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Phelps, Steven

From:	Julie Crocker <julie.crocker@noaa.gov>
Sent:	Monday, April 16, 2012 3:31 PM
To:	Balsam, Briana
Cc:	Logan, Dennis; Smith, Maxwell; Susco, Jeremy; Egan, Joseph
Subject:	Re: FW: Pilgrim question

Thanks! Looking at plate 3.44 and 3.45 it seems like the plume out to a delta T of 3C extends about 4,000 feet from the discharge canal and is about 5,000 feet wide. The width seems to be similar to the length - if the maximum size of the plume is 3,000 acres that would mean at its biggest it extends about 7,000 feet from the discharge canal which seems to be in line with what the plates are showing. Does this seem reasonable to you? .
Julie

On Mon, Apr 16, 2012 at 3:00 PM, Balsam, Briana <Briana.Balsam@nrc.gov> wrote:

Julie,

I am forwarding you an email from Joe Egan at Entergy. He was able to get a copy of the MIT study from a former Entergy employee and copied a large number of pages from the study (attached). I am unsure if this will help you, though, because it doesn't specifically characterize the plume in terms of acres or number of meters extending from the discharge. The MIT study was the last study that had the possibility of answering your question, so the best description seems to be in Table 5.1-2 of the 316 Demonstration, as you suggested. And yes--the area of 3,000 acres for the delta T of 1C would represent the worst case scenario.

Joe also provided some additional information on biocides in an email earlier today. I highlighted it in the email chain below.

Briana

Briana A. Balsam

Biologist

Division of License Renewal

Office of Nuclear Reactor Regulation

U.S. Nuclear Regulatory Commission

B|28

301-415-1042

briana.balsam@nrc.gov

From: Egan, Joseph [mailto:jegan1@entergy.com]
Sent: Monday, April 16, 2012 2:44 PM
To: Balsam, Briana
Subject: RE: Pilgrim question

Julie,

Enclosed is a representative excerpt of the MIT study. I copied/scanned almost a third of the pages and tried to be sure I got as many figures and plume survey maps as possible to demonstrate the scope of the document. As the "List of Plates" on pages 7 + 8 shows, there are almost fifty ISOTHERMS in the report.

Possibly because [1] it's from MIT, and [2] it was written in the 70's; I found it difficult to understand if this is what NMFS is looking for.

Let me know if there's anything else I can do.

Thanks,

Joe

From: Balsam, Briana [mailto:Briana.Balsam@nrc.gov]
Sent: Monday, April 16, 2012 1:35 PM
To: Egan, Joseph
Subject: RE: Pilgrim question

Joe,

I left you a message earlier, but I wanted to put it in an email, too, so that you don't go to the effort of printing that whole study if you don't need to. The information that Julie is specifically looking for is a characterization of the geographic extent of the thermal plume at the surface under the worst-case scenario (i.e., when the plume is the largest). If the MIT report summarizes this or provides any figures or isotherm maps that show this, just those few pages may be enough to answer the question. Below, I copied and pasted the last email I got from Julie asking about the thermal plume so you can see her specific words.

I will forward on what you wrote about biocides to Julie. Thanks for that extra info.

Briana

From: Julie Crocker [mailto:julie.crocker@noaa.gov]
Sent: Monday, April 16, 2012 11:50 AM
To: Balsam, Briana
Subject: Re: pilgrim question

Thanks - that info is helpful. Since there does not seem to be a description of the geographic area (i.e., extending X meters from the discharge canal and being X meters wide) occupied by the plume when it is at its largest, I'd like to be able to describe its maximum size. I seem to have what I need to describe the benthic plume but am still struggling with the surface plume -- do you recommend that I use the info from table 5.1-2 in the 316b study which states an area of 3,000 acres for the delta T of 1C? Do you consider that to represent the "worst case scenario"?

Julie

From: Egan, Joseph [mailto:jegan1@entergy.com]
Sent: Monday, April 16, 2012 12:00 PM
To: Balsam, Briana
Subject: RE: Pilgrim question

Briana,

I have two comments to offer:

1] Chlorine is the only biocide used in the operating systems at Pilgrim. About 10 years ago, we got permission from EPA to perform a pilot scale test of a non-oxidizing biocide (Mexel) which lasted a few months. This was the only time a biocide other than chlorine (sodium hypochlorite) was used at Pilgrim.

2] We have located a bound hard copy of the MIT study (Pagenkoff et al. 1974 -- **Oceanographic Studies ... of Condenser Water Discharge**). It has not been scanned and that may take several hours since it is tightly bound and the owner does not want his only copy ripped apart.

Please let me know if I can be of assistance.

Thanks,

Joe

From: Balsam, Briana [mailto:Briana.Balsam@nrc.gov]
Sent: Monday, April 16, 2012 10:25 AM
To: Julie Crocker
Cc: Logan, Dennis; Susco, Jeremy; Smith, Maxwell; Egan, Joseph
Subject: RE: pilgrim question

Julie,

In additional to chlorine, Entergy also adds sodium thiosulfate to neutralize chlorine in discharged water. Occasionally and with prior approval from the EPA or Commonwealth of MA, Entergy also adds molluscicides.

Entergy's 2006 Environmental Report for license renewal states the following:

> During spring, summer, and fall, the circulating water system is chlorinated for up to two hours per day, one hour each pump, to control nuisance biological growth. Total residual

chlorine cannot exceed 0.10 parts per million (ppm) in the cooling water discharge. Continuous chlorination of the service water system can be used to control nuisance biological organisms with a maximum daily concentration of 1.0 ppm and an average monthly concentration of 0.5 ppm in the service water discharge. During chlorination, the screens are operated, and sodium thiosulfate is added to the wash water to remove chlorine and protect organisms returned to the intake canal. Molluscicides are not permitted without the prior approval of the EPA and the Commonwealth.

To follow up on your question from Thursday's phone conversation about the geographic extent of the surface thermal plume; I was not able to locate specific details on the geographic extent of the thermal plume beyond what I had already provided you because all of the available studies (which I sent you last week) refer back to the 1974 MIT study. NRC does not seem to have a copy of this study, nor was my contact at Entergy able to readily locate a copy.

For the 1974 study, MIT collected temperature data over a range of tidal and climatic conditions to characterize the surface plume in June, August, and November of 1973. I am not sure if this study would include maps of the geographic extent of the plume, but this is the only remaining study that might include this information. If you think you need the information contained in this report, it might be best for you to request a copy directly from the MIT Civil Engineering Department. This would be faster than NRC requesting it and then transmitting it to you. Here is a link to the MIT Library catalog record for the study.

Pagenkoff, J.R., D.F. Harieman, A.T. Ippen and B.R. Pearce. 1974. Oceanographic Studies at Pilgrim Nuclear Power Station to Determine Characteristics of Condenser Water Discharge. Massachusetts Institute of Technology. Parsons Laboratory for Water Resources and Hydrodynamics. Cambridge, MA. 156 p.

Briana

Briana A. Balsam

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briana.balsam@nrc.gov

From: Julie Crocker [mailto:julie.crocker@noaa.gov]
Sent: Monday, April 16, 2012 9:26 AM
To: Balsam, Briana
Subject: pilgrim question

Are there any other biocides besides chlorine used at Pilgrim?

Thanks,

Julie

--

Julie Crocker

Protected Resources Division

Northeast Regional Office

National Marine Fisheries Service

55 Great Republic Drive

Gloucester, MA 01930

--

Julie Crocker

R74-20

OCEANOGRAPHIC STUDIES AT PILGRIM NUCLEAR POWER STATION TO DETERMINE CHARACTERISTICS OF CONDENSER WATER DISCHARGE (CORRELATION OF FIELD OBSERVATIONS WITH THEORY)

by

James R. Pagenkopf

Donald R. F. Harleman

Arthur T. Ippen

and

Bryan R. Pearce

RALPH M. PARSONS LABORATORY
FOR WATER RESOURCES AND HYDRODYNAMICS

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MIT

DEPARTMENT
OF
CIVIL
ENGINEERING

SCHOOL OF ENGINEERING
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Cambridge, Massachusetts 02139

B/28 Encl

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A	the discharge channel aspect ratio = h_o/b_o
$\bar{b}$	horizontal distance from the centerline to the jet boundary
b_o	one half the width of a rectangular discharge channel
$\mathbb{F}_o$	the densimetric Froude number of the discharge channel = $\dfrac{u_o}{\sqrt{\dfrac{\Delta\rho_o}{\rho_a} g h_o}}$
h_{max}	theoretical maximum penetration of the discharge jet
h_o	depth of the discharge channel
K	the surface heat loss coefficient = k/u_o
k	the thermal conductivity of water = $K/\rho C$
$\bar{s}$	the horizontal distance from the jet centerline to the boundary of the core region
T_a	the ambient temperature
T_c	the jet centerline temperature
ΔT_o	temperature rise across cooling water condensers
ΔT_c	the surface temperature rise above ambient at the jet centerline = $T_c - T_a$
u_o	the velocity of the discharge channel
V	the ambient cross flow velocity
ρ_a	the density of the ambient water
ρ_o	density of the heated discharge
$\Delta\rho_o$	the difference between the density of the heated flow in the discharge channel and the ambient density = $\rho_o - \rho_a$

1.0 Introduction

1.1 Statement of the Problem

The increased demand for electric power in New England has resulted in the construction of additional electric generating facilities to meet this demand. One of the new power plants is the Pilgrim Nuclear Power Station located at Plymouth, Massachusetts.

Nuclear generating plants such as this must have a heat sink for condenser cooling purposes and in this case the heat sink is Cape Cod Bay. In order to determine the environmental effects of the power plant waste heat on Cape Cod Bay, the area of the heat affected zone must first be determined. This study is designed to test in the field an earlier experimental and theoretical study entitled, "An Analytical and Experimental Investigation of Surface Discharges of Heated Water",[3] which was conducted at the R. M. Parsons Laboratory. The verification of this earlier study, with revisions if necessary, will allow the plant operators to predict the water volume affected by P.N.P.S. during operation. Further, it will permit reasonable extrapolations of plume characteristics to enable later modifications or expansion of the P.N.P.S.

2.0 Final Status of Project

2.1 Schedule of Observations

Three surveys have been conducted at the P.N.P.S. site by the faculty and staff of the R. M. Parsons Laboratory since the survey of April 19, 1973. These surveys were conducted on July 2 and 3, 1973; August 30, 1973; and November 13, 1973. The August 30 survey was coordinated with infra-red overflights by Aero-Marine Surveys and ground truth and vertical temperature profiles by Marine Research, Inc. During the November 13 survey, the plant was operating at only 50% capacity but field data under these conditions was considered valuable in light of the analytical model's predictive capabilities.

2.2 Field Measurement Equipment

2.2.1 Conductivity-Temperature-Depth Meter

The CTD (Conductivity-Temperature-Depth) Instrument was not used on the last three surveys. The reason for this is because of its limited use in the shallow areas at the P.N.P.S. site where vertical temperature profiles are important. Instead the "Hydrolab" instrument was employed which is described below.

2.2.2 Hydrolab Surveyor

The Hydrolab Surveyor is a portable, battery powered, integrated instrument system for accurately measuring dissolved oxygen, pH, conductivity, temperature and specific ion activity as functions of depth or time. It is designed to withstand severe weather conditions and is small enough to be used conveniently from a small boat. The Hydrolab has a temperature range of -5°C to 45°C and a temperature accuracy of ± 0.7°C. However, simultaneous calibration of the Hydrolab and the S.B.B.T. improves the overall accuracy close to that of the S.B.B.T.

Its conductivity accuracy is ± 1.5% of full scale for water temperature between 5°C and 45°C. Calibration procedures are straightforward and a maximum recording depth of 15 meters is possible. The Hydrolab Surveyor is a product of the Hydrolab Corporation of Austin, Texas.

2.2.3 Small Boat Bathythermographs

Some problems have been encountered with the use of the small boat Bathythermographs. These include damaged thermistors due to the "fish" hitting rocks or lobster pots or failure of operation due to loose wires in the system. Fortunately additional S.B.B.T.'s were available so that on the whole, little data was lost to these problems. Otherwise, the S.B.B.T. has operated to its highest capabilities and large quantities of data have been recorded.

2.3 Instrument Calibrations

The importance of proper instrument calibration can never be underrated as the accuracy of this whole study relies heavily on the accuracy of the field data. All instruments used by M.I.T. on the P.N.P.S. field surveys are calibrated before and after the survey. As an example, during the August 30 survey, temperature data was taken by three separate organizations; M.I.T., Aero-Marine Surveys and Marine Research, Inc. In order to be comparable, proper calibration is necessary.

At 1715, August 30, 1973, simultaneous readings were taken with the S.B.B.T. probes, the Hydrolab, and the Marine Research probe. The values obtained are:

M.R. Probe	S.B.B.T.	Hydrolab
22.1°C	22.2°C	22.5°C
Field value = Calibrated Value	Calibrated Value	Field value

The S.B.B.T. readings maintain an accuracy of 0.1°C.

2.4 Data Collection and Processing

2.4.1 Data Collection

The data collection scheme for horizontal data follows the same scheme as for the first three surveys. The only difference in data collection is in using the Hydrolab instead of the C.T.D. Because of its small size the Hydrolab was conveniently used from a small boat enabling vertical data collection to reach virtually any point desired in the plume.

S.B.B.T. fish were towed at water depths of approximately 0.5 feet and 4 feet. It is felt that the 0.5 foot level is a good representation of surface temperature. Also the 4 foot level seems to adequately indicate the depth of the plume especially in the far field. Equipment failure due to rocks or other reasons resulted in the loss of some data at the 4 foot level. Also at low tide 4 foot level data was generally not taken in the near shore area due to the numerous rocks that exist there.

During the November 13 survey period, because of the 50% operating status, surface isotherm areas were much smaller than usual. The measurement scheme was altered accordingly so that the same number of transects as before could be run within the plume area. Besides meaning better accuracy in isotherm plotting, this scheme also reduced the time of a survey period to approximately twenty minutes. This is obviously a much closer approximation to steady state conditions, which is important in working with the analytical model.

2.4.2 Data Processing

Reduction of all S.B.B.T. data followed the same procedure as for the first three surveys and is described in the Doret thesis.[1] Data from the Hydrolab is reduced to plots of temperature vs. depth at various points in the plume jet and finally to vertical temperature profiles drawn from these plots.

3.0 Field Data Results

3.1 Ambient Conditions

Ambient water conditions for the three survey periods are presented in Figures 3.1, 3.2 and 3.3. Since substantial ambient stratification exists for the July and August survey periods, a depth averaged ambient water temperature, $\bar{T}$ ambient, is approximated over a depth of about 20 feet. $\bar{T}$ ambient is used for determination of the model input parameters and data analysis. However, the isotherms are plotted using the ambient condition corresponding to the sampling depth of plot.

3.2 Summary of Horizontal Field Data

A summary of all the horizontal profile data collected since June is presented in Plates 3.1 to 3.47. Data presented represents field studies conducted on July 2 and 3, 1973; August 30, 1973; and November 13, 1973.

Plates 3.44 and 3.45 are illustrations of the loci of the limit of distances reached by the 3, 4, 5, 7, 9, 11 and 13°C isotherms. Plate 3.44 includes data from only the first three survey periods. During the respective study periods, the individual isotherms did not exceed these limits.

3.3 Summary of Vertical Field Data

A summary of all the vertical profile data collected is presented in Figures 3.4 to 3.14. Data presented represents field studies conducted on July 2 & 3, 1973; August 30, 1973; and November 13, 1973. The horizontal location of each vertical profile can be found on Plate 3.46 or 3.47, depending on the survey data and station numbers.

The November 13 vertical profiles were taken along the discharge channel centerline. These vertical profiles represent only one vertical plane which is approximately along the centerline of the discharge channel for all profiles.

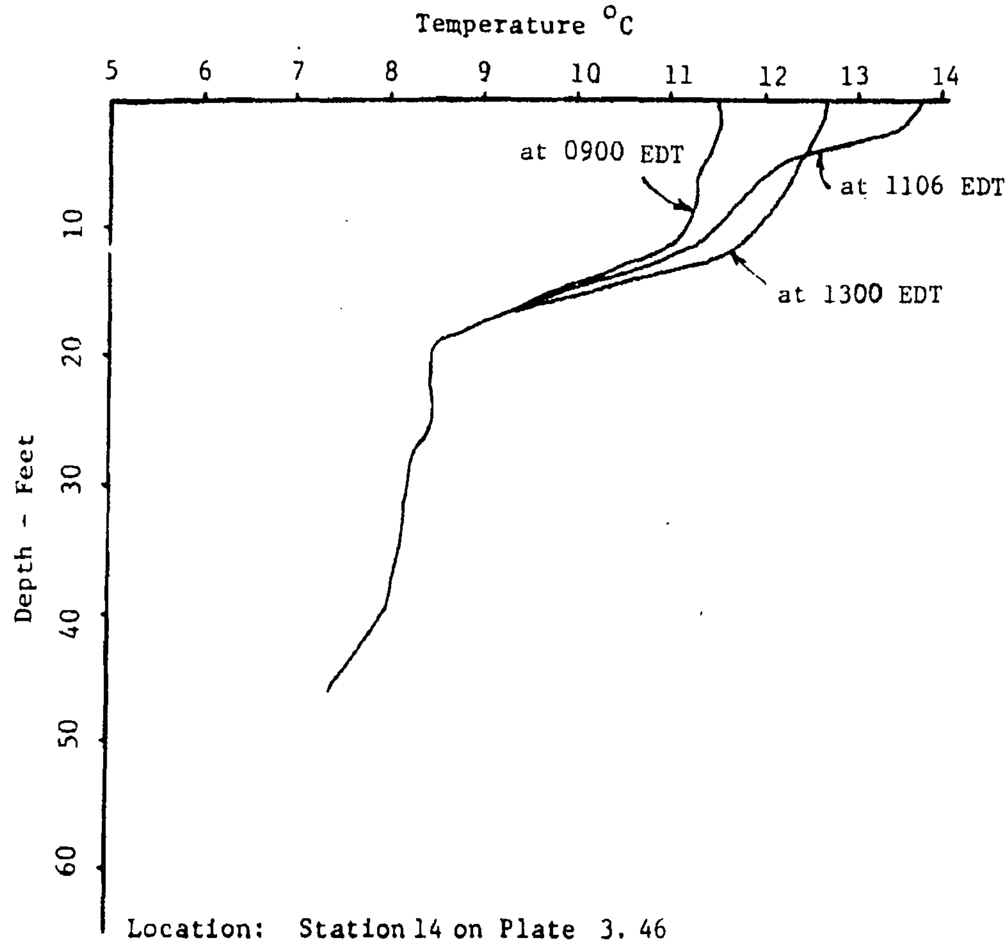


Figure 3.1 7-3-73 Ambient Conditions

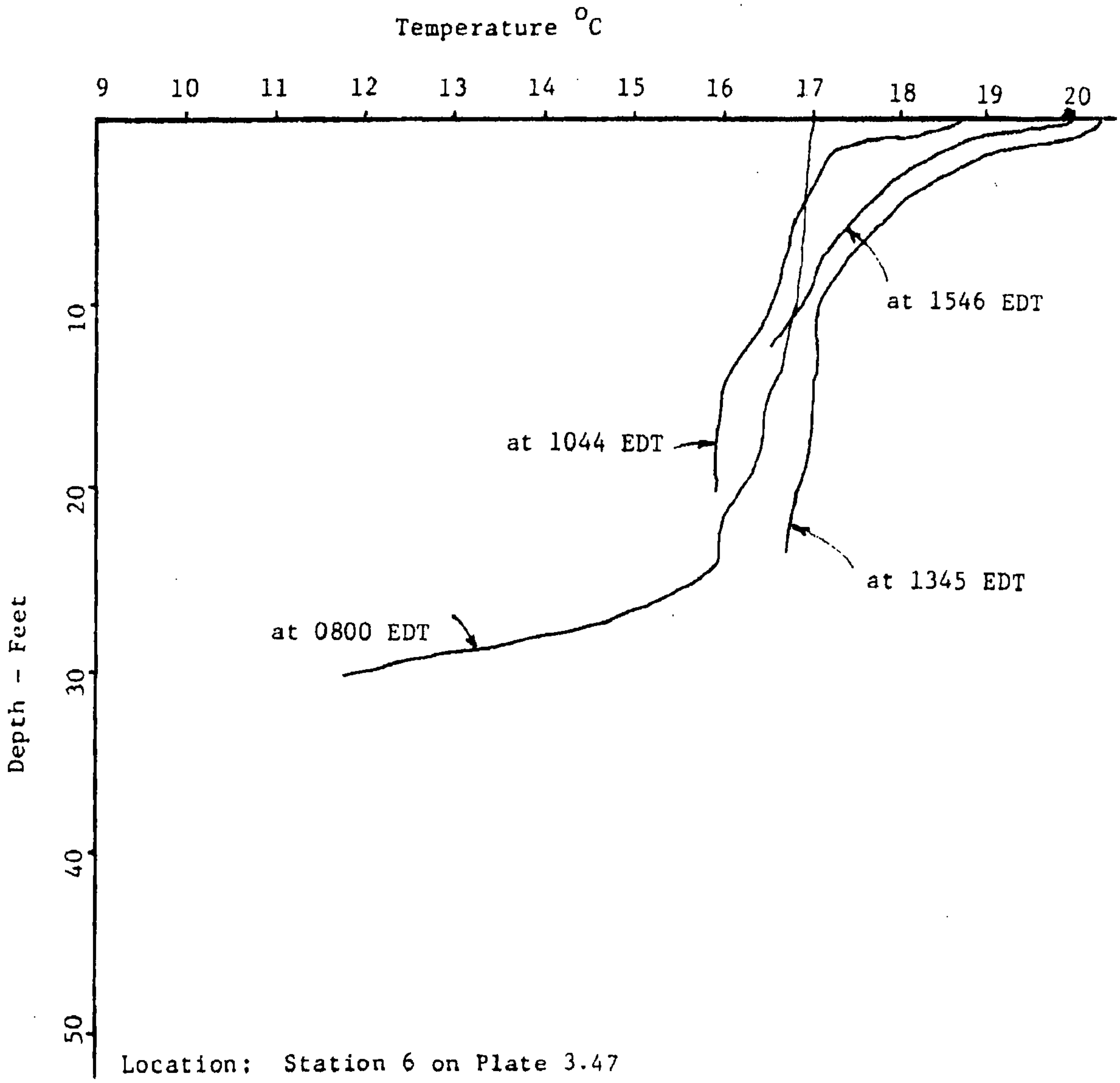


Figure 3.2 8-30-73 Ambient Conditions

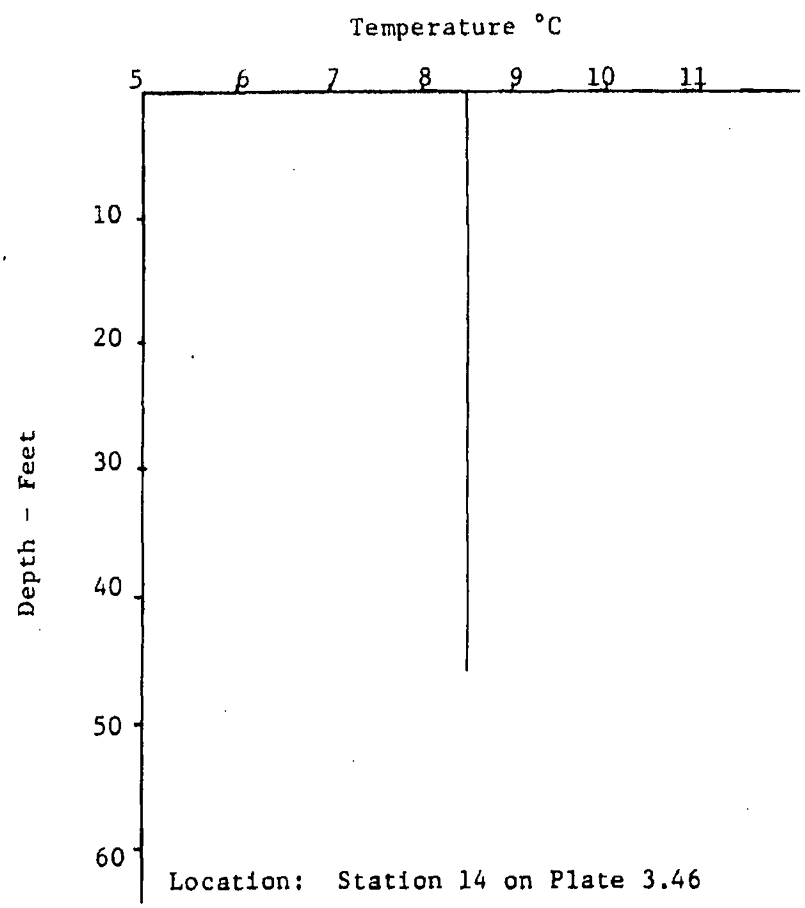


Figure 3.3 November 13, 1973 Ambient Conditions

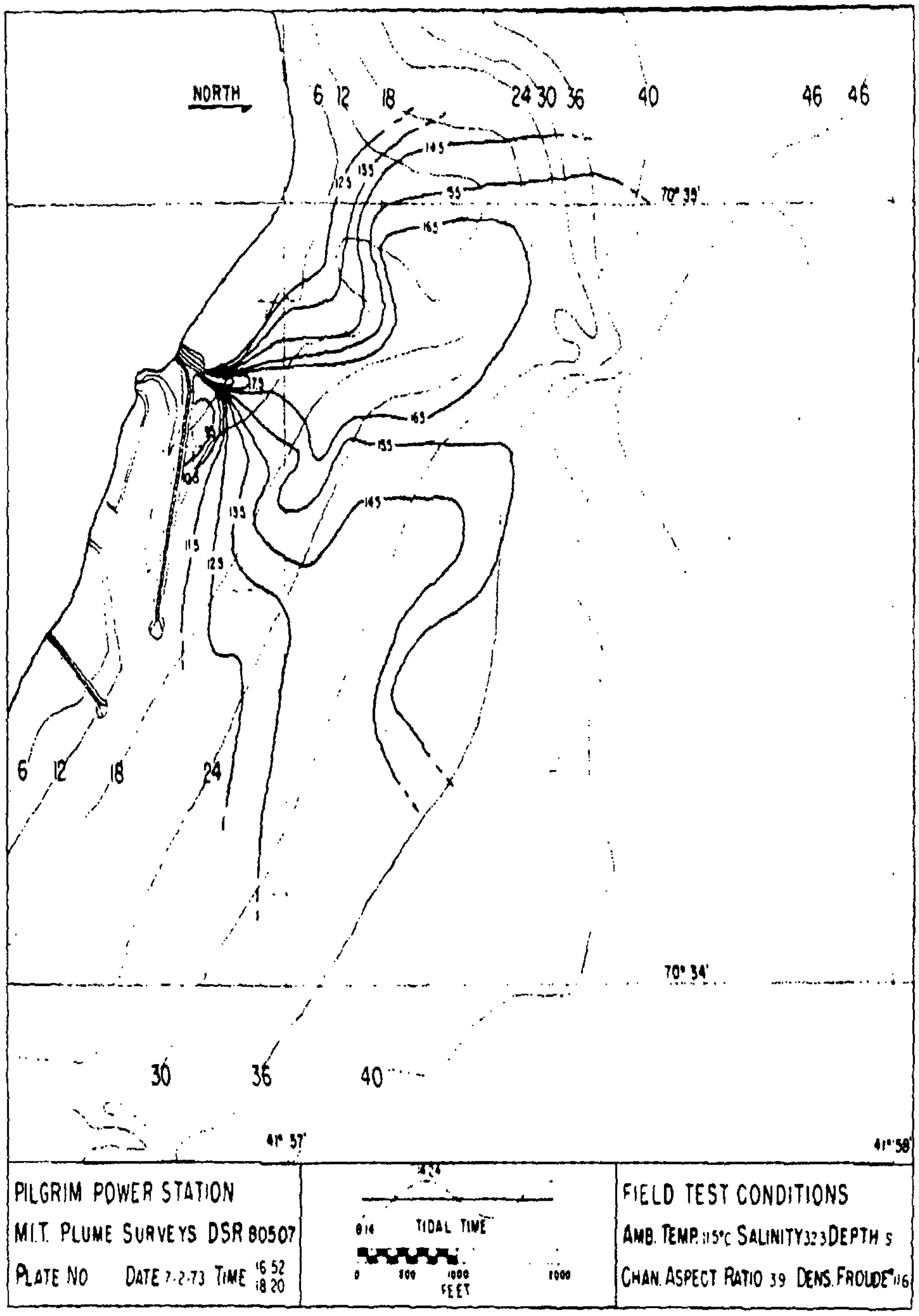


Plate 3.1 July Isotherms, $\mathbb{F}_0 = 11.6$, Surface

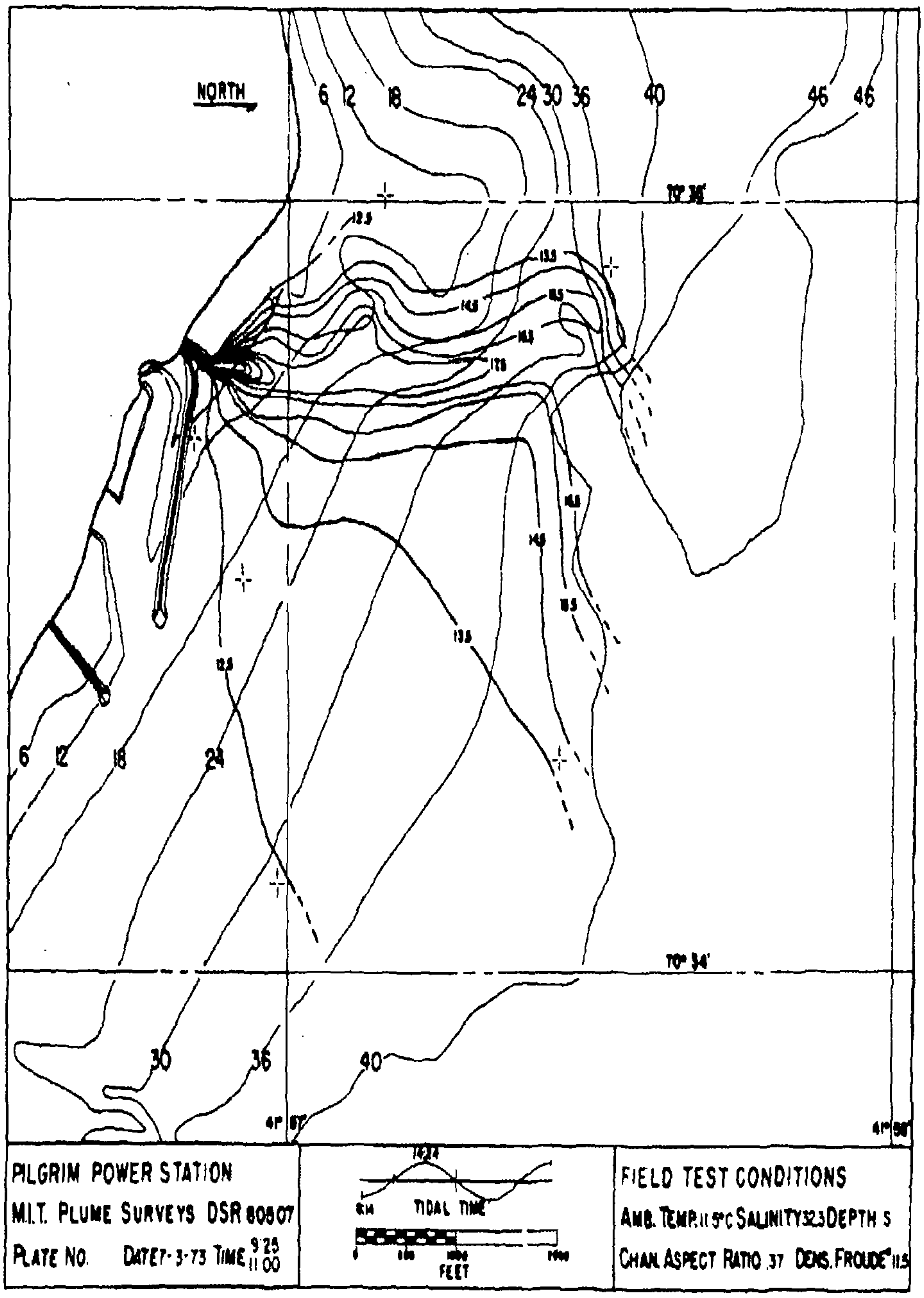


Plate 3.2, July Isotherms, $\mathbb{F}_0$ = 11.5, Surface

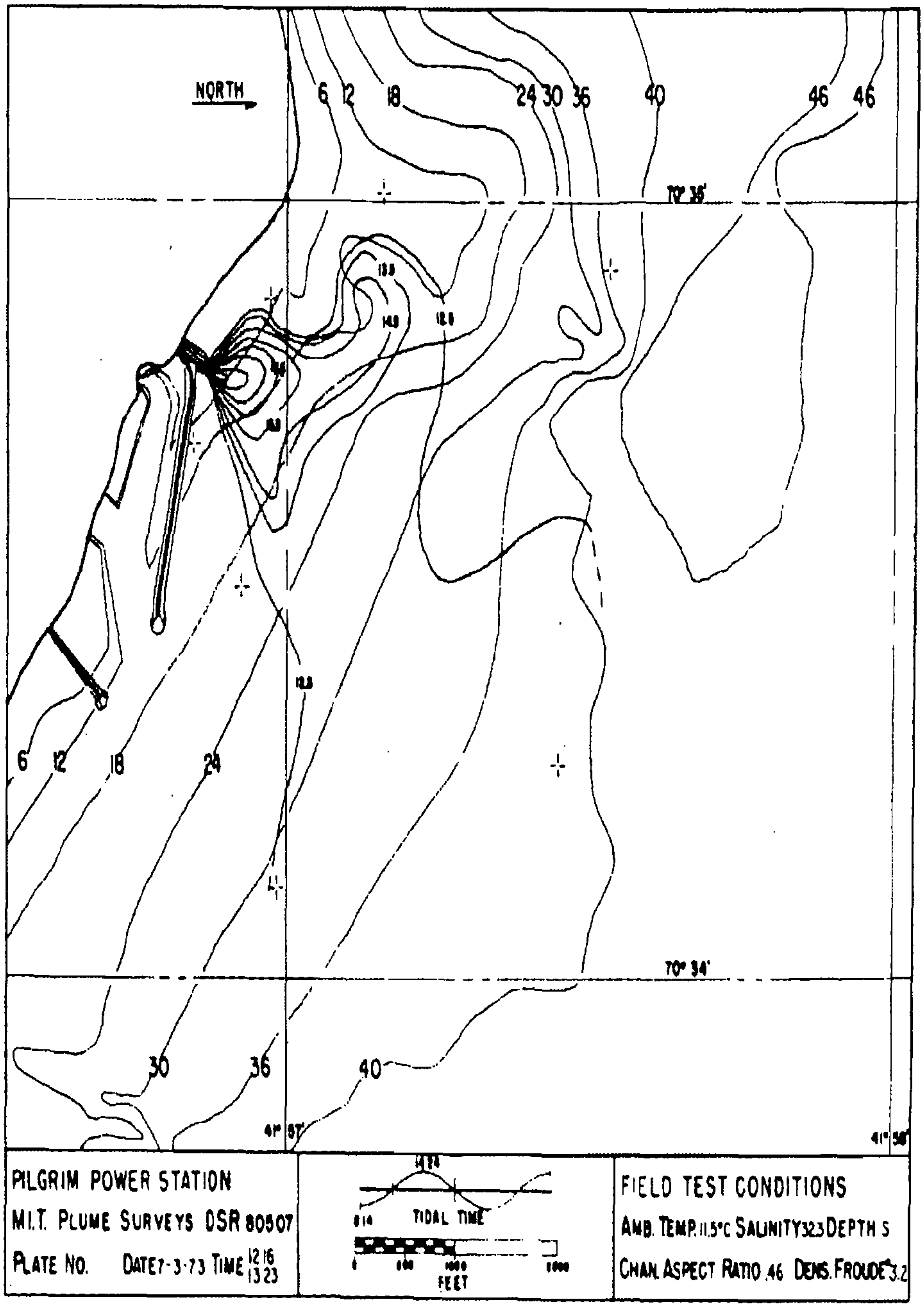


Plate 3.3, July Isotherms, $\mathbb{F}_0 = 3.2$, Surface

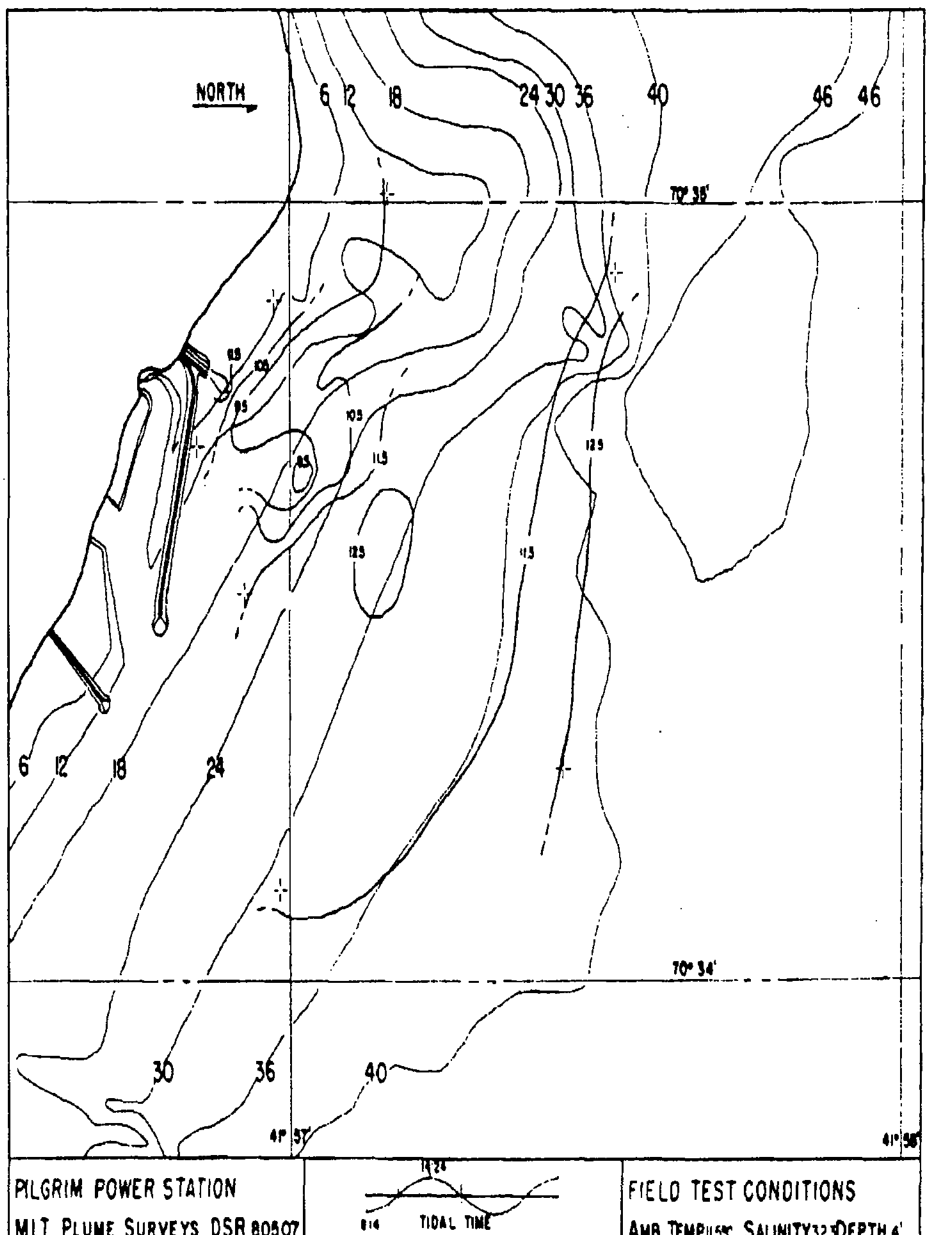


Plate 3.4, July Isotherms, F_0 = 3.2, 4 Sec.

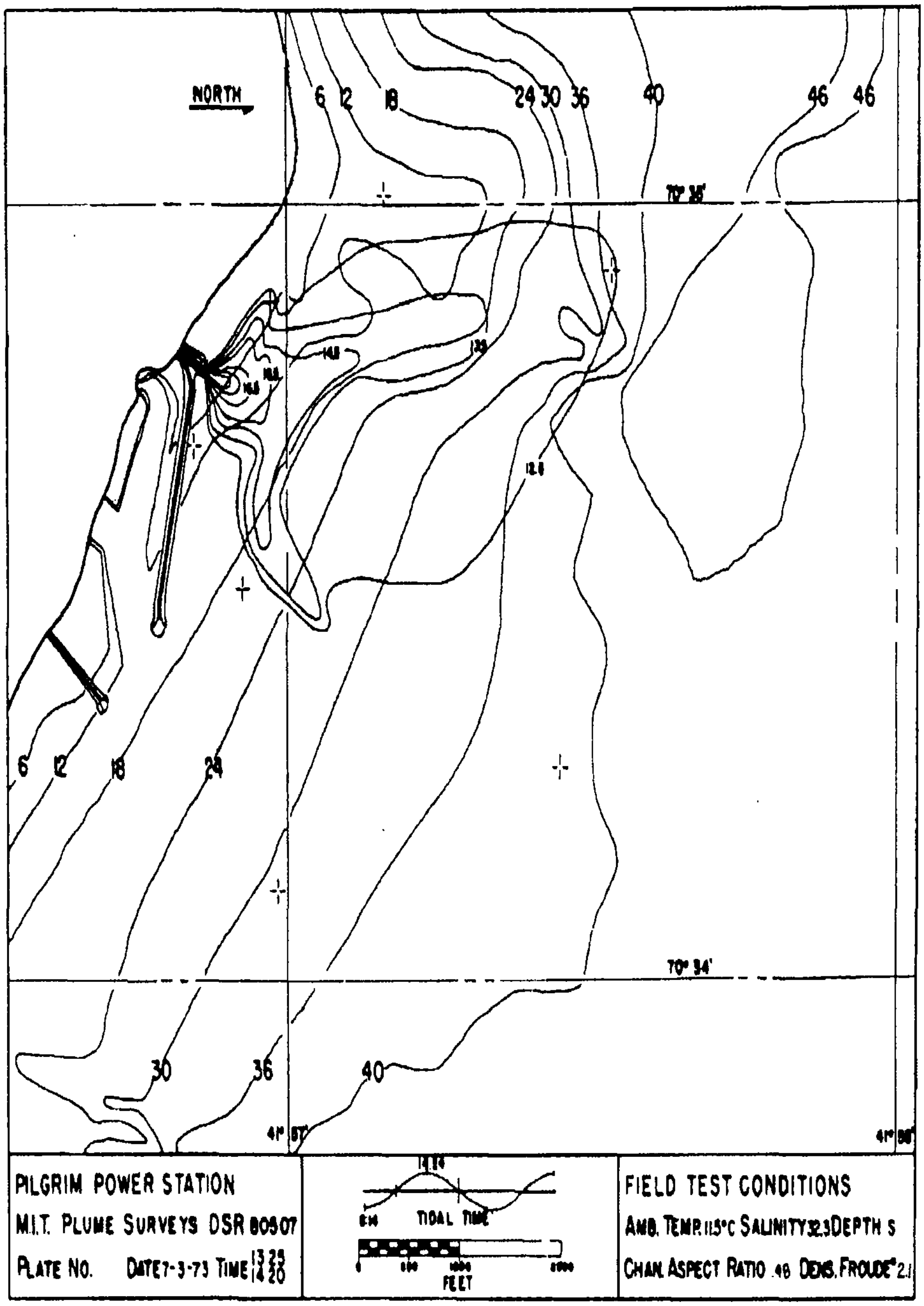
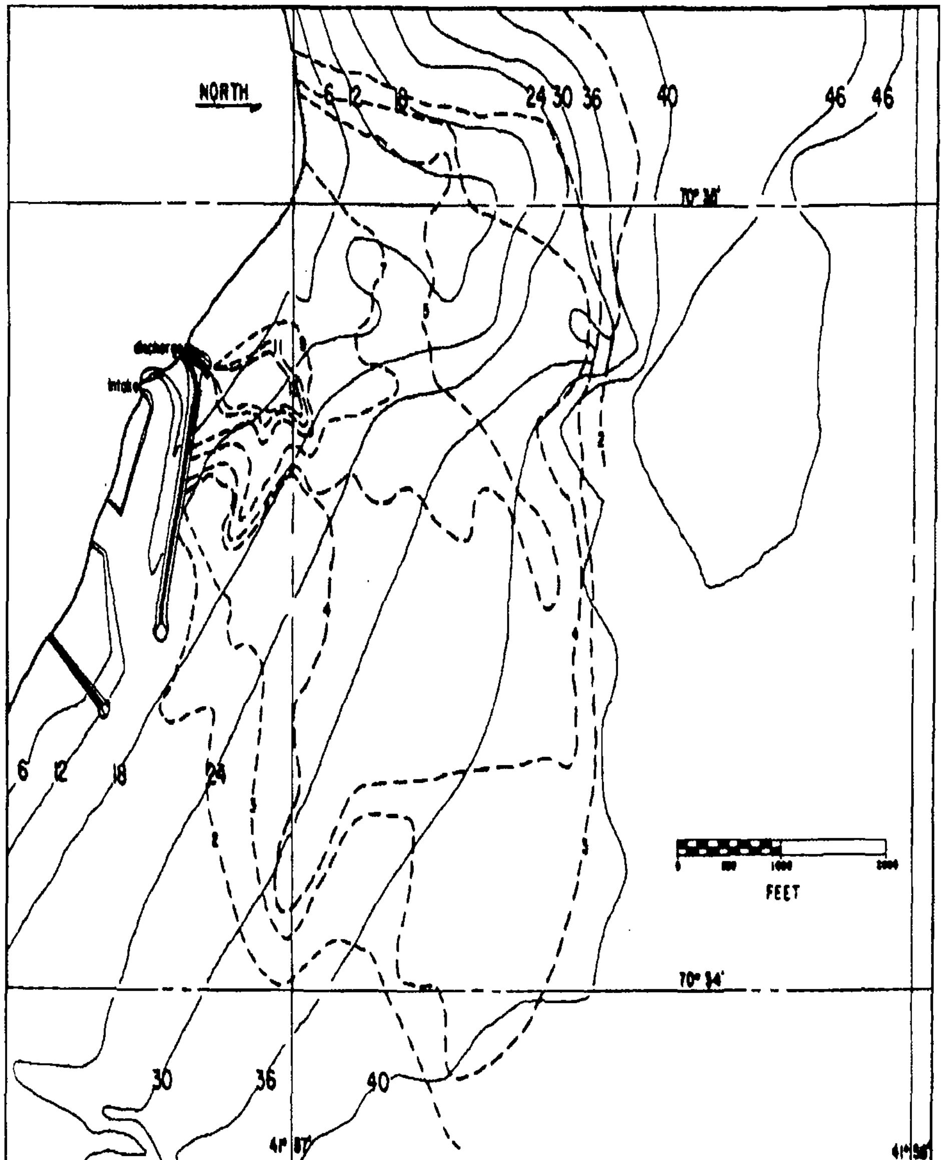


Plate 3.5, July Isotherms, $\mathbb{F}_0 = 2.1$, Surface



PILGRIM POWER STATION	RANGES OF FIELD TEST CONDITIONS
THREE SURVEY ISOTHERM LIMITS DSR80507	TIDAL TIME VARYING SALINITY 31.8 - 32.6 CHAN. ASPECT RATIO 14 - 35
PLATE NO. DATES 1-26-73, 3-25-73, 4-19-73	AMB. TEMP. 2.8°C-7.3°C DENS. FROUDE* 1.9-15.9 DEPTH SURFACE & 4' DATA COMB'D

Plate 3.44, Three Survey Isotherm Limits

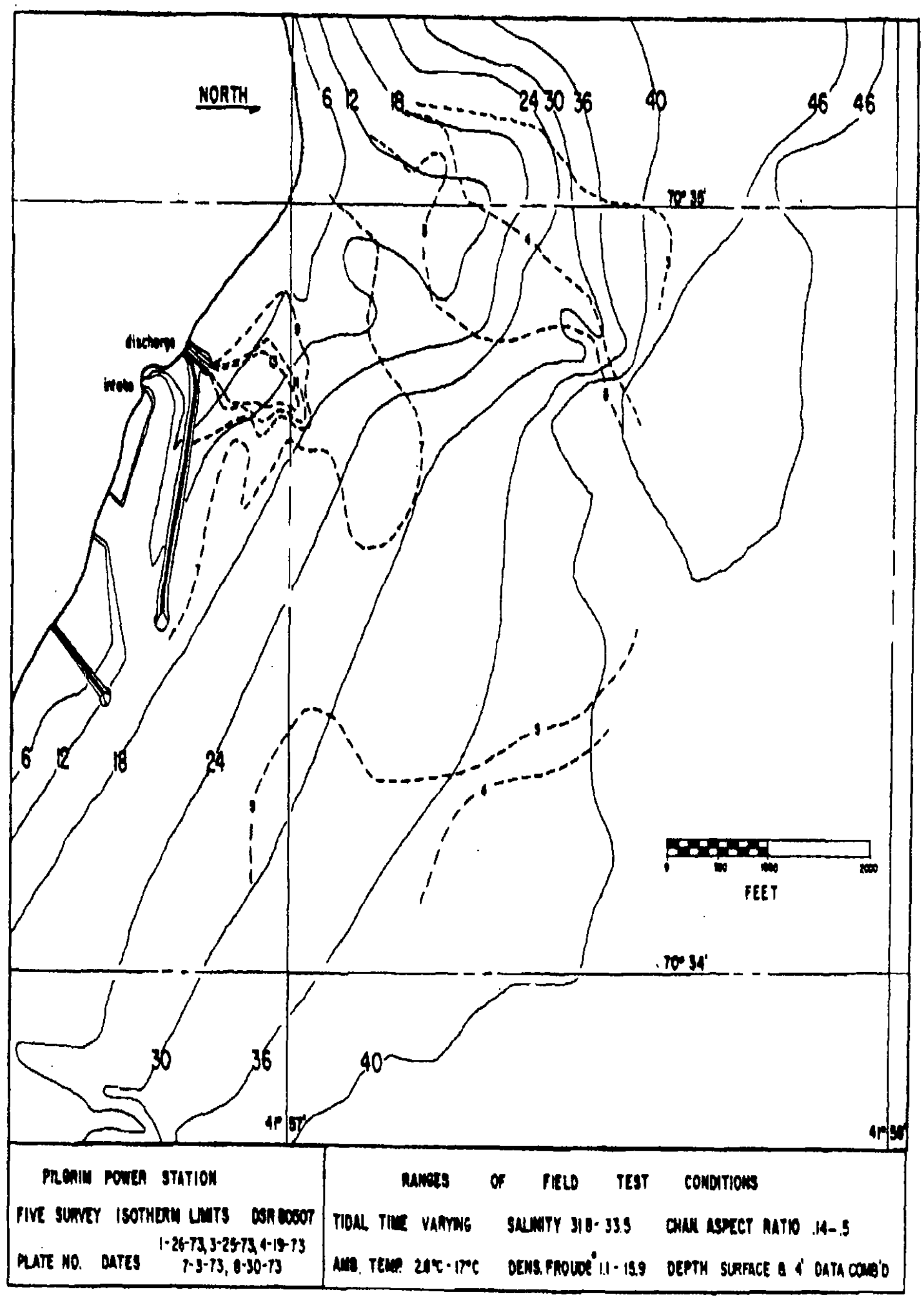


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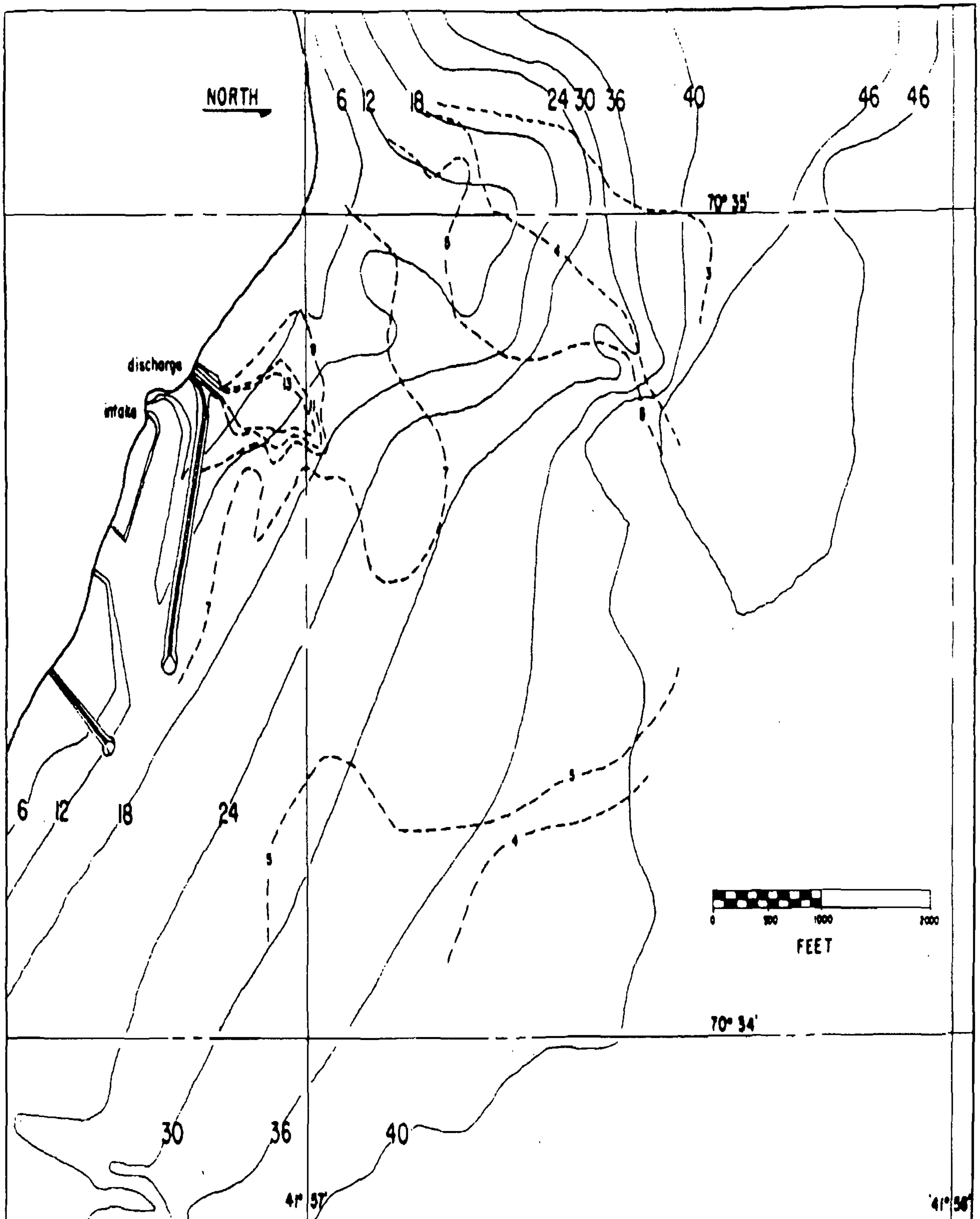
Plate 3.45, Five Survey Isotherm Limits



PILGRIM POWER STATION	RANGES OF FIELD TEST CONDITIONS
FIVE SURVEY ISOTHERM LIMITS DSR 80507	TIDAL TIME VARYING · SALINITY 31.8-33.5 · CHAN. ASPECT RATIO .14-.5
PLATE NO. DATES 1-26-73, 3-25-73, 4-19-73, 7-3-73, 8-30-73	AMB. TEMP. 2.8°C-17°C · DENS. FROUDE 1.1-15.9 · DEPTH SURFACE & 4' DATA COMB'D

Plate 3.45, Five Survey Isotherm Limits

areas for the 5 and 2°C above ambient isotherms occur on the rising tide and after high tide remain fairly constant well into mid tide following. Also, to support this analysis on tidal cycle effects, field survey transect runs from the first five survey dates were grouped by tidal stage and average areas for a similar $\Delta T_c/\Delta T_o$ were compared. The four tidal stages are high, mid after high, low, and mid after low. Based on a ΔT_o of 15°C, the average of all surveys in each group was compared and the following results were obtained:

Table 4.4a Average Field Isotherm Areas

ΔT_c-°C	$\frac{\Delta T_c}{\Delta T_o}$	High Tide	Mid After High	Low Tide	Mid After Low
10	.67	.7	.5	.8	1
9	.6	1.5	1.0	1.3	1.6
8	.53	3.5	1.5	2.0	2.3
7	.47	8	3.0	2.8	5
6	.4	19	5.5	6	8.5
5	.33	38	45	14	17
4	.27	96	150	43	36
3	.2	120	200	65	68

Field isotherm areas measured on November 13, 1973 were also grouped by tidal stage and average areas were compared. The three tidal stages are mid after low, high, and mid after high. Based on a ΔT_o of 7°C, the following results were obtained:

Table 4.4b Average Field Isotherm Areas

ΔT_c-°C	$\frac{\Delta T_c}{\Delta T_o}$	Mid After Low	High	Mid After High
7	1.0	-	.15	.1
6	.86	-	.55	.3
5	.71	-	.94	.8
4	.57	.2	4.2	2.0
3	.43	1.4	13	8.1
2	.29	2.5	34	29
1	.14	10	61	67

These figures show that, on the average, including variabilities of meteorological effects, the lowest isotherm areas occur between low tide and the following mid tide, and the highest occur between high tide and the following mid tide.

Table 4.5

Comparison of High Tide Analytical Model Data to Corresponding Field Data

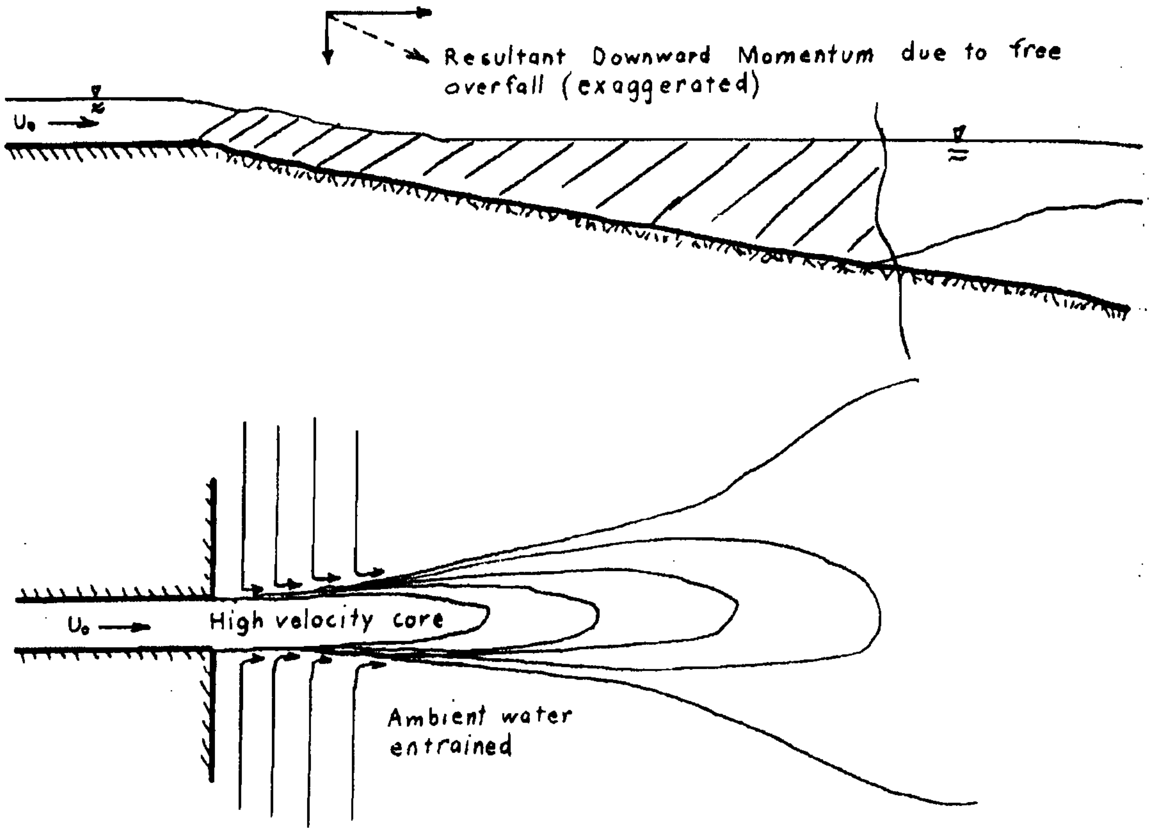
Field Data ΔT_c (°C)	Field Data Area (Acres)	Theory (without bottom slope) Area (Acres)	
$\mathbb{F}_o = 1.7$ $A = .47$		$V = .23$ ft/sec	$V = 0.0$ ft/se
4-19-73 $\Delta T_o = 15°C$			
6	1.0	3.2	139
5	3.4	7	243
4	28	19	391
3	76	61	560
$\mathbb{F}_o = 2.7$ $A = .46$		$V = .23$ ft/sec	$V = 0.0$ ft/sec
4-19-73 $\Delta T_o = 15°C$			
10	.9	.2	.2
9	1.3	.3	.3
8	2.0	.7	.5
7	2.5	1.8	1.0
6	4.0	2.9	6.0
5	7.0	4.5	67
4	75	9	210
3	156	22	402

Table 4.5 (Continued)

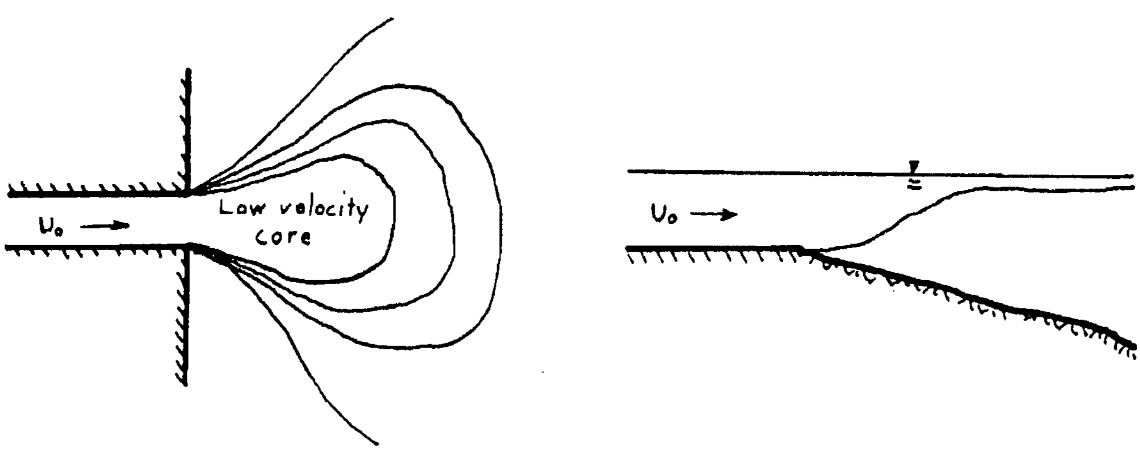
Field Data ΔT_c (°C)	Field Data Area (Acres)	Theory (without bottom slope) Area (Acres)	
		V = 0.0 ft/sec	
$\mathbb{F}_o$ = 2.3 A = .33			
1-26-73 ΔT_o = 16.9°C			
13	.5	.25	
12	1.0	.3	
11	1.8	.5	
10	2.4	1.0	
9	4.5	10	
8	8.3	66	
7	10	170	
6	21	300	
5	32	500	
		V = .35 ft/sec	V = 0.0 ft/sec
$\mathbb{F}_o$ = 3.2 A = .46			
7-3-73 ΔT_o = 15°C			
7	.1	.5	.4
6	.3	.8	.7
5	1.6	1.4	2.3
4	5.1	3.4	80
3	18	14	341
2	84	102	
1	144	240	

Table 4.5 (Continued)

Field Data ΔT_c (°C)	Field Data Area (Acres)	Theory (without bottom slope Area (Acres)
$\mathbb{F}_o$ = 2.2 A = .47		V = 0.0 ft/sec
8-30-73 ΔT_o = 15.6°C		
11	.8	.3
10	2.1	.5
9	6.3	1.0
8	11	4.0
7	27	25
6	88	102
5	151	260
4	235	450
$\mathbb{F}_o$ = 2.3 A = .5		V = 0.0 ft/sec
11-13-73 ΔT_o = 7°C		
7	.05	0
6	.7	.2
5	.9	.4
4	4.8	.8
3	14.4	26
2	33	91
1	56	210



TYPICAL LOW TIDE JET CONDITIONS



TYPICAL HIGH TIDE JET CONDITIONS

Figure 4.26 High and Low Tide Jet Comparison

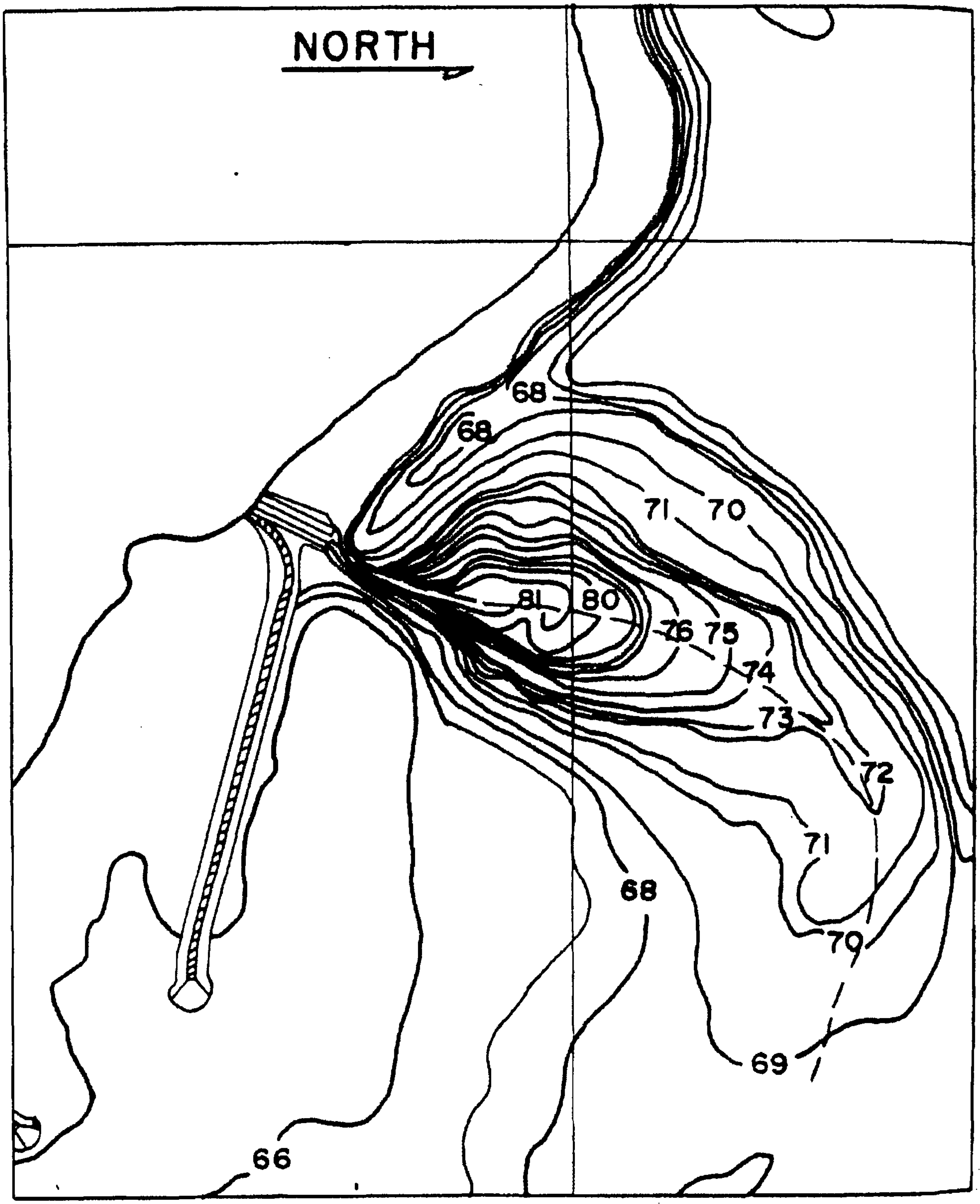


Figure 5.2 Infra-red Sortie 2

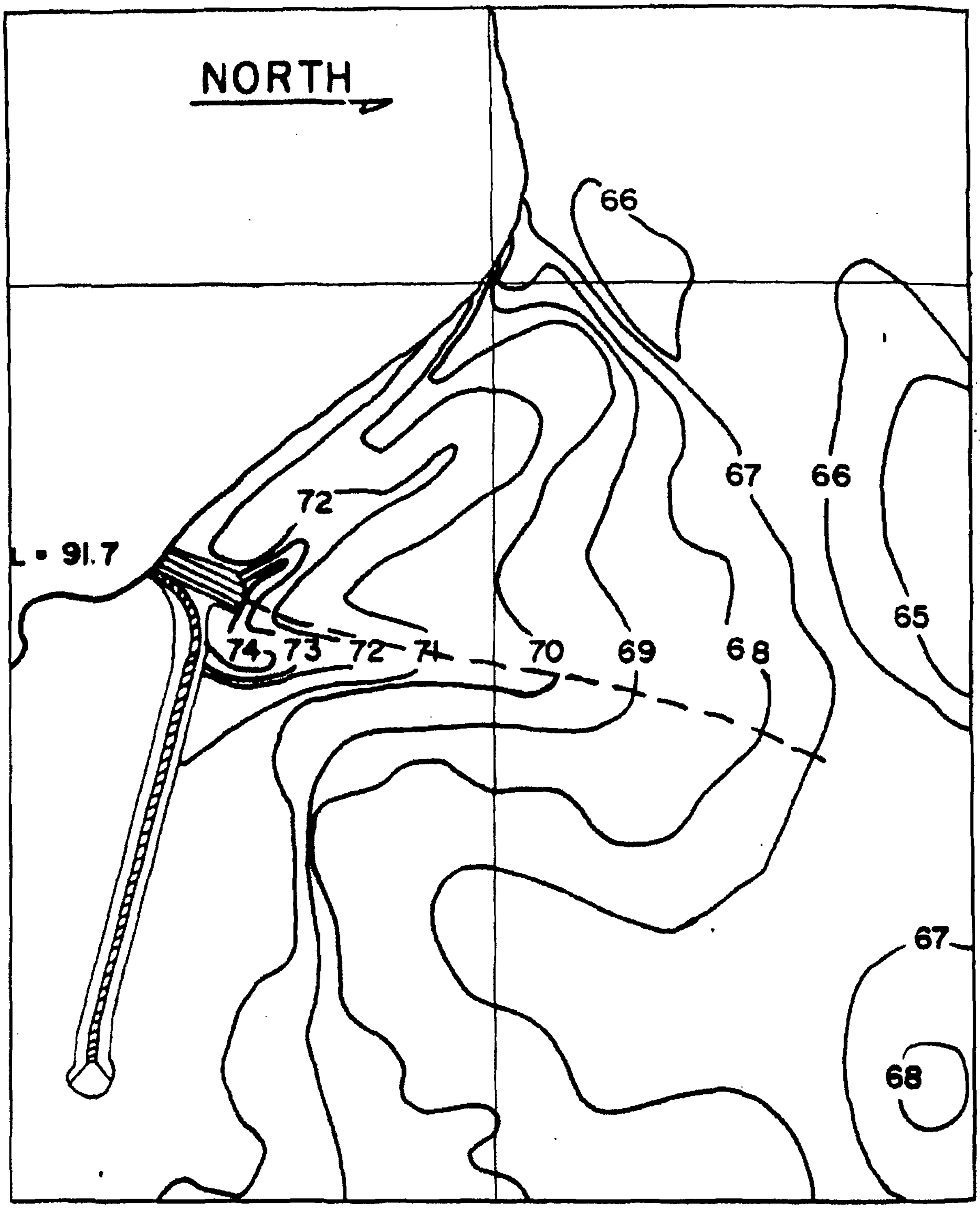


Figure 5.4 Infra-red Sortie 12

6.0 Summary and Conclusions for Entire Project

6.1 Objectives

The increased need for electric power in the United States has resulted in the need for new power generating facilities. Power generating facilities discharge waste heat to the environment. Public and governmental awareness of potential thermal pollution has resulted in the need to predict the thermal effects of contemplated power plant construction on the environment.

The characteristics of nuclear power plant waste heat discharged to the ocean by a once through cooling water system was studied. The study consisted of field measurements of the heated surface buoyant jet of the Pilgrim Nuclear Power Station located at Plymouth, Massachusetts. Field measurements were conducted to define the thermal plume characters of the Pilgrim Nuclear Power Station heated discharge as affected by tidal stage and variability of the ambient water and meteorological conditions. The variability of the ambient water dispersion characteristics is a function of wind velocity, coastal current, and the ambient water temperature stratification. The variability of surface heat loss is a function of wind velocity, direction, air temperature and amount of solar radiation.

Correlation was sought between the field data collected and a steady state analytical model for heated surface buoyant discharges for the prediction of the heat affected zone. Two versions of the analytical model were used for prediction of the heat affected zone in the receiving water body; one considers the effects of the shore body, the other does not.

6.2 Analysis of Field Data Results

Analysis of field data indicated high variability of surface isotherm areas from one survey date to the next at similar tidal conditions. The variability is due totally to meteorological conditions, which seem to be a greater factor than tidal conditions in determining the size of the surface isotherm areas. Sensitivity of surface isotherm area sizes to meteorological conditions was determined from field data analysis. It was concluded that sensitivity of isotherm areas above a $\Delta T_c/\Delta T_o = .5$ tended to be low whereas below a $\Delta T_c/\Delta T_o = .5$ sensitivity tended to be high.

The tidal cycle effect on isotherm areas was determined by taking an average of all field data collected. The average values indicate that the lowest surface isotherm areas occur between low tide and mid after low, and highest areas occur between high tide and mid after high. High tide and the early part of the following mid tide are thus a period where the plume surface isotherm areas, on the average, are maximized. Though surface isotherm areas are smaller at low tide, the jet is a deeper jet due to the high Froude numbers and the free overfall conditions. Bottom centerline temperatures were shown to be highest at low tide, depending on the degree of jet momentum, which is directly dependent on tidal height.

On August 30 infra-red overflights were taken in addition to the M.I.T. data. Because of the severe meteorological conditions that existed on that day, correlation between the infra-red and M.I.T. data is difficult. During the early morning surveys, however, the extreme weather conditions had not yet taken effect and agreement between the two sets of data is closer.

6.3 Comparison of Theory with Field Data

Comparisons were made between the analytical model and field data on the basis of observed and predicted plume centerline temperature reduction versus distance as well as observed and predicted surface isotherm areas. The sensitivity of the analytical model to the heat loss coefficient and to cross currents was determined. An evaluation of the usefulness of the steady state analytical model in conditions of rapidly varying jet characteristics due to tide level changes were made. The ability of the bottom slope version of the analytical model to predict the affects of shore bottom interaction are determined in relation to the tidal elevation variation at the site.

6.4 Results

The field results were grouped into three characteristic periods of time within a tidal cycle based on the jet Froude number and aspect ratio of the discharge which is a direct function of the tide elevation. The phases are characterized by the high, mid and low tide phase. The analytical model (without bottom slope) predictions for high tide field results of both centerline temperature reduction versus distance and surface isotherm areas show good agreement. High tide is a period when discharge conditions are relatively constant for a period of an hour or more. The addition of a cross current to the analytical model without bottom slope improved the agreement when the cross flow was actually present in the field conditions, but the high sensitivity to various cross flow inputs to the model at low Froude numbers is not fully understood at this time. Sensitivity of the analytical model to cross currents at high Froude numbers was determined to be minimal.[1]

Theoretical predictions of centerline temperature reduction versus distance and surface isotherm areas for the mid tide phase when the jet characteristics are changing most rapidly do not agree with the field results. An attempt to reduce the unsteadiness of the field conditions by time weighted average (1/2 tidal cycle) and comparison to the time weighted average of the theory was made for the centerline temperature reduction versus distance field results. The results were reasonably successful but the unsteady influence of the mid tide phase could not be completely eliminated by this method (See June Report[1]).

Low tide field results were not predicted by the analytical model with or without bottom slope. Because of the high amount of bottom interference present at low tide, agreement between field results and the analytical model without bottom slope was not expected. The theory with bottom slope has been found to be in error in predicting bottom interference effects and area computations so agreement was not expected here either.

Sensitivity of the analytical model to heat loss coefficient is minimal in the near field but high in the far field, which corresponds to the same effects of ambient weather conditions.[1] By including a heat loss coefficient in the analytical model that corresponds to the actual ambient conditions, reasonable far field agreement will result for high tide predictions.

Changes in channel geometry at the mouth of the discharge channel occured due to winter storms. An attempt was made to estimate the new cross sectional area because it was discovered that the obstruction significantly changed the height of water flowing in the discharge channel at low tide. Since the measurement is only a rough estimate, a precise comparison with the analytical model is difficult particularly at low tide when the free overfall condition exists.

6.5 Conclusions

The bottom slope version of the analytical model does not adequately provide the proper surface spreading equations in a unified model. The effect of shore bottom interferences for cases where the buoyant jet maintains significant bottom contact before it separates from the bottom should be analyzed.

The point of jet separation from the shore bottom as formulated in the analytical model with bottom slope is not adequately predicted. The inclusion of the proper point of jet separation and surface spreading should allow conservative predictions of plume centerline temperature reduction and surface isotherm areas for heated surface buoyant jets affected by bottom slope for steady state conditions.

Development of transient theories for heated surface buoyant jets in tidal regions should be pursued.

Introduction of an estimated cross current parameter to the model for high tide runs gives better results than with a zero cross current if an actual wind induced cross current was present in the corresponding field conditions. But the analytical model without bottom slope has high sensitivity to cross flows at low Froude numbers so complete confidence in the predicted results with a cross current can not be given.

The concept of automatic data reduction should be pursued further but an understanding of the field space requirements versus the size and weight of the necessary equipment is mandatory. Due to the shallow near shore areas involved in this type of survey, a small boat is necessary. If the equipment necessary for automated data reduction is large and requires substantial electrical power then a small survey craft may not suffice. Horizontal temperature profiles at the surface and at the four foot depths were generally sufficient to define the thermal plume. Measurements at greater depths are difficult due to bottom obstructions. Ship to shore radios would also be invaluable for coordination of data collection and as a much needed safety device. Cost justification for all these additional improvements can be based on the basis of more data collected and reduced for each hour spent in the field. An automatic data reduction system would also mean less time spent on data reduction and more time spent on data collection, analysis, and predictive model work.