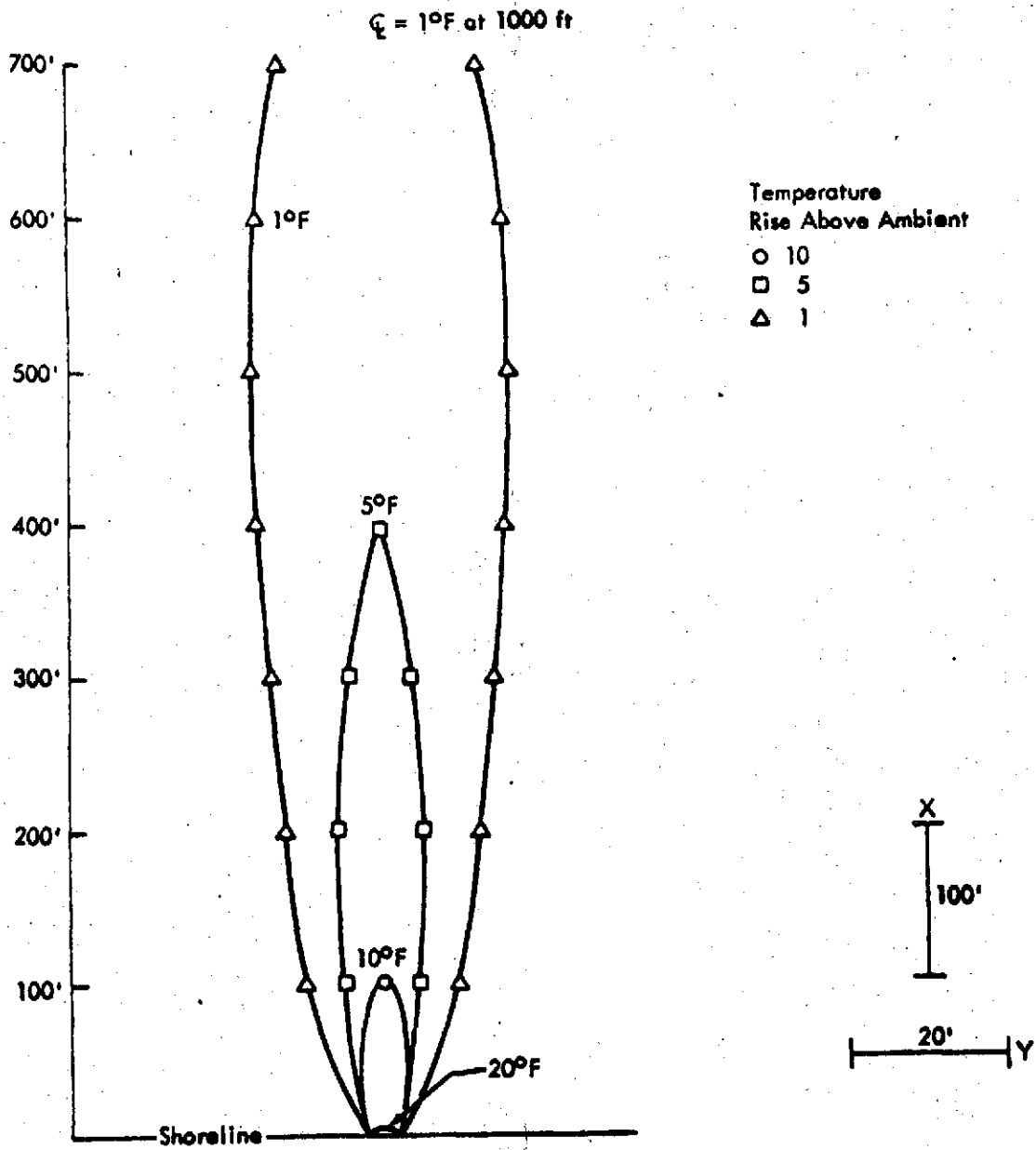
TABLE - EXPECTED HEAT RELEASE INTO LAKE ERIE FROM FERMI 2 PONDING AREA

<u>Month</u>	<u>Return Flow Rate, ppm</u>	<u>Temperature* Difference, F</u>	<u>Heat Release, Millions of Btu per Hour</u>
January	6,000	23	69.2
February	6,200	22	69.0
March	6,900	19	65.6
April	8,500	16	68.0
May	10,500	15	78.3
June	11,900	13	77.4
July	12,000	12	72.0
August	11,900	13	77.4
September	10,000	13	64.1
October	8,000	14	56.0
November	6,500	19	61.5
December	6,200	22	68.0

*Average temperature difference between returned water and Lake Erie intake water.

The figures shown are based on the conservative assumption of 105% power.

The maximum heat content of the water returned will be about 78,300,000 Btu per hour. This is less than 20% of the recommended limit proposed by the Lake Michigan Enforcement Conference in the spring of 1971 for Lake Michigan.



Q Temp. °F	Vel, ft/sec	@ Distance, ft
24	6.7	0
10.1	3.1	100
7.2	2.2	200
5.7	1.8	300
4.9	1.55	400
4.3	1.4	500
1	- -	1000

Given Conditions:

Flow = 12,000 gpm
 ΔT Above Ambient = 24°F
 Lake Temp. = 76°F
 Near Calm Atmospheric Conditions

**ENRICO FERMI ATOMIC POWER PLANT, UNIT 2
 THERMAL PLUME FROM POND DISCHARGE TO LAKE ERIE**

FINAL REPORT

THE APPLICATION OF REMOTE SENSING
TO DETECTING THERMAL POLLUTION

PART II: IMPLEMENTATION PLAN

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I. INTRODUCTION

As the world demand for electricity continues to increase, the supply of fossil fuels for power production is being depleted. More nuclear power plants will be built to meet this demand. One of the problems that hinders the acceptance of nuclear power plants is the thermal pollution associated with their cooling systems. This thermal pollution can cause adverse effects on the ecological systems. In a report (1) on Potential NASA Initiative in Water Resources, it is pointed out that controlling the heated water discharges has been identified by the Office of Water Resources Research as one of the important problem areas. Thermal pollution is also one of the problems to be considered in a NASA Environmental Quality Enhancement Program Study (2). Proper management will be based on the ability to detect thermal pollution and to alleviate it. In order to achieve this goal, it is necessary to have a thorough understanding of the motion and diffusion of thermal discharges and the extent of the region affected. Most studies in this area have been empirical or semi-empirical in nature. The few existing models are based on much too simplified assumptions, and are limited to one or two-dimensional studies. In order to obtain a better description of the physical situation, a more accurate prediction of the water body temperature distribution is needed. In the first part of this project, it has been concluded that the development of a three-dimensional generalized, predictive, analytical model involving remote sensing and in-situ measurements is feasible. It has also been found feasible to develop an active system to remotely measure turbidity.

In this section of the final report, the implementation plan for the development of a three-dimensional model and for the application of remote sensing to temperature and turbidity measurements will be outlined in detail.

References

1. Tremor, J.W., "Potential NASA Initiative in Water Resources," NASA Office of Application, 1973.
2. NASA Office of Applications, "Environmental Quality Enhancement Program Study," 1972.

II. PROJECT DESCRIPTION

It is planned to develop a generalized, vigorous, three-dimensional, predictive, analytical model for determining the temperature distribution in a water body receiving hot discharges from a power plant's cooling system. The model will make use of wind, tide, current and salinity distributions and their effects. Remote sensors and in-situ measuring systems will be used to quantitatively measure water surface temperature distribution, vertical water temperature profile, current, salinity, turbidity and other parameters that are pertinent to the model development.

The analytical model will be applied to two power plant sites, namely, the Florida Power and Light Company's Turkey Point and Port St. Lucie facilities, as case studies. Numerical calculations for these two sites, in conjunction with remote sensing and in-situ measurements, will be used for the checking, verification, and evaluation of the analytical model.

III. SITES SELECTED FOR IMPLEMENTATION PLAN

As explained in the feasibility study section of this report, there are several sites located on coastal regions or on lakes, on which there are nuclear power plants either in service or under construction. From these sites, two have been selected for the development and testing of the model and for the development of remote sensing for thermal pollution and turbidity detection. These two nuclear power plant sites are the Florida Power and Light Company's Turkey Point facility and Port St. Lucie Nuclear Power Plant units on Hutchinson Island. These two sites are located in south Florida, close to both the Kennedy Space Center and the University of Miami. Another interesting feature is their geographical contrast. The Turkey Point facility is located at a shallow lagoon type estuary, while the Hutchinson plant discharges into the off-shore continental shelf. Both sites should provide a good test area for the universal nature of the proposed three-dimensional model. A detailed description of these two sites are given in the Site Studies Section of Part I of this report. However, a brief discussion is presented here to provide background for the implementation plan.

The Turkey Point site is located on the western shore of Biscayne Bay approximately 25 miles south of Miami. This facility consists of two fossil fuel plants and two nuclear units with a combined 2320 MWe output. Its cooling system has been modified twice in the past due to the concern regarding the effects of hot discharges into the nearby estuaries. In the latest modification, the Florida Power & Light Company has adapted a complicated canal system aimed at the recirculation of the cooling water. The construction of this cooling system began in November 1971 and was scheduled for completion by November 1975. It has been determined that the completed part of the system has been set into preliminary testing. Some studies have been conducted at the Turkey Point site during various stages of its development. However, these do not include a predictive model study relating both

the dynamic and thermodynamic effects on this site.

The St. Lucie site is located on Hutchinson Island in St. Lucie County about halfway between Fort Pierce and Stuart on the east coast of Florida. The site is generally flat and has a dense vegetation characteristic of Florida coastal mangrove swamps. Two identical units will provide 850 MWe each of full load. The first unit is scheduled to enter service by September 1975 while the second unit will be put into service by September 1979. A preliminary design of the cooling system indicates that the intake pipes will be located approximately 2300 feet south of the discharge pipe. They will be buried from the intake points for a distance of about 1600 feet beneath the ocean bottom and under the beach, terminating in a canal on the west side of the sand dunes. The cooling water discharges will be carried in a twelve foot diameter pipeline about 1425 feet long, buried under the dunes, the beach and beneath the ocean bottom. The pipeline will terminate at a depth of 18 feet. The twelve foot diameter pipe will be modified with a short transition section and a two part Y-type discharge pipe will be added. Approximately 20 feet of water will be over the top of each port. Both ports in the Y-section will be 7.5 foot in diameter and the discharge velocity from each port will be about 13 feet per second. The FP&L company has sponsored some preliminary environmental studies offshore at Hutchinson Island.

Due to the rapid growth of the south Florida area, the FP&L Company has announced plans to build more power plant units to help supply the increasing electricity power demand. The proposed model study will be useful in the site selections for future power plants in the U.S. as well as the world.

IV. IMPLEMENTATION PROCEDURES AND SCHEDULE

The study program will be carried out in four parts. They are closely related and are to be conducted concurrently. The mathematical model development is the first part of the project. Remote sensing and in-situ measurements, the second and third parts, will be needed to support the model development. These parts of the study should be carefully scheduled, so as to obtain ground truth readings as well as calibrations of the remote sensing data. At the same time, a turbidity remote sensing system, forming the third part, will be developed. This portion will require some controlled study in the early stage, but the system is expected to be ready for field application in the latter stage of the program. The details of each part of the study are given in subsections A through D of this section.

The proposed study should take three years to complete - starting on January 1, 1974 and ending on December 31, 1976. The entire period will be divided, roughly, into four stages, corresponding to the proposed study plan. In the first six months, the work will be initiated on the mathematical model and numerical schemes for the solution of governing equations will be compared. Computer programming will be carried out. The in-situ measurement system will be designed and the acquisition of instruments will be started.

In the second stage, a twelve month period will be devoted to the development and application of the mathematical model to the Turkey Point site as a testing case. Both the remote sensing and in-situ measurements will be carried out at this site in order to provide the needed information for the model study. The results will be evaluated and the model will be examined and refined. In the third stage, the St. Lucie site (a site which has different characteristics than the Turkey Point site) will be used for another case study of the mathematical model. This stage of the study will cover a period of twelve months.

The final six months of the project will be devoted to the

evaluation and assessment of the program. Recommendations will be made and the Final Report will be prepared.

The aforementioned schedule and milestones of the project are summarized in Table 1, while the detailed schedules for the various phases of the program are given in the following subsections.

Table 1 Time Schedule and Milestones of the Study Program

Task	Months						
	1	6	12	18	24	30	'36
Model Formulation and Set Up of Numerical Scheme	xxxxxxx						
Remote Sensing & In-Situ Measuring System Design	xxxxxxx						
Semi-Annual Progress Report		I					
Model Development & Application to Turkey Point		xxxxxxx					
Semi-Annual Progress Report			I				
Continue Operations at Turkey Point Site			xxxxxxx				
Mid-Term Report				I			
Application to St. Lucie Site				xxxxxxx			
Semi-Annual Progress Report					I		
Continue Operations at St. Lucie Site					xxxxxxx		
Semi-Annual Progress Report						I	
Evaluation And Assessment						xxxxxxx	
Final Report							I

A. MATHEMATICAL MODEL DEVELOPMENT

The mathematical model study will be carried out in four stages. In the initial stage, three months will be devoted to the Model Formulation and the setting up of proper numerical scheme to be used for the solution of the governing equations. The Marker and Cell technique which was discussed earlier in the Feasibility Study portion of this project will be used for the numerical solution of the model. During this period, there will also be an intensive collection of previously measured field data from the lower Biscayne Bay and Card Sound area near the Turkey Point power plant site. This information will be used to help set up the preliminary initial and boundary conditions of the model for the trial runs and debugging during the next three months.

In the second stage, a total of twelve months will be spent to develop, test and evaluate the model using the Turkey Point power plant site as a case study. The development will consist of five steps, namely, 1) Set Up the Model, 2) Programming and Debugging, 3) Testing and Modifications, 4) Numerical Calculation and Refinements, and 5) Evaluation and Assessment of the Model. During this period, numerical results from the model will be constantly compared with actual remote and in-situ measurements to provide a critical assessment for the validity of the model. All calculations of Turkey Point site should be completed by the end of this stage.

In the following twelve months, the model will be modified and converted to be used to predict the Florida Power and Light Company's St. Lucie Plant discharge. This model study again will be developed in five stages similar to the Turkey Point site computations. It is expected that the time period necessary for the St. Lucie Plant model study will be substantially shortened because certain techniques developed in the Turkey Point Plant calculations may be directly used for the St. Lucie case. During this period, Remote and In-Situ Measurements at St. Lucie site will be collected and used to compare with the predicted values.

This will provide a further evaluation of the validity of the model.

The last six months of the project will be used for data analysis, final evaluation and assessment of the mathematical model, and the preparation of the final report.

Preliminary computations and debugging will be made through the computer facility of the University of Miami. This will involve a simplified version of the model with a minimum number of grid points. It is hoped that the computing facility at the Kennedy Space Center will be available for formal numerical calculations at later stages. In Fig.1 contained herein, a flow chart is given to show the steps to be used in the model development. A summary of the time schedule for various stages of the proposed model study is given in Table 2.

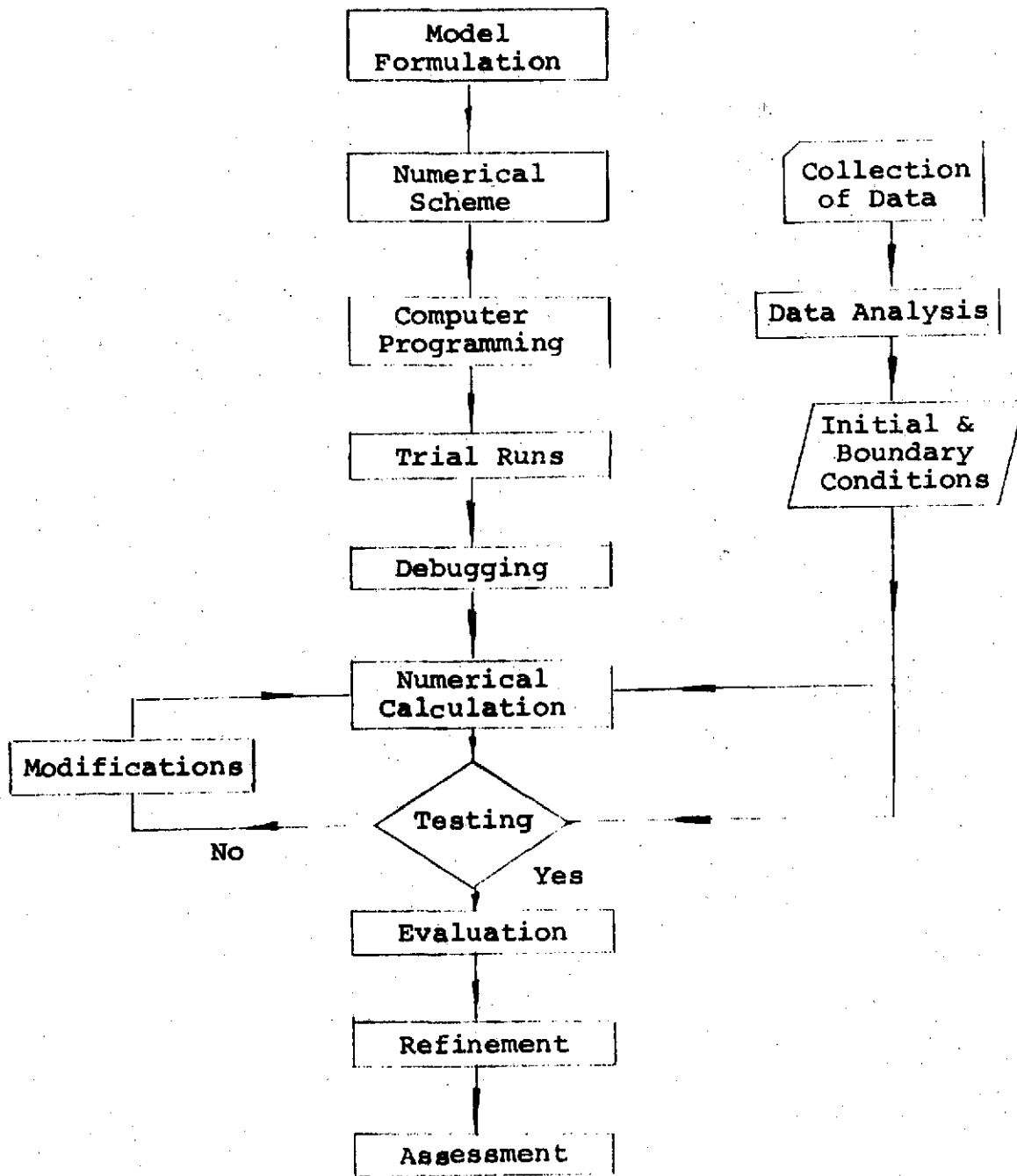


Fig. 1 Flow Chart for Mathematical Model Development

Table 2 Time Schedule for Mathematical Model Study

Task	Months							
	1	6	12	18	24	30	36	
Model Formulation & Set Up of Numerical Scheme	xxx							
Computer Programming		xxx						
Collection of Previous Measured Data for Turkey Point Site	xxx							
Data Analysis and Set Up of Preliminary Initial & Boundary Conditions		xxx						
Trial Runs, Debugging, Test and Modification			xxxx					
Analysis of Remote & In-Situ Data and Set Up of Initial & Boundary Conditions			xxx					
Numerical Calculation for Turkey Point Site				xxx				
Further Test, Modification & Numerical Calculation					xxxx			
Refinement and Evaluation of Model						xxx		
Conversion of Model for St. Lucie Site							xx	
Data Analysis and Set Up of Initial & Boundary Conditions						xxx		
Trial Runs, Debugging, Test and Modification							xxx	
Numerical Calculations for St. Lucie Site							xxxxxxx	
Refinement and Evaluation								xx
Final Assessment of Model								xx
Preparation of Final Report								xxxxx

B. GROUND TRUTH AND IN-SITU MEASUREMENTS

This part of the program will serve many purposes. It is to provide ground truth for the remote sensing measurements, to provide initial and boundary conditions and verification of the mathematical model and to assist in the development of new remote sensing techniques. Because of the special nature of this portion of the study, the planned procedures for the in-situ measurements will be carefully scheduled in conjunction with other phases of the project.

In the initial stage, four months will be devoted in the design of the in-situ measuring system, and in making plans for measurements using small boats. The flow diagram in Fig. 2 shows various steps of the system design and its relationship with other portions of the project. During this period, ocean instrumentation will be acquired and shipboard instruments will be assembled and coordinated. The assembled instruments will be carefully tested and calibrated. In the following eight months, in-situ measurements will be carried out at the Turkey Point site by boat. The important quantities in this part of the measurements are horizontal and vertical temperature profiles, current flows at strategic places, salinity, and turbidity. If deemed advisable for its effect on the ocean environment, dissolved oxygen and pH levels can also be determined; but these measurements would require additional instrumentation. This data, together with the results of previous measurements, will supply the needed information for the mathematical model study. It is contemplated that approximately 10 boat trips will be needed for this phase of the study. During the latter part of this period, shipboard instruments will be used together with remote sensing operation for ground truth and calibration purposes. Another important task in the shipboard tests will be to determine the temperature distribution at and near the surface. Since the remote sensor will indicate only the water surface temperature, there is some question as to the temperature distribution beneath the surface.

This will also be useful for the mathematical model study.

As data is received, data analysis procedures will be instituted using the Festsa time series routines on the University of Miami Univac Computer. These routines are available and have been widely used in the past and include almost all of the operations which will be needed in this project such as correlation, filtering, statistical distribution, fast Fourier transforms, etc.

In the latter part of the first year and early part of the second year, the fixed sensors will be installed at Turkey Point. For the three-dimensional mathematical model, temperature measurements at several depths will be desirable. Thermistor strings with 3 thermistors on each string, one near the surface, one near the bottom, and one at mid-depth should be adequate for this task. Since it is likely that these strings would be installed in unprotected waters, it seems advisable to use magnetic tape recording for the output and service the installations by boat at regular intervals. These service trips would also be useful to verify that the system is in proper operating condition. Telemetry equipment is quite expensive and would be inadvisable to use in a situation where this equipment could be lost. By proper timing of the temperature readouts, synchronization between this ground truth and the remote measurements is not necessary since the needed temperature data could be easily obtained from the time series data and due to the time constants involved will be sufficiently accurate.

During the second year, ship measurements will be started at the Port St. Lucie site in order to provide the necessary information needed for the model and for the installation of the fixed sensors. The remainder of the schedule at the Port St. Lucie site will proceed in the same manner as the program used at Turkey Point, and should be ready for measurements when the plant (St. Lucie) is scheduled for operation.

The final stage of the study will be devoted to evaluating the system, to making recommendations for further study, and to

the preparation of the final report.

An outline of the planned procedures to be used for this phase of the program is given in Table 3 . Table 4 gives the time schedule of the various stages of the study during the three year period of the project.

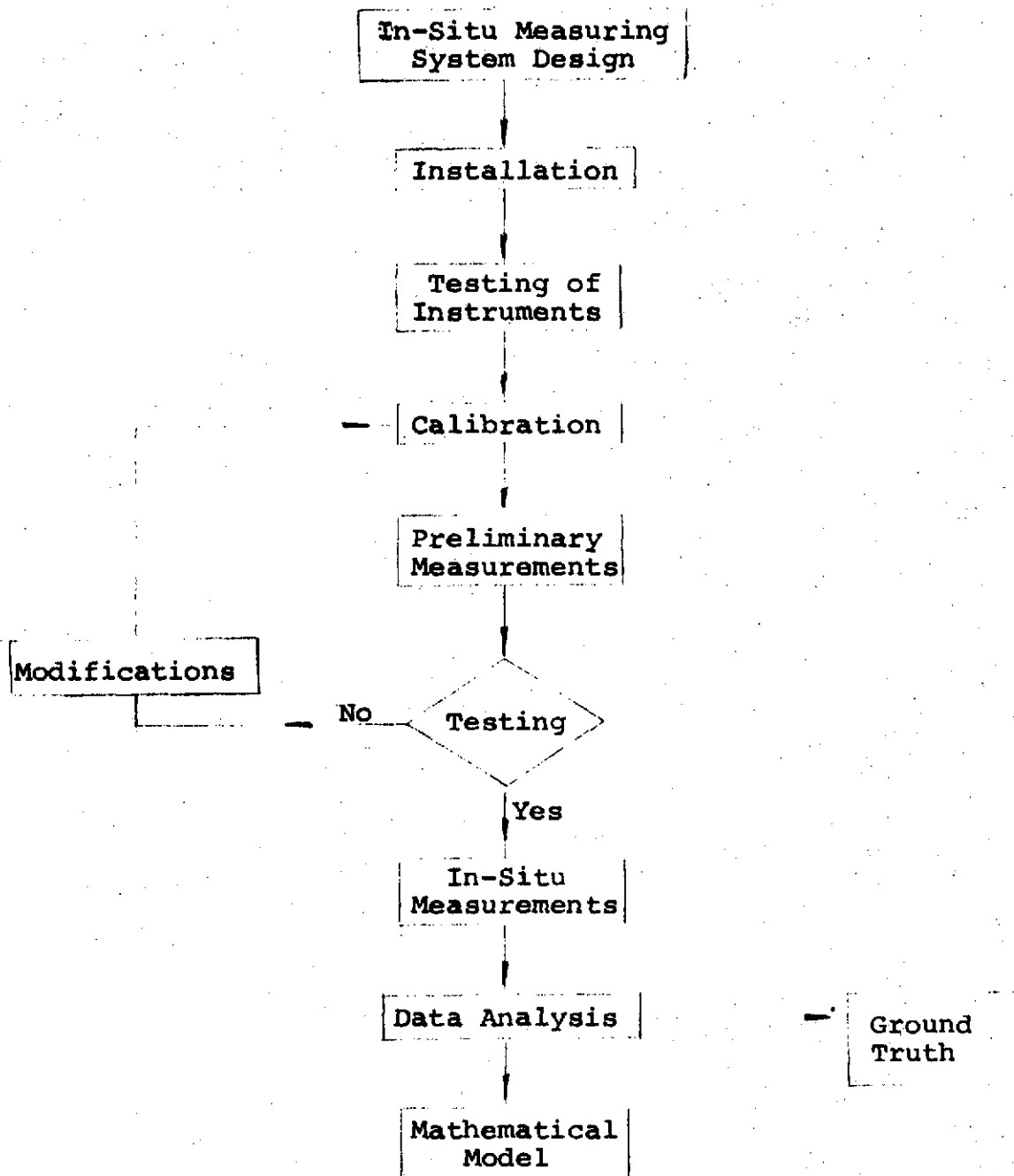


Fig. 2 Flow Chart for Ground Truth and In-Situ Measurement Study

Table 3 . Planned Procedures for In-Situ Measurement Study

- a. In-Situ Measurement System Design and Planning for Measurements Using Small Boat (4 months from January to April, 1974)
 - 1) Design of Measurement System
 - 2) Acquisition of Instrumentation
 - 3) Assembling and Coordination of shipboard Instruments for use with ocean sensors.
 - 4) Testing and Calibration of assembled instruments.

- b. In-Situ Measurements at Turkey Point Site by Boat (4 months from May to August, 1974)
 - 1) Measuring variables of interest: temperatures, salinity, current flow, current direction and turbidity.
 - 2) Data analysis
 - 3) Determination of locations for fixed sensor installations based on item 1).
 - 4) Determining suitability of results for mathematical model study.

- c. Ground Truth and Remote Sensing Calibration Experiments (4 months from September to December, 1974)
 - 1) Data correlation with remote sensors and boat.
 - 2) Calibration study
 - 3) Ground truth for remote sensing study.
 - 4) Investigation of ERTS DCS for collection of ground truth data.
 - 5) Set up of time series analysis routines for data interpretation.

- d. Installation of Fixed Sensors at Turkey Point Site and Boat Measurement at St. Lucie Plant by boat (6 months from January to June, 1975)

- 1) Installation and Calibration of sensors at Turkey Point Site.
 - 2) Testing and Modification of system.
 - 3) In-Situ Measurements at Turkey Point Site.
 - 4) Assembling instruments for boat measurements at St. Lucie Site.
 - 5) In-Situ measurements at St. Lucie site by boat.
- e. Data analysis for Turkey Point Site and Installation of Sensors at St. Lucie Site (6 months from July to December, 1975)
- 1) Further measurements at Turkey Point site.
 - 2) Data analysis and correlation.
 - 3) Installation and Calibration of sensors at St. Lucie Site.
 - 4) Further measurements at St. Lucie site by boat.
- f. In-Situ measurements at St. Lucie Site (6 months from January to June, 1976)
- 1) In-situ measurements in conjunction with remote sensors.
 - 2) Data analysis and correlation.
- g. System Evaluation (6 months from July to December, 1976)
- 1) Evaluation of measurement system
 - 2) Recommendation for future study
 - 3) Final report Preparation.

Table 4. Time Schedule for In-Situ Measurement Study

Task	Months						
	1	6	12	18	24	30	36
Design of In-Situ Measuring System	xx						
Installation, Testing and Calibration of Boat Instruments	xxx						
In-Situ Measurement at Turkey Point Site by Boat Only		xxxxxxxx					
Installation Testing and Calibration of Fixed Sensors at Turkey Point Site				xx			
Preliminary Measurements by Fixed Sensor Testing of Results and Modification of System				xx			
Continue In-Situ Measurements at Turkey Point Site					xxxxxx		
Data Analysis					xxxxxxxxxxxxxxxx		
Installation, Testing and Calibration of Boat Instruments at St. Lucie Site				xx			
In Situ Measurements at St. Lucie Site by Boat Only					xxxxxxx		
Installation, Testing and Calibration of Fixed Sensors at St. Lucie Site						xxxx	
Continue In-Situ Measurements at St. Lucie Site						xxxxxxxxxx	
Data Analysis					xxxxxxxxxxxxxxxx		
Evaluation of System							xxxx
Final Report Preparation							xxxx

C. REMOTE SENSING WATER SURFACE TEMPERATURE STUDY

The water surface temperature will be remotely measured by Infrared Scanners to provide information needed for the mathematical model development. This data will be used for providing initial and boundary conditions of the model as well as for testing and evaluating the model. It is expected that the Kennedy Space Center's NASA-6 aircraft and its infrared equipment will be made available for use in this phase of the study. The Air Force DAPP satellite IR data will also be required. This aspect of the study will be conducted in conjunction with in-situ measurements for ground truth and calibration purposes. The study will be carried out in stages as follows:

In the initial stage, two months will be used for the design of the remote sensing system. The system design and its interface with other parts of the project is given in Figure 3. Arrangements will be made for the use of the Air Force DAPP satellite IR data and the Kennedy Space Center's NASA-6 aircraft along with its infrared equipment.

In the second stage, six months will be devoted to conducting an Atmospheric Effect Convection Study. During this period, experiments will be conducted in the use of the Air Force DAPP satellite IR data for measuring sea surface temperatures. Data and a computer program will be acquired from NOAA to compute the total atmospheric moisture column as observed from a NOAA-3 satellite. Atmospheric moisture computed from the NOAA-3 satellite will be compared with measurements by radiosonde where possible. The best estimate of total moisture will then be used to correct the DAPP satellite IR measurements of sea surface temperature for atmospheric absorption losses.

In the later stages of the study, preliminary tests will be made of NASA-6 aircraft and DAPP satellite IR measurements of sea surface temperatures by comparing them with each

other and with our ground truth measurements. This should produce some preliminary results for use in the mathematical model. In this stage, a series of comparisons will be made between DAPP satellite IR sea surface temperature measurements and related ground truth measurements. ERTS-B IR data will also be used if it becomes available by this time. Sea surface temperature data for the model will be provided. A period of approximately eight months will be needed to complete this stage of the study.

In the fourth stage, thermal mapping on the Turkey Point site will be prepared using IR data from the NASA-6 aircraft and the DAPP and/or ERTS-B satellites. Checks of the results will be made of by use of ground truth measurements. This data will be analyzed and then made available for the mathematical study.

During the mid-term of the project, this remote sensing operation will be moved to the St. Lucie site for background study and thermal mapping of the heated discharges in the area. The measured data will be calibrated and analyzed.

In the last six months, the system will be critically evaluated, recommendations will be made for future studies and a final report will be prepared. A summary of the time schedule for this phase of the study is given in Table 5.

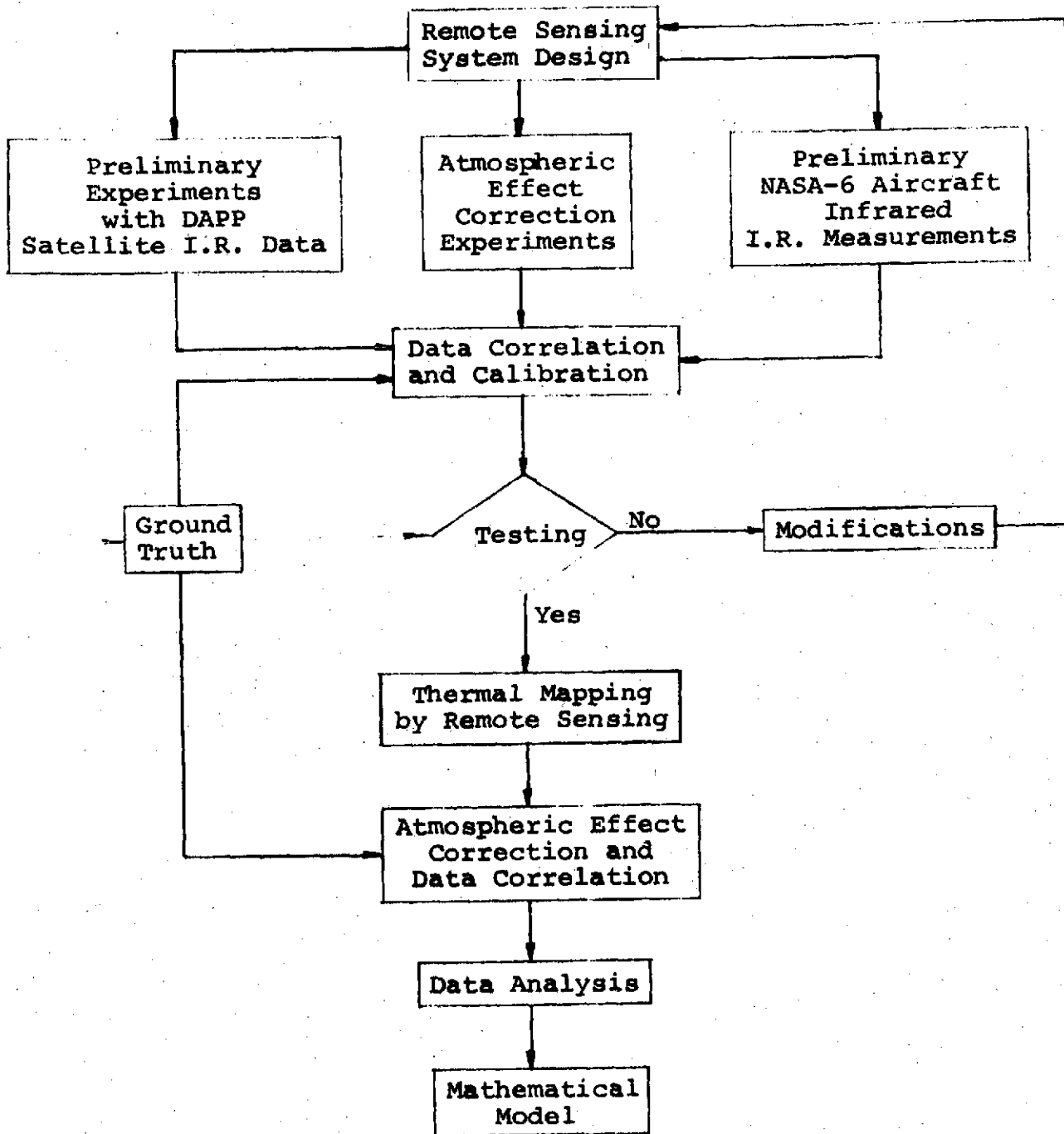


Fig. 3 Flow Chart for Remote Sensing Study

Table 5. Time Schedule for Water Surface Temperature Remote Sensing Study

Task	Months						
	1	6	12	18	24	30	36
Design of Remote Sensing System	xx						
Atmospheric Effect Correction Study		xxxxxx					
Preliminary Experiments with DAPP Satellite I.R. Data		xxxxxx					
Preliminary NAS-6 Aircraft I.R. Measurements				xxxx			
Data Correlation, Correction and Calibration Study				xxxx			
Testing of Results and Modification of System					xx		
Continue Remote Sensing of Turkey Point Site					xxxx		
Data Analysis					xxxxxxxxxxxx		
Preliminary Remote Sensing at St. Lucie Site, Testing and Calibration Study						xxxx	
Thermal Mapping at St. Lucie Site by Remote Measurement							xxxxxxxxxx
Data Analysis						xxxxxxxxxxxx	
Evaluation of System							xxxx
Final Report Preparation							xxxx

D. TURBIDITY LASER SYSTEM AND GROUND TRUTH WATER SURFACE TEMPERATURE STUDY

This phase of the project can be divided into three parts, namely, 1) Ground Truth Water Temperature Study, 2) Atmospheric Effect Correction Study and, 3) Turbidity Laser System Study.

These studies and the planned procedures are explained here below:

1) Ground Truth Water Temperature Study

Infrared remote sensing of the sea surface can only hope to measure the temperature of the top 1/10 millimeter of the water. This is because the transmission of water for the 8-14 micrometer radiation used for remote sensing temperature measurements is almost zero. Therefore only the top layers of water within less than 1/10 millimeter of the surface participate in sending their radiation up to the sensor aloft. For this reason, remote sensing measurements may not agree exactly with sea temperatures (ground truth) measured with thermistors. Under conditions of heat loss from the surface due to evaporation, and poor mixing of the upper layers of the sea, the skin temperature may differ appreciably from the body temperature. This would cause a false correction to be applied to the remote sensing measurements. To prevent this, the skin temperature will be measured with an infrared sensor at the same positions that temperature measurements are being made in the ordinary way with thermistors.

The infrared sensor will be procured and tested during the first 6 month period of the program, and will be applied routinely with the other ground truth equipment thereafter.

2) Atmospheric Effect Correction Study

In the measurement of temperature from aircraft or satellites, the 8-14 micron band of infrared is utilized.

Severe absorption and radiation from the atmosphere itself exists over part of this band, and under some conditions of temperature and humidity lapse-rate, certain corrections have to be made in the data. These corrections (normally between one and four degrees C.) are made on the basis of radiosonde observations where they are available, and average conditions modified by intelligent guesses where they are not. There is also a possibility that satellite data at more than one frequency will also yield the necessary information, but this will probably be rather approximate. By the use of interference filters, one to maximize and one to minimize the effects of the intervening atmospheric layers, it is hoped to provide internal means of correcting for the atmosphere without recourse to other observations. Recent advances in multilayer filter technique leads us to believe that we can obtain filters which either transmit those parts of the 8-14 micron window most affected by water vapor (a filter transmitting the water vapor bonds) or avoid them. By the use of this pair of filters the effect of water vapor in the column of air between the observer and the ground can be ascertained and corrected.

These filters will be procured during the first six months of the program and will be tested in the aircraft thereafter, using ground truth and radiosonde measurements (where available) to assess their performance. It is felt that if this part of the experiment is successful, it will greatly enhance the future value of remote sensing temperature measurements both from air and spacecraft.

3) Turbidity Laser System Study

Turbidity is an important quality for our program, not only because of its obvious aesthetic importance, but

because of its decisive effect on the radiation balance of the deeper layers of the water. Ordinary methods of remote sensing do not measure turbidity because the upwelling radiation from the sea depends primarily on the sea state and the character of the bottom. Using our proposed method, outlined in detail in the feasibility section of the report, we can separate the effects of surface and bottom reflection and measure the back-scattering from the water directly. This is possible because the short pulse (about 5 nanoseconds) of the glass-neodymium pulsed laser allows us to distinguish in time between layers only a few centimeters apart. By using a ADP crystal frequency doubler, blue-green light at 5-30 nanometers can be employed, for which sea water has nearly maximum transparency.

It is planned to purchase and test the components of the TULAS during the first year of the project. During the ensuing six months, the system will be tested from the sea surface. During the next twelve months, aircraft will be used to carry the experiment and develop the system.

V. MANAGEMENT PLAN

Personnel will include Drs. T. Nejat Veziroglu, Samuel S. Lee, Robert L. Lee, Norman L. Weinberg, Homer W. Hiser and Joseph G. Hirschberg of the University of Miami Faculty, graduate research assistants, technicians, and secretarial support. The following list gives the special fields of interest of each member of the investigation team:

<u>Investigators</u>	<u>Special Fields of Interest</u>
T. Nejat Veziroglu Principal Investigator	Heat Transfer, Thermal Pollution, Two-Phase Flows
Samuel S. Lee Co-Principal Investigator	Fluid Mechanics, Heat Transfer, Thermal Pollution
Robert L. Lee Co-Investigator	Fluid Mechanics, Atmospheric Sciences, Heat Islands
Norman L. Weinberg Co-Investigator	Underwater Acoustics, Wave Propagation, Ocean Measurements
Homer W. Hiser Director, Radar Laboratory	Meteorological Sciences, Radar, Air Pollution, Remote Sensing
Joseph G. Hirschberg Director, Optics Laboratory	Optics, Radiation, Holography, Remote Sensing

Dr. T. Nejat Veziroglu, Professor and Chairman, Mechanical Engineering Department, will be in charge of the management of the project as the Principal Investigator. He will: 1) Provide leadership and scientific input in establishing overall goals and objectives; 2) Coordinate the efforts of the co-investigators to reach the project objectives; 3) Maintain liaison essential to project support, both on and off campus; 4) Monitor progress of the project; and 5) Assume full administrative responsibility for the implementation of the project. Dr. Samuel S. Lee, Associate Professor of Mechanical Engineering, will help Dr. Veziroglu in the overall management of the project as the Co-Principal Investigator.

The day-by-day administration and coordination of individual research activity will be the responsibility of each investigator. However, much of the administration detail, such as purchasing and

and fiscal reporting, will be handled centrally. This will minimize the redundancy and free the investigators to concentrate on the scientific aspects of the project.

VI. WORKLOAD DISTRIBUTION

Every member of the team, including the principal investigators, will be involved in the investigation. The workload distribution among the researchers in general will be as follows:

<u>Research</u>	<u>Major Responsibilities</u>
Dr. T.N. Veziroglu	<ol style="list-style-type: none">1. Principal Investigator and Study Manager2. Administration and overall Coordination3. Assessment of results
Dr. S.S. Lee	<ol style="list-style-type: none">1. Co-principal Investigator2. In charge of Technical Aspect of entire project3. Mathematical Model Study
Dr. R.L. Lee	<ol style="list-style-type: none">1. Mathematical Model Study
Dr. N.L. Weinberg	<ol style="list-style-type: none">1. Ground Truth and In-Situ Measurements
Dr. H.W. Hiser	<ol style="list-style-type: none">1. Remote Sensing of Water Surface Temperature
Dr. J.G. Hirschberg	<ol style="list-style-type: none">1. Turbidity Laser System Study2. Ground Truth Surface Temperature Study

However, the above distribution is not meant to be strict. There will be close cooperation between researchers, and in some instances two or more researchers may work closely (e.g. on different aspects of a given subject). The team members will meet regularly to coordinate their efforts.

VII. UNIVERSITY AND FACILITIES

The University of Miami is a full-fledged university composed of nine colleges and schools. They are the School of Engineering and Environmental Design, the College of Arts and Sciences, the Rosenstiel School of Marine and Atmospheric Sciences, the Graduate School, the School of Medicine, the School of Nursing, the School of Education, the School of Law and the School of Business Administration.

Among the laboratories of the School of Engineering and Environmental Design are the Remote Sensing Laboratory, Fluid Mechanics Laboratory, Heat Transfer Laboratory, Electronics Laboratory, Instrumentation Laboratory, Ocean Measurements Laboratory and Hanger Electronic Computer Laboratory. The College of Arts and Sciences possesses the Optics Laboratory. In addition, the University possesses a Computer Center which houses a UNIVAC 1106. In the execution of the project, use will be made of the above listed laboratories and the computer facility.