A Two Depth Averaged Numerical Temperature Model of Narragansett Bay

John J. Alfano
University of Rhode Island

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A TWO DIMENSIONAL DEPTH AVERAGED NUMERICAL TEMPERATURE MODEL OF NARRAGANSETT BAY

BY

JOHN J. ALFANO

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN OCEAN ENGINEERING

UNIVERSITY OF RHODE ISLAND

1973
ABSTRACT

The numerical temperature model proposed in this thesis approximates the temperature distributions produced by natural or man made conditions in Narragansett Bay. The model approximates the temperature distribution by averaging the vertical structure over depth. A two dimensional, planar coordinate system continuously specifies the temperatures within the bay. A hydrodynamic model calculates the necessary velocities and depths required by the thermal model. The combined thermal-hydraulic model calculates bottom roughness, Coriolis acceleration, non-linear convective terms, astronomical tidal series for Rhode Island Sound, and air-water heat exchange. Known river flow inputs are used as boundary conditions. To simplify the model geometry the Mount Hope Bay structure is replaced by a boundary flow rate at the Mount Hope Bridge grids.

Narragansett Bay has an average depth of 32 feet and a length of approximately 24 nautical miles with a maximum width of six nautical miles. By specifying a total of 325 square grids with eleven boundary grids 1/2 nautical mile in length the model approximates the features of the estuary.

Verification of the model is achieved through conservation of mass analysis and comparison of predicted temperatures
for given meteorological and water temperature data. The model is used to predict the thermal fields from a proposed power plant near Rome Point in the West Passage of Narragansett Bay. By specifying plant flow rates and dispersion coefficients characteristic temperature field conditions are observed. Under specified plant operating conditions, a maximum temperature rise of $5.5^\circ C$ above ambient in the discharge grid is predicted. For a temperature rise of $5.5^\circ C$ the area encompassed by the $1^\circ C$ excess isotherm is approximately two square miles while the $0.5^\circ C$ isotherm area is about four square miles. Temperature isotherms over a tidal cycle retain the same general shape, especially in the far field where temperatures fall below $0.4^\circ C$ excess.

This model can simulate salinity or other non-decaying constituents if appropriate boundary condition changes are made.

In summary, the thermal model gives valuable insight into natural and man-made temperature distributions that will aid the marine scientist in preserving and understanding the dynamics of Narragansett Bay.
ACKNOWLEDGEMENT

Although computer modeling is primarily a struggle between the modeler and the model it would be a grave injustice not to mention the support I received from my committee. In particular Dr. Frank White's encouraging words on the model, this thesis and other related matters deserve commendation. During the darkest days Dr. George Brown's help proved invaluable as well as Professor Warren Hagist's encouraging support.

It is unfortunate that certain ultimate goals were not achieved but the confidence and love of my wife clarified my perspective and stimulated this work. We weathered the storm together.

Mr. Kurt Hess's constant support and patience went beyond the normal bounds of friendship.

Miss Linda Weinreich, showing profitable enthusiasm with the many drafts made the manuscript into a thesis.
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A. GENERAL

A model tries to represent the salient characteristics of a system so that the user can gain insight into the governing features of the particular site. This thesis explains the implementation of a model that will predict vertically-averaged temperature distribution in Narragansett Bay. The thermal model, as it is called, uses a tidal model (Hess, 4) to provide the necessary hydrodynamic structure in the bay. The hydrodynamic inputs are velocity, tidal elevation, and bottom friction. The thermal model then predicts the effect of thermal convection and diffusion as well as the heat exchange that takes place at the air-water interface for specified locations or grids. Pertinent meteorological data must be read in for periods of simulation. In essence, the model predicts the movement or mixing of heat subject to eleven known boundary conditions around the bay.

The model is a digital computer program, written in Fortran language, that uses over three hundred 1/2 by 1/2 nautical mile cells to represent the characteristic features of the bay. The model is two dimensional in that
it determines a temperature value for each cell volume in both a general north-south and east-west direction.

With this model, marine life behavior and electric generating plant thermal discharges can be studied. Other applications, such as salinity prediction, are possible with minor model modifications.

To begin this study, a breakdown of main model components is shown in Figure 1.1. It can be seen that to understand the convective, diffusive and time varying quantities we must rely on a hydrodynamic model that will simulate the transporting medium accurately. The grouping of these terms, in block diagram form, indicates no interaction of constituent on flow behavior. If the model had a vertical structure, one would couple the hydrodynamic model with constituent model through the vertical buoyancy flux term, creating a much more difficult problem and many more cells.

B. HISTORICAL DATA

General historical information consists of data obtained from various cruises and buoy measurements taken in and around the bay area during the last 100 years. Tables 1.1, 1.2, and 1.3 present a summary of temperature informa-
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<td>Daily (Average)</td>
<td>Surface</td>
<td>Narragansett Marine Lab</td>
<td>40</td>
</tr>
<tr>
<td>Summer 1959</td>
<td>Hourly</td>
<td>Surface-Bottom</td>
<td>Upper Narragansett Bay</td>
<td>42</td>
</tr>
<tr>
<td>1960</td>
<td>Daily (Average)</td>
<td>Surface</td>
<td>Narragansett Marine Lab</td>
<td>43</td>
</tr>
<tr>
<td>1960 to 1966</td>
<td>Monthly</td>
<td>Surface</td>
<td>Newport, R.I.</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Daily (Available)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1967 to Present</td>
<td>Weekly</td>
<td>Surface</td>
<td>Fox Island, Whale Rock</td>
<td>46</td>
</tr>
<tr>
<td>3/71 to 10/71</td>
<td>Continuous</td>
<td>Near Bottom</td>
<td>East of Saunderstown (71°25', 41°30'30&quot;)</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>Daily (Max., Min.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6/72 to 8/72</td>
<td>Hourly</td>
<td>Variable</td>
<td>Narragansett Bay</td>
<td>48</td>
</tr>
</tbody>
</table>

**TABLE 1.3. TEMPERATURE DATA, 1958-PRESENT**
tion for the Narragansett Bay. This compilation of data provides some understanding of boundary conditions and very general spatial variations throughout the bay.

First, the Brenton's Reef Data (31) provides an estimate for the monthly surface temperature for the lower bay boundary condition. The averaged monthly temperature for Brenton's Reef is shown in Figure 1.2. For the thermal model, the average value during the prediction period is read off Figure 1.2 and specified as the Rhode Island Sound boundary condition. Included in reference 31 is a brief temperature record for Newport during the period May, 1881 to March, 1883 and the average values are also seen in Figure 1.2.

The data collected by Wehe (32) is given in chart form with longitude and latitude, date, time in minutes, various depths, temperature of water (°F), salinity, oxygen, sound velocity, Secchi Disk measurements, sea state, wind direction and magnitude, and weather conditions. The report has 91 pages of data with measurements taken on August 24, 27-31, September 5, 10-12, 14, 17, 18 in 1951, and February 2, 19-22, March 25-27, August 13, 27-29, September 4, 9, 11, 15, 16 in 1952.

The weekly temperature variations of surface water in
FIGURE 1.2. MONTHLY SURFACE WATER TEMPERATURE FOR NEWPORT, RHODE ISLAND AND BRENTON'S REEF (31)
Wickford Harbor and bottom water in Greenwich Bay for May through March of 1951 and 1952 can be found in Reference 33. Figure 11 in Reference 33 shows the seasonal variation of temperature from approximately 16°C in late May to 25°C at the beginning of August and then a decrease to 17°C for the end of September.

Hicks et al (58) report made an unexpected appearance this fall after being classified for twenty years. This report, which encompasses the period summer of 1951 through the summer of 1952 was undertaken to increase the overall physical data available on Narragansett Bay. The report has over 25 tables and figures that are a cornucopia of important bay temperature distribution information throughout the year. It is highly recommended for workers interested in Bay modeling.

Hicks (34) in Chapter III discusses the distribution of temperature and salinity in Narragansett Bay at the surface and the bottom of water column for the tidal period, slack before ebb. For the February 1956 period, (Cruise, 14) the bottom temperature increases from 1°C at Rhode Island Sound to 3°C half way up the bay and down to 2°C in Providence River area. Surface temperatures for Cruise 14 remain at 2°C for the entire bay. The isothermal pattern
for the April 1956 period (Cruise 15) is very irregular, with variations in bottom water from $1^\circ C$ to $7^\circ C$ while the surface water is $3^\circ C$ in Rhode Island Sound and increases to $10^\circ C$ in the Providence River.

Hicks (34) undertook two more cruises one in June (Cruise 18) and another in August, 1956 (Cruise 19). The isothermal pattern for the June cruise shows a surface temperature variation of $19^\circ C$ at Rhode Island Sound to $20^\circ C$ in the Providence River while the bottom water changes from $11^\circ C$ to $17^\circ C$ respectively. For the second cruise, the temperature variation in the surface water was about $4^\circ C$ or the difference between $23^\circ C$ in the Providence River compared with $19^\circ C$ in the lowest portions of the bay. The bottom water varied from $20^\circ C$ in the upper portion of the bay to about $17^\circ C$ in the Rhode Island Sound.

Continuous temperature readings were taken at the Narragansett Marine Laboratory on a Bristol Recorder. These temperature readings were reduced into maximum and minimum values (36, 38) and then to just a daily average (40, 43). The average values for each month are listed and these are plotted against the Brenton's Reef data (31) to estimate how weather conditions affect general bay behavior.

Hicks (37), in a comprehensive report, presents temper-
ature data in four quarterly cruises. In this report are tables estimating seasonal temperature trends and ranges as well as vertical distribution of temperature during the various cruises. In addition, his Figure 14 (37) shows the surface and bottom temperature variation at Narragansett Marine Lab Pier for the period February, 1957 through June, 1958. The information for this figure is contained in Appendix Table 5 (37) for which temperature data is taken about once a week.

Weekly surface water temperatures for Mt. Hope Bay and Fox Island for the interval May 18, 1957 to March 18, 1958 were taken by Herman (39). The general temperature pattern can be seen in Figure 1.3.

Since August, 1955, surface water temperature data (41, 45) has been gathered at Newport, Rhode Island. The surface water temperatures are measured several times a week and these data sheets (available) are compiled into monthly maximum, mean maximum, mean, mean minimum, and minimum temperatures. The temperature variations for Narragansett Marine Lab Pier and Newport are shown in Figure 1.4.

The Corps of Engineer Survey (42) did extensive measurements during the summer of 1959 in the portion of Narragansett
FIGURE 1.3. SURFACE WATER TEMPERATURE, MT. HOPE BAY AREA AND FOX ISLAND (39)
FIGURE 1.4. MONTHLY WATER SURFACE TEMPERATURE AVERAGES FOR NEWPORT AND NARRAGANSETT MARINE LAB PIER (41, 38)
Bay north of Prudence Island. The report includes average isotherms that are compared with a physical model that was built to simulate bay dynamics during hurricane conditions.

Jeffries (46) has maintained a weekly surface temperature record for Fox Island and Whale Rock that complements historically the data obtained from Herman (39). This data for 1967 can be seen in Figure 1.5.

The Environmental Protection Agency, National Water Quality Lab, Kingston, has obtained continuous temperature readings from a data buoy. Mr. Rick Lapan kindly supplied the averaged and raw data showing the response of water temperature measured 8 feet from bottom in water 30 feet deep near Saunderstown, Rhode Island (Reference 47).

The Ocean Engineering Department has taken water temperature measurements in conjunction with other studies during the summer of 1972. The surface and bottom temperatures were determined by a thermistor probe at seven stations in bay. Temperature versus depth plots are provided for each run and clearly show the vertical structure with a thermocline below the ten foot depth for most stations.

Having reviewed the data, a decision to use the period, Summer 1957, was made because it represents the best collection of published data in the bay for use in
FIGURE 1.5. SURFACE WATER TEMPERATURES AT FOX ISLAND AND WHALE ROCK, 1967, (46)
verifying the model.

c. APPLICATIONS

The model calculates the movement of thermal energy in the bay and specifies the average temperature in each grid as well as the depth and average velocity components in the x and y direction. The thermal model is designed to realistically model two dimensional, vertically averaged heat content in the bay. Other conservative properties, such as salinity, can be suitably modeled by changing physical values specified at boundaries and negating the effect of the air-water interface. For instance, instead of specifying a heat content in a grid by tagging the grid with a value of T, \(^{\circ}C\) you could have used S \((^\circ/oo)\) for salinity where the formulation would be the same with regard to a non-reacting substance.

To what purpose might this information be used? Biological modeling requires an understanding of ambient temperature and salinity, and provides one general use of the model. A second use would be to model a source of heat, such as a power plant, to determine thermal structure around an outfall area. An analysis of re-entrainment of heated effluent would be a valuable aid in determining de-
sirable site locations from both a power plant operation and biological viewpoint.

One of the important physical parameters of the bay that determines the mixing of heat is the dispersive term. This dispersive term has a dispersion coefficient that can be varied to simulate various bay conditions. Since most biologists are interested in mixing patterns in the aquatic environment the thermal model and its dispersion coefficient effects would be enlightening for large scale effects.

D. APPROACH

Kurt Hess (4) has adapted Leendertse's (1) [pronounced: lee an der' see] two-dimensional, depth averaged model to simulate hydrodynamics of bay. The hydrodynamic model is a computer program that formulates the fluid equations of linear momentum and continuity into a usable finite difference scheme applicable for use on a high speed computer.

The fundamental equations of motion and energy can be formulated into a general finite difference scheme. The specific technique for arranging spatial and time variables are many in number. Anyone is free to choose a method that he feels will work satisfactorily, but the burden of proof
is on him. Grimsrud (6) conducted an investigation of various methods as well as this author to see if better methods were available for modeling Narragansett Bay. A general summary for hydrodynamic, non-reacting concentration models is presented in Table 1.4.

Masch et al (57) have followed an approach similar to Leendertse (3) with a slightly different spatial arrangement for grid depth specification. The governing equations are explicitly formulated using forward difference substitutions for the partial derivatives in the time varying concentration-salinity model.

Pritchard (5, Chapter II) develops the equations for a three dimensional dynamic concentration model for an estuary, which includes isobaric slope for the pressure force term. The equations of linear momentum, continuity, salt and energy when applied with phenomenological relations can only be solved by an interative numerical approach given reasonable spatial distributions of velocity, energy and salt. Hess (59) is developing a three dimensional time averaged model that uses tidally averaged values from the two dimensional vertically averaged hydraulic model. This model has six levels that are equally spaced for all grid depth specifications to determine vertical structure.
<table>
<thead>
<tr>
<th>MODEL CHARACTERISTICS</th>
<th>MASCH ET AL (57)</th>
<th>PRITCHARD (5)</th>
<th>LEENDERTSE (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumptions</td>
<td>Uniformly vertically mixed water conditions</td>
<td>Vertically averaged with relative pressure surface slope and cross product of turbulent velocity fluctuation</td>
<td>Vertically averaged components using distribution functions for vertical column</td>
</tr>
<tr>
<td>Application</td>
<td>Estuary-fresh and tidal inlets</td>
<td>Estuary-fresh and tidal inlets</td>
<td>Estuary-fresh and tidal inlets</td>
</tr>
<tr>
<td>Influence</td>
<td>Wind included</td>
<td>Wind included</td>
<td>Wind included</td>
</tr>
<tr>
<td>Time Scale</td>
<td>Long Term Lasting Effect</td>
<td>Short or Long Term</td>
<td>Short or Long Term</td>
</tr>
<tr>
<td>Comments</td>
<td>Steady state and time varying salinity capability, 300 grid, prototype available for verification</td>
<td>No application presented</td>
<td>Jamaica Bay, 2000 Grids</td>
</tr>
</tbody>
</table>

TABLE 1.4.a. HYDRODYNAMIC CONCENTRATION MODELS
<table>
<thead>
<tr>
<th>MODEL CHARACTERISTICS</th>
<th>MASCH ET AL (57)</th>
<th>PRITCHARD (5)</th>
<th>LEENDERTSE (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boundary Condition</td>
<td>Reflective boundary condition for zero concentration gradient at fixed boundary</td>
<td>Not Applicable</td>
<td>Computational scheme formulates grids next to land as boundary value for row or column</td>
</tr>
<tr>
<td>Computer Time</td>
<td>2 min./tidal cycle</td>
<td>Not Applicable</td>
<td>30 min./tidal cycle</td>
</tr>
<tr>
<td>Dispersion Coefficient</td>
<td>2,500 ft$^2$/sec (Very High)</td>
<td>Realistic (5-40 ft$^2$/sec)</td>
<td>Realistic (5-40 ft$^2$/sec)</td>
</tr>
<tr>
<td>Verification Error Magnitude</td>
<td>2-3 ppt, 10-20% tidal estimation</td>
<td>Not Applicable</td>
<td>1-2°C, 10% tidal estimation</td>
</tr>
</tbody>
</table>

TABLE 1.4.b. HYDRODYNAMIC CONCENTRATION MODELS
Taking a more conservative approach, Pritchard, reduced the three dimensional problem to a two dimensional vertically averaged model that calculates the horizontal velocity components and a time varying slope.

The conservation of dissolved constituent equation is presented and interfaced in development of a solution technique.

The two dimensional formulations are similar to equations used by Leendertse (3) and by Masch et al (57) with two significant differences. The first variance is the inclusion of the slope term for the pressure surfaces due to horizontal variation in density (salinity). The second is the ensemble average of the turbulent velocity fluctuations time averaged for the squared velocity components, \((u')^2\) in x and \((v')^2\) in y direction, and also their cross product \((u'v')\). According to Pritchard, the inclusion of these terms will improve model accuracy for a velocity field with a predominant sign.

Since Leendertse (3) had proven workability of a two-dimensional, depth averaged water quality model with realistic dispersion, it was decided to convert this into a thermal model that required the hydrodynamic input currently available. This coordination between hydrodynamic and thermal models greatly facilitated implementation and
eventually led to improvements in boundary condition formulation for the hydrodynamic model.

If a pioneering effort had been undertaken in the development of a different hydrodynamic-thermal model formulations it would have taken considerably more time and effort just to prove feasibility, not to mention prediction ability. One of the major problems in model development is turn around time of one day and slow computational speed of the present computer system at the University of Rhode Island.

It should be made quite clear that the depth averaged model does have limitations if one is very concerned with near field buoyant plumes. The physical dimensions of the bay necessitated a large grid size of about 1000 yards which, in general, makes the input box the entire near field. Yet, with temperature rises of several degrees around the source one would expect stratification in the surrounding grids. This stratification is mixed into the entire depth and the grid displays the average temperature required by the total heat content in the box for any tidal condition.
E. VERIFICATION

As previously mentioned, the year 1957 was chosen for verification purposes. The model will be run under identical meteorological and boundary conditions for an initial constant temperature field of 21°C during the period of verification. In most instances, the data was taken at isolated points either at or near surface water at various times during the day. Keeping this in mind, grid temperature discrepancies between the data points are to be expected, but spatial agreements should be reasonable.

Ideally, a dozen continuous temperature recorders could be dispersed around the bay to measure both vertical and horizontal temperature distributions to verify validity of model beyond question.

F. CONCLUDING REMARKS

The lengthy discourse on the temperature data for Narragansett Bay provides information for future development of model predictive ability.

The work presented in the following sections will elaborate on the various inputs of model development and implementation. The power plant site was chosen at Rome Point because it appears to be a reasonable first choice.
even though the proposed atomic plant seems doubtful at this time. The experimental runs for the various boundary conditions and siting variables are an outline of the procedure to be followed in making an environmental impact judgement. A comprehensive investigation of power plant siting throughout the bay is beyond the scope of this work. Other applications of the model, such as the salt modeling or biological studies are discussed, but no computer modeling was attempted.

In summary, the thermal model is a very valuable tool that allows the engineer to graphically display natural, natural plus man made and man made temperature fields to serve some useful estuarine requirement. The thermal model, in essence, provides the spatial arrangement of water temperatures subject to boundary conditions and source inputs.
II. MODEL DEVELOPMENT

A. INTRODUCTION

Any modeling procedure is derived from the fundamental equations of nature combined with the pertinent phenomenological relations. The basic differential equations (Bird, 27) to be considered for a Newtonian fluid are as follows:

Momentum x:
\[
\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} = - \frac{1}{\rho} \frac{\partial p}{\partial x} + f_v + \frac{1}{\rho} \left( \frac{\partial \tau_{xx}}{\partial x} \right)
\]
\[
+ \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z} \tag{2.1}
\]

Momentum y:
\[
\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} = - \frac{1}{\rho} \frac{\partial p}{\partial y} - f_u + \frac{1}{\rho} \left( \frac{\partial \tau_{yx}}{\partial x} \right)
\]
\[
+ \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z} \tag{2.2}
\]

Momentum z:
\[
\frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} = - \frac{1}{\rho} \frac{\partial p}{\partial z} - g + \frac{1}{\rho} \left( \frac{\partial \tau_{zx}}{\partial x} \right)
\]
\[
+ \frac{\partial \tau_{zy}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} \tag{2.3}
\]

where

- \( f \) - Coriolis parameter, \( 2\Omega \sin \phi \)
- \( \tau_{ij} \) - shear stress tensor,
- \( g \) - gravitational acceleration, \( \text{ft}^2/\text{sec} \)
- \( \rho \) - density of fluid, \( \text{lb}_m/\text{ft}^3 \)
Conservation of mass ($\rho = \text{constant}$):

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$  \hspace{1cm} (2.4)

where

$$u(x,y,z,t) = \text{velocity in the x direction}$$

$$v(x,y,z,t) = \text{velocity in the y direction}$$

$$w(x,y,z,t) = \text{velocity in the z direction}$$

$$p(x,y,z,t) = \text{pressure}$$

Concentration or energy equation:

$$\Phi \rho \left( \frac{\partial c}{\partial t} + u \frac{\partial c}{\partial x} + v \frac{\partial c}{\partial y} + w \frac{\partial c}{\partial z} \right) - \frac{\partial}{\partial x} \left( e_x \frac{\partial c}{\partial x} \right)$$

$$- \frac{\partial}{\partial y} \left( e_y \frac{\partial c}{\partial y} \right) - \frac{\partial}{\partial z} \left( e_z \frac{\partial c}{\partial z} \right) = S(x,y,z,t) + \text{Dissipation Terms}$$  \hspace{1cm} (2.5)

where

$$\rho \text{ - specific heat of water in Btu/lb}^{0}\text{F}$$

$$\Phi \text{ - the diffusion tensor - molecular and viscous}$$

$$S(x,y,z,t) \text{ - source term in Btu/ft}^3\text{-sec}$$

$$c \text{ - non-reacting substance}$$

In this thesis, the dissipation terms are neglected.

At present, (2) computational techniques are inadequate to deal with three dimensional fluid flow problems. The approach here is to reduce the equations to a two dimensional system by vertically averaging the $u, v, c$
components of the fundamental equations. This is shown in Equation 2.6, in symbolic form

\[
\begin{align*}
\left< u \right> = & \frac{1}{h + \eta} \int_{-h}^{h} \left< u' \right> \, dz \\
\left< v \right> = & \frac{1}{h + \eta} \int_{-h}^{h} \left< v' \right> \, dz
\end{align*}
\] (2.6)

where \( \eta \) is surface elevation, and \( h \), bottom depth, are shown in Figure 2.1. In general, these variables have a distinct vertical distribution. For example,

\[
\begin{align*}
u = & U \left[ 1 + E_u(z) \right] \\
v = & V \left[ 1 + E_v(z) \right]
\end{align*}
\] (2.7a, 2.7b)

where \( E_u \) and \( E_v \) are distribution coefficients.

In order to simplify equations 2.1 to 2.3, we make two general assumptions. First, that the magnitude of the vertical velocity is much less than the magnitude of horizontal velocity components. Secondly, that the partial derivatives, \( \partial / \partial x \) and \( \partial / \partial y \) are much less than the vertical term, \( \partial / \partial z \). These assumptions reduce equations 2.1 to 2.3 as follows:

\[
\begin{align*}
\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = & - \frac{1}{\rho} \frac{\partial p}{\partial x} + fv + \frac{1}{\rho} \frac{\partial \tau_{xz}}{\partial z} \\
\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = & - \frac{1}{\rho} \frac{\partial p}{\partial y} - fu + \frac{1}{\rho} \frac{\partial \tau_{yz}}{\partial z}
\end{align*}
\] (2.8, 2.9)
FIGURE 2.1. COORDINATE AND VARIABLE SCHEME FOR THE MODEL
\[ \frac{\partial p}{\partial z} + \rho g = 0 \]  \hspace{1cm} (2.10)

Assuming uniform density and integrating from bottom, 
\[ z = -h, \] to water surface, \[ z = h, \] Equation 2.9 becomes
\[ p(x,y,t) = \rho g \left[ h(x,y,t) - z \right] + p_o \]  \hspace{1cm} (2.11)

where \( p_o \) is surface pressure. Taking partial derivatives of Equation 2.10 for substitution into Equation 2.7 and Equation 2.8 we have
\[ \frac{\partial p}{\partial x} = \rho \frac{\partial n}{\partial x} \]  \hspace{1cm} (2.12)

\[ \frac{\partial p}{\partial y} = \rho \frac{\partial n}{\partial y} \]  \hspace{1cm} (2.13)

because
\[ D p_o = 0 \]  \hspace{1cm} (2.14)

Making use of Leibnitz' rule the resulting simplification shown by Grimsrud (6) gives us the hydraulic equations in the following form
\[ \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = - \frac{\partial n}{\partial x} + f v + \frac{1}{\rho (h+n)} \left( \tau_{sx} - \tau_{bx} \right) \]  \hspace{1cm} (2.15)

\[ \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = - \frac{\partial n}{\partial y} - f u + \frac{1}{\rho (h+n)} \left( \tau_{sy} - \tau_{by} \right) \]  \hspace{1cm} (2.16)
\[
\frac{\partial \mathbf{n}}{\partial t} + \frac{\partial (\mathbf{HU})}{\partial x} + \frac{\partial (\mathbf{HV})}{\partial y} = 0
\]  
(2.17)

where

\( \mathbf{\gamma}_{bi} \) - bottom shear stress

\( \mathbf{\gamma}_{si} \) - surface shear stress

\( H = h + n \)

with boundary condition

\[
w(n) = u(n) \frac{\partial n}{\partial x} + v(n) \frac{\partial n}{\partial y} + \frac{\partial n}{\partial t} = \frac{Dn}{Dt}
\]

The bottom stresses in the x and y directions are approximated by the Chezy relationship of the form

\[
\mathbf{\gamma}_{bx} = \rho g \frac{\left(\frac{u^2 + v^2}{2}\right)}{C_z}
\]  
(2.18)

\[
\mathbf{\gamma}_{by} = \rho g \frac{\left(\frac{u^2 + v^2}{2}\right)}{C_z}
\]  
(2.19)

where \( C_z \) = Chezy coefficient \([(8g/\text{friction factor})^{1/2}] \ and is a function of bottom roughness and depth and calculated from

\[
C_z = \frac{1.49}{N} (h + n)^{1/6}
\]  
(2.20)

with \( N \) - Manning's formula, \((\text{len})^{1/6}\)
The basic model equations now contain all the phenomenological relationships necessary for conversion to a finite difference scheme. Equation 2.5, as yet unmodified, is now time averaged to eliminate the turbulent fluctuations associated with the flow. We introduce, for a vertically averaged substance

$$c = \frac{1}{h} \int_{-h}^{h} c_a \, dz$$  \hspace{1cm} (2.21)

where

$$c_a(z) = C \left[ 1 + E_a(z) \right]$$  \hspace{1cm} (2.22)

and $E_a$ is the density distribution function.

Bearing definitions 2.21 and 2.22 in mind we have

$$\int_{-h}^{h} E_a(z) \, ds = 0$$  \hspace{1cm} (2.23)

which actually defines the density distribution function.

Vertical integration of Equation 2.5 and use of Leibnitz' rule in conjunction with Equations 2.21 and 2.22 we have:

$$\frac{\partial HC}{\partial t} + \frac{\partial}{\partial x} \left[ \langle 1+E_u(z)E_a(z) \rangle UC \right] + \frac{\partial}{\partial y} \left[ \langle 1+E_v(z)E_a(z) \rangle VC \right]$$

$$= \frac{\partial}{\partial x} \left[ \underset{\frac{\partial c}{\partial x}}{\langle e_x \rangle} \right] + \frac{\partial}{\partial y} \left[ \underset{\frac{\partial c}{\partial y}}{\langle e_y \rangle} \right] + \frac{\partial}{\partial z} \left[ \underset{\frac{\partial c}{\partial z}}{\langle e_z \rangle} \right] + \text{HS}$$  \hspace{1cm} (2.24)
Assuming that Narragansett Bay is well mixed imposes the condition that no differences in mass concentrations exist over vertical structure.

\[ E_a \equiv 0 \] (2.25)

Applying the above considerations to the model, Equation 2.24 reduces to

\[
\frac{\partial HC}{\partial t} + \frac{\partial (HUC)}{\partial x} + \frac{\partial (HVC)}{\partial y} = \frac{\partial}{\partial x} \left( HD \frac{\partial C}{\partial x} \right) + \frac{\partial}{\partial y} \left( HD \frac{\partial C}{\partial y} \right) + HS
\] (2.26)

where \( D_x \) and \( D_y \) are dispersion coefficients.

In order to develop relations to express adequately these dispersive terms a brief attempt will be made to investigate the mechanisms of dispersion.

B. DISPERSION

Dispersion of substances is caused by the mean flow velocity differences that occur in all directions. These variations of velocity, greater in the deeper portions and smaller in the shallow areas, cause stretching and spreading of substances in a non-homogenous fluid. Turbulent diffusion is primarily responsible for the cross-sectional spreading that tends to transfer constituents
from the areas of higher concentration to those of lower concentration.

Considering one-dimensional steady flow the longitudinal dispersion coefficient found by Elder (28) is

$$D_l = 5.93 Hu^*$$  \hspace{1cm} (2.27)

where $u^*$ - friction velocity (shear stress velocity)

The friction velocity is related to the mean velocity by the relation:

$$u^* = \left(-\frac{b_x}{\tau_{bx}} \right)^{1/2} = ug^{1/2} C_z^{-1}$$  \hspace{1cm} (2.28)

where $\tau_{bx}$ - bed shear due to $u$, the uniform flow velocity

Now combining Equations 2.27 and 2.28 results in

$$D_l = 5.93 Hug^{1/2} C_z^{-1}$$  \hspace{1cm} (2.29)

For the lateral turbulent dispersion, perpendicular to the mean flow, Elder (28) obtained:

$$D_y = 0.23 Hu^*$$  \hspace{1cm} (2.30)

Oddly enough, this formulation, designed specifically for river flow, underestimated the longitudinal dispersion for river flow. For the slowly time varying flow conditions such as Narragansett Bay it is considered in better agreement. In addition, the longitudinal dispersion is influenced by wind generated local circulation and wave
action (Wilson & Masch, 29). Rather naturally, the lateral turbulent diffusion is affected by the same wind and wave processes.

Since the longitudinal dispersion coefficient is generally larger, except around a source term than the lateral coefficient, the dispersion is anisotropic. To make the model suitable for arbitrary direction and the influence of large scale substance variations from grid to grid, the general expression for dispersive transport becomes

\[
\frac{\partial}{\partial x} [\left( E_{xx} \frac{\partial c}{\partial x} + E_{xy} \frac{\partial c}{\partial y} \right) H] + \frac{\partial}{\partial y} [\left( E_{yx} \frac{\partial c}{\partial y} + E_{yy} \frac{\partial c}{\partial x} \right) H] \tag{2.31}
\]

where the dispersion coefficients \( E_{xx}, E_{xy}, E_{yx} \) and \( E_{yy} \) are dependent on the current magnitude and direction. The relationship 2.31 more closely models the physical bay situation but requires four dispersion coefficients which are at least as difficult to determine as the two included in Equation 2.26. In addition the coupling of the longitudinal and lateral diffusion coefficient makes the computation cumbersome because it would couple the \( x \) and \( y \) conservation equations requiring at least twice the effort to solve substance distribution. Realizing the computational limitations of available computer this approach was deemed unacceptable.
A possible alternate approach by Holley (30) is to compare magnitudes of mass transport by longitudinal dispersion versus advective transport. Since the ratio of dispersion over advection is generally very small, except around outfall areas where steep gradients do exist, the general procedure is to assume that variations in the longitudinal dispersion will not affect the solution. The net result of the above discussion is to assume that the process is isentropic in the sense that there is uncoupled lateral and longitudinal dispersion which are independent functions of velocity, Chezy coefficient and depth in one coordinate direction.

Finally, after all various alternatives were evaluated, the formulation in Equation 2.29 was considered the best choice and is currently being used in the model.

This concludes the introduction of basic differential equations with phenomenological relations as shown below, as the basic equation set for the forthcoming finite difference formulation.

\[ \frac{\partial U}{\partial t} + U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} - fV + \frac{\partial n}{\partial x} + \frac{g(U^2 + V^2)^{1/2}}{C_z H} = 0 \]  (2.32)
\[
\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + f u + g \frac{\partial n}{\partial x} + \frac{g v (u^2 + v^2)^{1/2}}{c_z^2 H} = 0 \tag{2.33}
\]

\[
\frac{\partial n}{\partial t} + \frac{\partial H U}{\partial x} + \frac{\partial (H V)}{\partial y} = 0 \tag{2.34}
\]

\[
\frac{\partial (H C)}{\partial t} + \frac{\partial (H U C)}{\partial x} + \frac{\partial (H V C)}{\partial y} = \frac{\partial}{\partial x} (5.93 \, H U g^{1/2} c_z^{-1}) \\
+ \frac{\partial}{\partial y} (5.93 \, H U g^{1/2} c_z^{-1}) + S \tag{2.35}
\]

c. **Finite Difference Approximations**

For the solution of the Equations 2.32 to 2.35 the approach of Leendertse (1) will be followed. In this scheme, the variables \( \eta, c, v, u, h \) are arranged, with general coordinate system explanation, as shown in Figure 2.2.

This scheme has the advantage that for the variable operated upon in time there is a centrally located spatial derivative for the linear term. In the x-momentum Equation 2.32, the time-derivative of water level \( (g \frac{\partial n}{\partial x}) \) is an example of this.

In accordance with the semi-implicit method the time-step is split into two halves, and the time-derivative taken over the half time-step. Semi-implicit means solving
\[ x_c = \left( m - \frac{1}{2} \right) \frac{L}{2} \]

\[ y_c = \left( n - \frac{1}{2} \right) \frac{L}{2} \]

\[ \eta_{m,n} = \eta(x_c, y_c) \]

\[ u_{m,n} = u(x_c + L/2, y_c) \]

\[ v_{m,n} = v(x_c, y_c + L/2) \]

\[ h_{m,n} = h(x_c + L/2, y_c + L/2) \]

\[ c_{m,n} = c(x_c, y_c) \]

**FIGURE 2.2. SPACE STAGGERED GRID SYSTEM**
first explicitly (individual values are calculated at next time step) and then implicitly (solve whole row simultaneously). Thus, for the function \( F \), continuous in space and time, the notation is:

\[
F(mDL, nDL, tDT) = F^t
\]  

(2.36)

where \( DL \) is the grid spacing. The first forward time derivative is:

\[
\frac{\partial F}{\partial t} = \frac{2}{DT} \delta F^t_{m,n} = \frac{2}{DT} (F_{m,n}^{t+1/2} - F_{m,n}^t)
\]  

(2.37)

where \( DT \) is time interval. We adopt the following notation for various convenient functions of space and time:

\[
\frac{\partial x}{F^x_{m,n}} = \frac{1}{2} (F_{m+1/2,n} + F_{m-1/2,n})
\]  

(2.38)

\[
\frac{\partial y}{F^y_{m,n}} = \frac{1}{2} (F_{m,n+1/2} + F_{m,n-1/2})
\]  

(2.39)

\[
\delta_x F^x_{m,n} = (F_{m+1/2,n} - F_{m-1/2,n})
\]  

(2.40)

\[
\delta_y F^y_{m,n} = (F_{m,n+1/2} - F_{m,n-1/2})
\]  

(2.41)

\[
\delta_x *F^x_{m,n} = \frac{1}{2} (F_{m+1,n} - F_{m,n-1})
\]  

(2.42)

\[
\delta_y *F^y_{m,n} = \frac{1}{2} (F_{m,n+1} - F_{m,n-1})
\]  

(2.43)

\[
\frac{\partial}{F^z_{m,n}} = \frac{1}{4} (F_{m+1/2,n+1/2} + F_{m-1/2,n+1/2} + F_{m+1/2,n-1/2} + F_{m-1/2,n-1/2})
\]  

(2.44)
The momentum and conservation of mass equations may then be transformed into finite-difference equations and solved for the new value in time for a total of eight equations, four for each time step. The equations are given in Appendix B and D.

The solution of Equations B.1 to B.6 (Appendix B and D) is called by Leendertse a "multi-operation" method, which is a modification of the "leap-frog" method. In the first half time-step, values of \( U \) and \( \mathbf{n} \) are computed implicitly along a grid row in the x-direction at the time \((t+1/2)\ DT\). Then \( V \) is computed at the same time level explicitly. In the second half time-step, \( V \) and \( n \) are computed implicitly at \((t+1)\ DT\) along grid rows in the y-direction, after which \( U \) is calculated explicitly at \((t+1)\ DT\).

In the first half of the time-step, the time derivative of \( U \) in the x-momentum equation is approximated by a backward difference:

\[
\frac{\partial}{\partial t}(U^{t+1/2}) = \frac{2}{DT}(U^{t+1/2} - U^t) = fcn\ (n^{t+1/2}) \tag{2.45}
\]

In the second half time-step, a forward difference is used:

\[
\frac{\partial}{\partial t}(U^{t+1}) = \frac{2}{DT}(U^{t+1} - U^{t+1/2}) = fcn\ (n^{t+1/2}) \tag{2.46}
\]
Thus, over a full time-step, the time derivative is a
central difference with respect to the water level:
\[
\frac{\partial U}{\partial t} = \frac{u_t^{t+1} - u_t^t}{\Delta T} = \text{fcn} \ (n_{t+1/2})
\] (2.47)

This composite relation defines the leap-frog method.

The set of difference equations for the implicit time-
step on \( U \) and \( n \) may be written as
\[
[A] (u_{t+1/2} \text{ or } n_{t+1/2}) = (b)
\] (2.48)

where \([A]\) is a tridiagonal matrix and \((b)\) is a column
vector of known terms. Equation 2.48 may then be solved
by Gaussian elimination (see Mitchell (24) for example) for
the new values of \( U \) and \( n \) at \((t+1/2)\). A similar procedure
is used for the second implicit operation involving \( V \) and
\( n \) at time \((t+1)\). The details are given in (Hess (4),
Appendix B and C).

D. DIFFERENCING COMMENTS

D.1. Stability

An extensive analytical treatment of stability
has been given by Leendertse (1, 2) with further comments
by Grimsrud (6), Hess (4), and Spaulding (16). Whenever a
problem in the physical values produced by a computational
scheme occurs by a model user the word 'stability' is gen-
erally used. Instability may be defined as the unlimited amplifications of errors. This can occur because of the dissimilar nature of upstream or central differencing or the simplified unidimensional dispersion coefficient used with a source with significant temperature gradients.

D.2. Boundary Conditions

In Figure 2.3, the general boundary conditions format is outlined for the model. Hess (4) summarized the difficulty encountered by Leendertse (1) when handling the spatial derivatives, Equations 2.41 and 2.42. Briefly stated, the convective terms encountered at land boundaries are dropped in the solution of the momentum equation. This effect causes an inaccuracy in the hydraulic model and will create computational problems for a source term with a low dispersion coefficient if the substance varies significantly from grid to grid. Some model users adhere to the policy that the upstream differencing technique (Appendix E), which enhances the dispersion coefficient a thousand fold in the model, should be used. In essence, the model creates far field conditions for a dispersed substance in what is considered the intermediate zone.

A technique that might be used (Spaulding, 16) is an upstream differencing technique around a source and conver-
<table>
<thead>
<tr>
<th>LOCATION</th>
<th>VARIABLE</th>
<th>MODEL INPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>source (Power plant)</td>
<td>Flow Rate (Fixed)*</td>
<td>Velocity*Concentration</td>
</tr>
<tr>
<td></td>
<td>Temperature Difference Through Plant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>YDS$^3$/SEC</td>
<td>(YDS/SEC) - °C</td>
</tr>
<tr>
<td>Rivers</td>
<td>Flow Rate (Fixed)</td>
<td>Velocity*Concentration at Boundary</td>
</tr>
<tr>
<td></td>
<td>YDS$^3$/SEC</td>
<td>(YDS/SEC) - °C</td>
</tr>
<tr>
<td>Mt. Hope Bay</td>
<td>Tidal Flow Rate (Variable)</td>
<td>Velocity*Concentration at Boundary</td>
</tr>
<tr>
<td></td>
<td>YDS$^3$/SEC</td>
<td>(YDS/SEC) - °C</td>
</tr>
<tr>
<td>Rhode Island Sound</td>
<td>Tidal Height (Variable)</td>
<td>Velocity*Concentration at Boundary</td>
</tr>
<tr>
<td></td>
<td>YDS</td>
<td>(YDS/SEC) - °C</td>
</tr>
</tbody>
</table>

FIGURE 2.3. BOUNDARY CONDITIONS
sion to a central differencing scheme (see Appendix E) at some specified distance from source discontinuity. This author prefers, if necessary, to use a formulation suggested by Kurt Hess that would naturally enhance dispersion coefficient for large discontinuities of concentration in the model near a source. This is then an alternative to arbitrarily increasing the dispersion coefficient in the upstream differencing technique, for the entire bay, as shown below.

\[
D_{m+1/2} = D[1 + \frac{(C_{m+1} - C_m)^2}{(C_{m+1} + C_m)^2} E] \quad (2.49)
\]

\[
D_{m-1/2} = D[1 + \frac{(C_m - C_{m-1})^2}{(C_m + C_{m-1})^2} E] \quad (2.50)
\]

where

\(D\) - is the normal model dispersion coefficient

\(E\) - arbitrary constant of order one.

This means that the centered spatial derivative can be used when the adjacent concentrations are different without having computational problems for suitable values of \(E\). This technique was not used here.
D.3. Computational Differences for Central and Upstream Differencing

An explanation of the computational problems with regard to upstream and central differencing is now necessary. According to Leendertse (2), certain difficulties are encountered upstream from sources with respect to the convective term. Consider Figure 2.4, and the case of a centered spatial derivative \( A = B = 1/2 \). Suppose the concentration at \( m+1 \) is unity, and zero elsewhere. Applying the finite-difference equation at \( M \) leads to a decrease.

\[
C_{mm} - (1-B) (A-B) C_m - (1-A) C_{mp} = 0
\]

where \( mm = m-1 \)
\( mp = m+1 \)

FIGURE 2.4. ONE DIMENSIONAL CONCENTRATION SCHEME

in concentration \( C_m \). The remedy is to use upstream dif-
ferencing \((B = 0, A = 1)\) at grid \(m\) \((\text{or } B = 1, A = 0 \text{ if } u < 0)\) so that concentration at \(m\) will then remain zero.

A few calculations will show that if upstream differencing is used only at \(m\), mass will not be conserved elsewhere. Therefore, for consistency, upstream differencing would have to be used everywhere. However, as shown by Leendertse (1, p. 34), this approximation results in an effective increase in the dispersion coefficient.

One possible alternative is to use the centered spatial derivative, and increase the dispersion coefficient artificially as shown before in Equation 2.49, which allows a higher dispersion when the adjacent concentrations are different, but no increase when they are the same.

The primary purpose of this thesis is to verify the techniques and applicability of thermal model to Narragansett Bay. With this in mind, the model now uses the formulation conceived by Leendertse (3) with a central differencing scheme. The final decision on whether adjustment in the present dispersion coefficient, using for instance Equation 2.49, will occur after an evaluation of the results.
III. TEMPERATURE AND AIR WATER INTERFACE BOUNDARY CONDITIONS AND VERIFICATION DATA RELATIONSHIPS

A. AIR WATER INTERFACE—SURFACE HEAT TRANSFER PROCESSES

The literature, (5, 9, 11, 12, 15, 17, 25), has treated the heat transfer rate at air—water interface as a formulation of a net heat flux equation which is composed of specific transfer terms by distinguishing air, water and air—water terms.

Figure 3.1 shows the term by term formulation of the heat transfer processes which control the water temperature at the air—water interface. Figure 3.2 shows general temperature, pressure and velocity profiles expected at the interface.

The general continuity equation for the interface is:

\[ \frac{\partial}{\partial t} (m_{cv}) = \int dw_{\text{in}} - \int dw_{\text{out}} \]  

(3.1)

where

- t - time
- cv - refers to the control volume in Figure 3.1

Since the volume of the control volume is assumed small

\[ m_{cv} \approx 0 \]  

(3.2)

Equation (3.1) becomes) (see Figure 3.1)

\[ 0 = w_w - w_a \]  

(3.3)
HS1 - incident solar radiation heat transfer rate (HTR)

HS1\_SR - reflected solar radiation HTR

HS1\_NET = HS1 - HS1\_SR

HA - incident atmospheric radiation HTR

HA\_SR - reflected atmospheric radiation HTR

HA\_NET = HA - HA\_SR

BH - back radiation HTR from surface

HC - conduction heat transfer rate from atmosphere side of interface conversion

w_a - evaporation mass flow rate, atmosphere side of interface

w_w - evaporation mass flow rate, water side of interface

h_f - enthalpy, saturated liquid state

h_g - enthalpy, saturated vapor state

**FIGURE 3.1. SCHEMATIC, SURFACE HEAT TRANSFER PROCESS**

PER UNIT AREA
TA - temperature of air

TS - temperature surface water

TW = TS - water temperature, constant for depth of grid

EA - air vapor pressure, function relative humidity, TA

ES - saturated vapor pressure, function of TW

PA - atmospheric pressure

WA - wind velocity in MPH

V - water velocity constant for depth of grid, assumed independent of wind velocity

FIGURE 3.2. TEMPERATURE, PRESSURE AND VELOCITY PROFILES NEAR INTERFACE
or

\[ w_w = w_a = w_e \]  \hspace{1cm} (3.4)

where \( w_e \) is the evaporation rate.

The general steady flow energy equation for the control volume is:

\[ q - P_x = \left( \frac{\partial E}{\partial t} \right)_{CV} + \int (A)_{\text{out}} dw_{\text{out}} - \int (A)_{\text{in}} dw_{\text{in}} \]  \hspace{1cm} (3.5)

where

\[ \begin{align*}
q &\text{ - net heat transfer rate to control volume (positive into cv)} \\
\mathbf{P}_x &\text{ - net shaft power to control volume (power to external elements from cv positive)} \\
E &\text{ - energy inside control volume} \\
A &= (h + \frac{\mathbf{V}^2}{g} + gz) \\
h &\text{ - enthalpy} \\
\mathbf{V} &\text{ - velocity} \\
g &\text{ - acceleration of gravity} \\
z &\text{ - height in gravitational field above arbitrary level}
\end{align*} \]

Since mass is conserved, as shown in Equation 3.2,

\[ E_{CV} = 0 \]  \hspace{1cm} (3.6)

Also for conditions in Figure 3.1

\[ P_x = 0 \]  \hspace{1cm} (3.7a)
\[ v = 0 \quad (3.7b) \]
\[ z = 0 \quad (3.7c) \]

Equation 3.5 with substitution of 3.6, 3.7a, 3.7b, and 3.7c reduces to

\[ q = w_e (h_g - h_f) \quad (3.8) \]

or

\[ q = w_e h_{fg} \quad (3.9) \]

where \( h_{fg} \) is the latent heat of vaporization evaluated at the surface temperature, \( T_s \). Summing heat transfer rates for control volume in Figure 3.1, Equation 3.9 becomes:

\[ H_{S1}\text{NET} + H_{A}\text{NET} - BH + HC + HTOT = w_e h_{fg} \quad (3.10) \]

where, by definition

\[ HE = w_e h_{fg} \quad (3.11) \]

Equation 3.10 becomes

\[ H_{S1}\text{NET} + H_{A}\text{NET} - BH + HC + HTOT - HE = 0 \quad (3.13) \]

or

\[ -HTOT = H_{S1}\text{NET} + H_{A}\text{NET} - BH + HC - HE \quad (3.13) \]

Note that \( HE \) is considered an enthalpy flux and not a heat transfer rate. Reviewing sign convention, we see that if the right hand side (RHS) of Equation 3.13 is positive, \( HTOT \) is negative and the heat transfer across the interface is to the water below the interface. If the RHS of
Equation 3.13 is negative, HTOT is positive and the heat transfer across the interface is from the water below the interface.

A common formulation found in the literature (Edinger and Geyer, 12) is the grouping of water independent heat exchange rates for solar and atmospheric radiation as shown

\[ HR = H_{SL\text{NET}} + H_{AN\text{NET}} \] (3.14)

In order to be consistent with current usage of HC and HE having the same signs in the heat balance, the following change is made:

\[ HC = -(-HC) \] (3.15)

Finally, the equation used in the model is:

\[ HTOT = HR - (BH + HC + HE) \] (3.16)

In summary, the specific formulation of some of these quantified heat exchange rates into functions of model variables that are both physically complex and interrelated poses a challenge. Each net heat transfer rate, as described in the model, will be discussed with regard to literature formulations and current thinking.

B. INCIDENT SOLAR RADIATION HEAT TRANSFER RATE

When no solar radiation data is available, a common approach (Harleman, 15, 24) is to formulate the solar radi-
ation heat transfer rate as a function of a solar constant, solar altitude, normalized radius of earth's orbit, atmospheric transmission coefficient, optical air mass and cloudiness. In Wonderlich (19) and List (20) equations for calculating these values can be found.

Fortunately for the Narragansett Bay area, Eppley Laboratory in Newport, Rhode Island have been taking continuous readings of net solar energy since the early 1950's. If no data is read in on an hourly basis the model requires the total solar input for that day or $H_{S1}$. One can determine what hourly variations, $H_{S2}$, there would be for clear sky conditions by using the following empirical equations derived from actual solar radiation plots throughout the year:

$$D = \frac{H_{S1}(IDY)}{1.7 + (H_{S1}(IDY) - 100.0)/350.0} \quad (3.17a)$$

$$G = 2 \cdot \pi \left( \text{TIMEX} - 6.0 \right) \cdot \left( 1 + 2 \cdot \exp(-3 \cdot (182.0 - \text{ABS(DAY - 182.0)})/182.0) \right) \quad (3.17b)$$

$$T = 24 \cdot \left( 1 - 2 \cdot \cos(2 \cdot \pi \cdot \text{DAY}/365.0) \right) \quad (3.17c)$$

$$H_{S2}(IDY) = D \cdot \sin(G/T) \quad (3.17d)$$

$$H_{S1}(IDY) = 17.85 \cdot H_{S2}(IDY) \quad (3.17e)$$

where

$H_{S1}(IDY)$ - total solar input for day IDY

TIMEX = initial starting time = 0 at 7 a.m.
DAY = IDY = Day of year, e.g., 14 July is DAY 195

\[ \pi = 3.1416 \]

\[ 17.85 = 0.2 \times 24 \frac{\text{hours}}{\text{day}} \div 0.27 \]

0.2 = Eppley Laboratory scale factor (can also be 0.1)

0.27 = conversion factor from Grm-Cal/cm\(^2\) to Btu/ft\(^2\)

Since hourly solar data is read in, the final step of determining the affects of cloudiness on above formulation was not pursued. A simple procedure of taking total solar radiation for input day and determining hourly values on this basis and adding or subtracting a certain amount depending on the cloudiness factor for an hour versus average cloudiness factor for a day should bring results within 10-20% of the true value.

C. REFLECTED SOLAR RADIATION HEAT-TRANSFER RATE

The reflected solar radiation heat-transfer rate is usually calculated from the incident solar rate and a solar reflectivity, \( R_{sr} \), defined as:

\[ R_{sr} = \frac{H_{sl}}{H_{sl}} \]

Typical data can be found in Anderson (21). \( R_{sr} \) can be estimated from the following empirical formula:

\[ R_{sr} = a_1 \alpha + b_1 \]
FIGURE 3.3. TYPICAL NET SOLAR RADIATION DATA FOR NARRAGANSETT BAY
where \( \alpha \) is the solar (sun) altitude in degrees and \( a_1 \) and \( b_1 \) are functions of cloudiness, CL, and given in Table 3.1.

<table>
<thead>
<tr>
<th>Cloudiness, CL</th>
<th>Sky</th>
<th>( a_1 )</th>
<th>( b_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Clear</td>
<td>1.18</td>
<td>-0.77</td>
</tr>
<tr>
<td>0.1-0.5</td>
<td>Scattered</td>
<td>2.20</td>
<td>-0.97</td>
</tr>
<tr>
<td>0.6-0.9</td>
<td>Broken</td>
<td>0.95</td>
<td>-0.75</td>
</tr>
<tr>
<td>1.0</td>
<td>Overcast</td>
<td>0.35</td>
<td>-1.45</td>
</tr>
</tbody>
</table>

**TABLE 3.1. REFLECTED SOLAR RADIATION CONSTANTS**

As previously mentioned, Eppley Laboratory measures continuous net input solar heat transfer rate, \((H_{S2})\), so that the use of the previously outlined procedure on reflected solar radiation is not required.

**D. INCIDENT ATMOSPHERIC RADIATION HEAT-TRANSFER RATE**

The incident atmospheric radiation heat-transfer rate may be calculated from a relationship formulated by Brunt (Anderson (21))

\[
H_A = SB(T_A + 460)^4(C_B + 0.031(E_A)^5) \quad (3.20)
\]

where
HA - Btu/ft² - day

SB - Stefan-Boltzman constant, $4.15 \times 10^{-8} \text{Btu/ft}^2\text{day}^\circ\text{R}^4$

TA - air temperature, °F, (measured six feet above surface)

EA - atmospheric vapor pressure, mmHg (measured six feet above surface)

CB - coefficient determined by air temperature and $C'$, the ratio of the measured solar radiation to the clear sky solar radiation

CL is determined from the total daily solar radiation by integrating the solar radiation curve for a particular day from the pyrheliometer reading and dividing this value by the clear sky solar radiation. The values of TA and CL then determine CB as shown in Reference 12, Figure 2.5, page 26. The effect on HA can be seen in Reference 12, Figure 2.4, page 25.

The Brunt coefficient may be estimated from the following equation:

$$CB = .74 - \frac{3.5(96 - TA)^{1.67}}{10^{(4 + 3CL)}}$$  \hspace{1cm} (3.21)

where

TA - temperature of air in °F

CL - cloudiness ratio
An alternate method, not used in the model for determining HA, from Swinbank (22) is:

\[ HA = 1.2 \times 10^{-13} (TA + 460)^6 (1 + 0.17CL^2) \]  
(3.22)

If less accuracy is desired assume black body radiation in Equation 3.20 and let the second bracket equal 0.87 or emissivity constant.

E. REFLECTED ATMOSPHERIC RADIATION HEAT-TRANSFER RATE

The reflected atmospheric radiation heat-transfer rate is usually calculated from the incident atmospheric rate and an atmospheric reflectivity, \( R_{ar} \), defined as:

\[ R_{ar} = \frac{HA}{HA_{ar}} \]  
(3.23)

The value of \( R_{ar} \) is usually taken as 0.03 (Edinger and Geyer (12)). The result is:

\[ HA_{NET} = HA - HA_{ar} = 0.97HA \]  
(3.24)

F. BACK RADIATION HEAT-TRANSFER RATE FROM WATER SURFACE

The back radiation heat-transfer from the water surface is calculated from black-body radiation with an emissivity of 0.97:

\[ BH = EW \times SB(TW + 460)^4 \]  
(3.25)
where

\[ BH = \text{Btu/ft}^2\text{-day} \]

\[ EW = \text{emissivity of water surface} = 0.97 \]

\[ SB = \text{Stefan-Boltzmann constant} = 4.2 \times 10^{-8} \frac{\text{Btu}}{\text{ft}^2\text{day}^\circ\text{R}^4} \]

\[ TW = ^\circ\text{F water temperature} \]

G. AIR VAPOR PRESSURE, EA

EA is empirically determined by first finding partial pressure, PMM as follows:

\[ PMM = A - B \cos (\pi ((TA-30)/70.) C + D)/180.) \quad (3.26) \]

and A, B, C, and D in mmHg are found in Table 3.2

<table>
<thead>
<tr>
<th>TA (°F)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.00-59.99</td>
<td>94.5</td>
<td>90.</td>
<td>54.5</td>
<td>2.5</td>
</tr>
<tr>
<td>60.00-79.99</td>
<td>94.5</td>
<td>90.</td>
<td>51.</td>
<td>14.</td>
</tr>
<tr>
<td>80.00-89.99</td>
<td>94.5</td>
<td>90.</td>
<td>61.</td>
<td>-3.0</td>
</tr>
<tr>
<td>90.00-100.00</td>
<td>99.5</td>
<td>100.</td>
<td>59.5</td>
<td>0.</td>
</tr>
</tbody>
</table>

**TABLE 3.2. AIR VAPOR PRESSURE CONSTANTS**

\[ EA = (PMM - ((TA-30)/70.) 3.5 + 1.) (RH-10.)/90. + ((TA -30.)/70.) 3.5+1. \quad (3.27) \]
where RH is relative humidity in percent.

H. SATURATED VAPOR PRESSURE (DUE POINT TEMPERATURE)

The vapor pressure, $E_S$, is found from the simple empirical formula

$$ES = 99.0 - 96.0 \cos\left(3.14\left(\frac{(T_W - 30.)/50.}{33. + 7.}/180.\right)\right)$$  \hspace{1cm} (3.28)

I. EVAPORATION HEAT-TRANSFER RATE

The evaporation heat-transfer rate is calculated from:

$$HE = f(V)(ES - EA)$$  \hspace{1cm} (3.29)

where

- $HE = \text{Btu/ft}^2 \cdot \text{DAY}$
- $V$ - wind velocity measured at specific elevation above the water surface, MPH
- $f(V)$ - wind velocity function, energy/time-area-pressure
- $ES$ - vapor pressure at water surface temperature, $T_W$
- $EA$ - vapor pressure measured at specific elevation above the water surface at air temperature $T_A$

The wind velocity function $f(V)$ is usually expressed as

$$f(V) = a_2 + b_2 V$$  \hspace{1cm} (3.30)
Table 3.3 presents typical values of $a_2$ and $b_2$.

<table>
<thead>
<tr>
<th>Source</th>
<th>$a_2$ (Btu/day-ft$^2$-mmHg)</th>
<th>$b_2$ (Btu/day-ft$^2$-mmHg-mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Hefner</td>
<td>0</td>
<td>11.4</td>
</tr>
<tr>
<td>Lake Colorado</td>
<td>0</td>
<td>16.8</td>
</tr>
<tr>
<td>City</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meyer</td>
<td>73</td>
<td>7.3</td>
</tr>
</tbody>
</table>

**TABLE 3.3. WIND VELOCITY FUNCTION PARAMETERS**

Note that Table 3.3 implies the following set of units on Equations 3.29 and 3.30.

- $HE$ - Btu/ft$^2$-day
- $V$ - mph
- $[EA, ES - mmHg]$

It should also be noted that certain quantities in Equations 3.29 and 3.30 are time averages and are measured at specified elevations above the water surface. Table 3.4 summarizes these details.
TABLE 3.4. EVAPORATION FORMULA MEASUREMENT PARAMETERS

<table>
<thead>
<tr>
<th>Source</th>
<th>Averaging Period</th>
<th>V Elevation (Ft.)</th>
<th>EA, ES Elevation (Ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Hefner</td>
<td>3 hours</td>
<td>24</td>
<td>3 hours</td>
</tr>
<tr>
<td>Lake Colorado City</td>
<td>24 hours</td>
<td>24</td>
<td>24 hours</td>
</tr>
<tr>
<td>Meyer</td>
<td>Monthly</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

The Lake Hefner values are more widely used because of the extensive investigative work that went into their formulation but the equation, at best, is a rough approximation of a physical process that is not well defined. When a calculation of the net heat transfer rate is performed the result is of the order of the evaporation rate. Thus, long computer runs and a massive data gathering effort to precisely measure air and water temperature at several elevations in conjunction with wind speed, humidity and wave height measurements are necessary to justify the application of the Lake Hefner values on Narragansett Bay. In summary, improvement on the present formula is very necessary and a plausible research area.
J. **EVAPORATION MASS FLOW RATE**

The evaporation mass flow rate can be estimated from the evaporation heat-transfer rate by:

\[
\frac{w_e}{A} = \frac{HE}{h_{fg}}
\]  

(3.31)

where

- \( \frac{w_e}{A} \) - evaporation mass flow rate, mass/time-area
- \( HE \) - energy/time-area
- \( h_{fg} \) - latent heat of vaporization at \( TW \), energy/mass

with \( h_{fg} \) estimated from

\[
h_{fg} = 1087 - 0.54 \, TW
\]  

(3.32)

for \( TW \) - °F and \( h_{fg} \) in Btu/lb

Use of Equations 3.29 through 3.32 with values from Table 3.3 will yield evaporation mass flow rates in lb/ft\(^2\)-day.

K. **CONDUCTION HEAT-TRANSFER RATE**

The conduction heat-transfer rate is approximated as a fraction of the evaporation heat-transfer rate through the Bowen ratio, \( B \):

- \( HC = HE \times B \)  

(3.33)

and

\[
B = C_3 \frac{(TS - TA)}{(ES - EA)} \times \frac{P}{760}
\]  

(3.34)
where

\[ TS - \text{surface temperature (°F)} = TW \]

\[ TA - \text{air temperature, °F} \]

\[ ES - \text{saturated vapor pressure at water surface temperature, TS} \]

\[ EA - \text{air vapor pressure calculated from air temperature, TA, and relative humidity, RH} \]

\[ P - \text{barometric pressure, mmHg} \]

\[ C_3 - \text{an experimental constant usually taken as 0.26} \]

(0.24 for smooth water surfaces and 0.28 for rough water surfaces).

Note that a minus sign has been introduced into Equation 3.33 due to the sign convention in Figure 3.1. If TS is less than TA then from Equations 3.33 and 3.34, HTOT will be positive and the heat transfer will be from the air to the water surface in agreement with the sign convention of Figure 3.1.

Combining Equations 3.29, 3.30, 3.33, and 3.34 yields

\[ HC = -C_3 f(V) (TS - TA) \frac{P}{760} \] (3.35)

or for \( P = 760 \text{ mmHg} \) we have

\[ HC = -C_3 (a_2 + b_2 V) (TS - TA) \] (3.36)

Again, emphasis must be placed on the empirical
nature of conduction heat rate formulation with regard to the Bowen ratio and the wind factor.

L. MODEL FORMULATION

Substitution of Equations 3.20, 3.25, 3.29, and 3.36 into 3.14 and 3.16 results in the model formula 3.37, shown below.

\[
HTOT = HS2 + SB (TA + 460)^4 (CB + .031(ES)^{0.5})
\]

\[
- EW * SB * (TW + 460)^4 - (a_2 + b_2 V) (ES-EA)
\]

\[
- C_3 (a_2 + b_2 V) (TW - TA)
\]

Since ES is a function of water temperature only, we assume that for the time increment used in the model there is no significant error introduced by using the calculated water temperature value from the previous time step. In addition, the previous water temperature values are used to predict current heat exchange rates as shown in Equation 3.37. The other variables, air temperature, wind speed, relative humidity, solar radiation, and cloudiness are given, so one can now determine HTOT directly from Equation 3.37.

The model vertically averages (no buoyant effects) temperature structure so the energy equation is considered
linear if the net heat exchange is linear for the temperature range considered. The net heat exchange rate for man made conditions requires only the water temperature excess, assuming that the air and natural water temperature remain unchanged as formulated in the following way:

Forced Water Temperature Rise = Man Made Rise - Natural Condition

\[ \text{FMTR} = \text{HS}^2_{\text{MM}} + \text{HA}_{\text{MM}} - \text{BH}_{\text{MM}} - \text{HE}_{\text{MM}} - \text{HC}_{\text{MM}} - \text{HS}^2_{\text{N}} + \text{HA}_{\text{N}} \]

where MM index means man made condition, N is natural condition, and FTR equals forced water temperature rise (DELTAT in model). The following assumptions are made with regard to Equation 3.39:

1) \( \text{HS}^2_{\text{MM}} = \text{HS}^2_{\text{N}} \) (net solar input)
2) \( \text{HA}_{\text{MM}} = f(TA, \text{cloudiness}) = \text{HA}_{\text{N}} \) (incoming radiation)
3) \( \text{BH}_{\text{MM}} = \text{BH}_{\text{N}} + \text{BH}_{\text{FTR}} \) (back radiation)
4) \( \text{HE}_{\text{MM}} = \text{HE}_{\text{N}} + \text{HE}_{\text{FTR}} \) (evaporation)
5) \( \text{HC}_{\text{MM}} = \text{HC}_{\text{N}} + \text{HC}_{\text{FTR}} \) (conduction)

Noting that we must know approximate temperature range of water for linearized saturated vapor pressure, ES, we now rewrite 3.39 into the following form:
\[(\text{Net Heat Exchange})_{\text{FTR}} = BH_{\text{FTR}} + HE_{\text{FTR}} + HC_{\text{FTR}} \quad (3.40)\]

where

\[BH_{\text{FTR}} = EW \ast SB \ast (TW_{\text{FTR}} + 460)^4\]

\[HE_{\text{FTR}} = (a_2 + b_2 V) ES \ast TW_{\text{FTR}}\]

\[a_2 + b_2 V \text{ - wind evaporation function}\]

\[ES \text{ - saturated vapor pressure for water temperature (mmHg)}\]

\[TW_{\text{FTR}} \text{ - calculated forced water temperature rise from model (°C)}\]

\[HC = 0.26(a_2 + b_2 V) TW_{\text{FTR}}\]

Linearization of \(BH_{\text{FTR}}\) is done by using the following binomial expansion:

\[(Y + G)^m = G^m + mG^{m-1}Y + \frac{m(m-1)}{2!} G^{m-2} Y^2\]

\[+ \frac{m(m-1)(m-2)}{3!} G^{m-3} Y^3\]

\[(3.41)\]

for

\[Y = TW\]

\[G = 460°F\]

\[m = 4\]

Equation 3.41 becomes
and neglecting the last three terms as small we have

\[
B_{FTR}^H = EW(460)^3 TW_{FTR}^W
\]  

(3.43)

The use of the forced temperature rise for a heated effluent is ideal because it allows predictions that are much less sensitive to inaccuracies in the meteorological data being used. This method improves predictive confidence for intelligent "worst case" analysis by separately considering maximum temperature rise during tidal cycle coupled and the maximum natural rise, say, during a hot summer day. As an add to understanding the tidal excursions of isotherms and the maximum value and location they attain, the forced temperature rise calculations are very valuable especially if one is concerned with small temperature differences of the order of 0.1°C in the far field.

M. EQUILIBRIUM TEMPERATURE

If the net heat transfer rate, HTOT, to the water, as given in Equation 3.37 is zero the grid point water temperature is then said to be at its equilibrium temperature, TE. Therefore, Equation 3.37 becomes:
\[
0 = HS2 + SB(TA + 460)^4(CB + .031(EA)^{1/2})
- EW*SB(TE + 460)^4 - (a_2 + b_2V)(ES - EA)
- C_3(a_2 + b_2V)(TE - TA)
\] (3.44)

Solving Equation 3.44 in terms of TE requires at worst an iterative procedure because the saturated vapor pressure function, ES is calculated from the equilibrium temperature. In actuality, the solution of Equation 3.43 requires about six iterations in the computer model for five place accuracy. In the next section, the heat exchange coefficient approach will be used to actually calculate the equilibrium coefficient.

N. EXCHANGE COEFFICIENT

The use of Newton's law of cooling, Equation 3.45, is essential for making an engineering estimate of the equilibrium temperature.

\[Q = K * DT\] (3.45)

where

\[
Q - \text{heat transfer rate (HTOT in model) normal to grid surface area (Btu/ft}^2\text{-day)}
\]

\[
K - \text{idealized heat transfer coefficient (Btu/ft}^2\text{-day}^{-0\circ}\text{F)}
\]
DT - temperature difference (TE - TW) (°F)

By subtracting Equation 3.44 from 3.37 it follows that

\[
HTOT = -[EW * SB[(TW + 460)^4 - (TE + 460)^4] \\
+ (a_2 + b_2v)(ES - EE) + C_3(a_2 + b_2v)(TW - TE) \]

(3.46)

where EE is saturated vapor pressure evaluated at TE. Now by combining 3.45 and 3.46 and solving for K we have the relationship

\[
K = EW * SB [(TW + 460)^4 - (TE + 460)^4] \\
+ (a_2 + b_2v)(ES - EE) + C_3(a_2 + b_2v)(TW - TE) / (TW - TE)
\]

(3.47)

By using the binomial expansion and neglecting second and higher order terms in Equation 3.41 and Equation 3.48 the linear vapor pressure approximation, BETA, shown below

\[
ES - EE = BETA(TW - TE)
\]

(3.48)

where BETA is found in Table 3.5, we have, from Equations 3.46 to 3.48,

\[
K = 4EW * SB 460^3 + (a_2 + b_2v)(C_3 + BETA)
\]

(3.49)

After substitution of

\[
EW = 0.97 \text{ and } SB = 4.2 \times 10^{-8} \frac{\text{Btu}}{\text{ft}^2 \cdot \text{day} \cdot \circ \text{R}}
\]

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TABLE 3.5. LINEARIZED VAPOR PRESSURE CONSTANT, BETA

(REFERENCE 12)

<table>
<thead>
<tr>
<th>Temperature Range °F</th>
<th>BETA (mmHg °F⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40-50</td>
<td>0.291</td>
</tr>
<tr>
<td>50-60</td>
<td>0.405</td>
</tr>
<tr>
<td>60-70</td>
<td>0.553</td>
</tr>
<tr>
<td>70-80</td>
<td>0.774</td>
</tr>
<tr>
<td>80-90</td>
<td>0.990</td>
</tr>
<tr>
<td>90-100</td>
<td>1.289</td>
</tr>
</tbody>
</table>

The final result is:

\[ K = 15.7 + (a_2 + b_2 V)(c_3 + \text{BETA}) \]  \hspace{1cm} (3.50)

where \( K \) has units of Btu/ft² - day °F and \( a_2, b_2, V, c_3, \) \( \text{BETA} \) are all constants. Finally, we substitute 3.37 and 3.50 into Fourier's law, Equation 3.45, and the result is:

\[ \text{TE} = \frac{\text{HTOT}}{K} + \text{TW} \]  \hspace{1cm} (3.51)

Equation 3.51 now is used to calculate the equilibrium temperature in the model.
IV. COMPUTER MODEL SUMMARY

A. PRELIMINARY MODEL DETAILS

A.1. General

The computational scheme is controlled from the main section of the computer program by calling subprograms in order with suitable comments inserted to guide user through model operation. Pertinent hydrodynamic information for Narragansett Bay can be found in Kurt Hess's, Numerical Tidal Model of Narragansett Bay (4). Following the general computational procedure in the main section of the thermal model we encounter the following input control parameters:

IPRIND - Number of 4-minute intervals after which temperature displays are read into storage.
If IPRIND equals 15, it does this once an hour.

HSl(IDY) - Total daily solar radiation for day-IDY (not used if hourly values are available)

RDCNP - Logical variable, if true, one should specify temperature field. If false program defaults to a constant bay temperature field of arbitrary specification, TBNB.
A.2. Computation Parameters

DELTAT - Logical variable, if true, model will calculate temperature above ambient (forced temperature rise, FTR) where we now define boundary temperature to be nearly zero:

\[ TMHOPE = 0.0001^\circ C \]
\[ TRIVER = 0.0001^\circ C \]
\[ TSOUND = 0.0001^\circ C \]

- If false, the model calculates ambient plus forced temperature rise

TBNB - Arbitrary temperature field specification

UPCON - Variable that increases dispersion coefficient, same for x and y direction with a range of values from 2 to 500 yd²/sec. (Divided by 5.93 from Equation 2.27)

TIN - Temperature increase in condenser (°C)

QIN - Condenser flow rate (cfs)

SITE - Various location choices for surface or submerged discharge from heat source

NPRINT(I) - Print out of velocity and temperature field, first index must be 1 and all numbers thereafter must be
in increments of 15 or 30, e.g., 15, 30, 60, 75, 105 . . .

A.3. Main Body of Program

Subroutine HEATIN - Specifies source term and indices for power plant siting

Subroutine INVAL - Reads and writes all initial values for program

Subroutine OPENED - Specifies all hydrodynamic and thermal boundary conditions

Subroutine UPNFHT - Calculates $V_P$ and $S_E$ on column $n$ (north-south) for first half timestep

where

$$U_P = u^{t+1/2} \quad U = u^t$$

$$S_E = n^{t+1/2} \quad S_E = n^t$$

$$V_P = v^{t+1/2} \quad V = v^t$$

so "P" means higher time level in notation seen above

Subroutine VPMFHT - Calculates $V_P$ on row $m$ (east-west) for first half timestep

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contained within subroutine VPMFHT are the following:

a. Subroutine WATDEP - Heat exchange values that are a function of water temperature

b. Subroutine WATIND - Heat exchange values that are independent of water temperature

c. Subroutine AZ - Calculates the average bay temperature from a total of six arbitrary subdivisions

d. Subroutine PRINT - Controls all print punch operations as well as time-step reallocation for variables

Subroutine VPMSHT - Computes VP and SEP on column m second half timestep

Subroutine UPNSHT - Computes SEP on row n second half timestep

Subroutine DISPLY - Graphical output of thermal model at end of the computational run. Calls IBM subroutine PLOT at the end of the computer run

Subroutine ANALYZE - Tidal pattern real vs. actual
A.4. Data

YR - Year, e.g., 57 for 1957
DAY - Day of Year, e.g., 194 for July 17
THR - Hour in Day, e.g., 17
TMIN - Minute, e.g., 48
TMHOPE - Mt. Hope temperature condition
TRIVER - River temperature conditions around bay
TSOUND - Rhode Island Sound temperature condition.

A.5. Execution Parameters

IMODES = 2, for central and, 1 for upstream differencing
IPUNCH - timestep at which model will punch out data
AT - half timestep = 120 sec
MAXST - computational length, MAXST/15 = number of hours real time

B. MODEL APPLICATION FOR NARRAGANSETT BAY, HYDRODYNAMICS SECTION

B.1. Introduction

Now that the fundamentals of the computer scheme have been discussed, the model may be applied to the
specific case of Narragansett Bay. This requires the selection of the grid net which describes the Bay geography, with physical data on grid depths and bottom friction read in. The hydrodynamic boundary conditions are given as time varying functions at Mt. Hope Bay and Rhode Island Sound. The following sections outline the application procedure.

B.2. Grid Net Selection

Few, if any, guidelines exist for the selection of an optimum grid system for a water body, especially one like Narragansett Bay with its complicated geography. The first step taken, however, was the choice of the water boundaries. The area of the Bay to be modeled is bounded on the south by Rhode Island Sound, on the east by the entrance of Mt. Hope Bay, and the north at the narrowing of the Seekonk River. This area represents about two-thirds of the entire Bay. The portion excluded, Mt. Hope Bay and the Sakonnet River, comprises another estuarine system, and is connected to the main part of the Bay by a narrow passage.

Secondly, the computation scheme imposes a minimum of two grids per row or columns in the field. Thus, the narrowest channel must be at least two grids wide. These critical areas occur in the lower Bay, in the East and West
passages, and in the upper Bay in the Providence River
(Figure 4.1). Therefore, a grid length of one-half nautical
mile (1012.7 yds.) was chosen. The resulting grid net
consists of 314 water and 11 water-boundary grids within
the rectangular (19 by 48) field for a total of 325 grids.
The model axis has been rotated 10.1 degrees clockwise
from the true north-south direction for more accurate
representation of the shore geometry.

B.3. Model Time Step Selection

One important property of the implicit solution
method is its unconditional numerical stability, (values
need only be bounded) regardless of time step. However,
the size of the time step has an effect on the accuracy of
the solution.

Leendertse (1) has shown that the solution is accurate
when Equation 4.1, shown below, is less than 5.

\[
\frac{\Delta T}{L} \left( g h_{\text{max}} \right)^{1/2} \leq 5
\]

(4.1)

where

\[\Delta T\] - time step

\[L\] - grid length

\[g\] - acceleration of gravity

\[h_{\text{max}}\] = maximum bay depth
RHODE ISLAND SOUND

BOUNDARY CONDITION
GRID ELEMENTS

FIGURE 4.1. GRID SYSTEM FOR NARRAGANSETT BAY
Note that the factor \( \sqrt{gh} \) is the maximum long-wave celerity. For a maximum depth of 152 feet in the bay a grid length of 3038 feet, and a time step of 220 seconds Equation 4.1 has a value of 4.91. Therefore, a time step, \( AT \), of this size or less insures good accuracy, especially since the average depth of the Bay is only 30 feet.

B.4. Bay Depths

Bathymetric variations are accounted for in the depth specification at each grid square. In accordance with the placement of variables within the grid, Figure 4.2, the depth in the corner of the grid at \((x_c + 1/2, y_c + 1/2)\) is entered as data for all grids in the computation field.

![Figure 4.2. Depth Specification](image-url)
The number entered is the actual depth at mean sea level at that point on the grid, and not the average depth over the grid square as shown in Figure 4.2. Depths may also be entered without harm at grid squares outside the computation field, such as those adjacent to water grids.

General information on the bathymetry was obtained from the U.S. Coast and Geodetic Survey chart No. 353, which gives depths at mean low water. It should be noted that while such charts are useful, certain small-scale features may not be evident from them. For certain critical locations, therefore, depth surveys would be quite useful. These were carried out in the West Passage at the James-town Bridge, and at the Mt. Hope Bridge.

B.5. Chezy Coefficient

The effects of bottom friction are introduced through the Chezy coefficient

\[ c_z = \frac{1.49}{N} (h + \eta)^{1/6} \]  

(2.20)

The dependence of Equation 2.20 on \( \eta \) makes \( c_z \) a time-varying function. However, since the water level, \( \eta \), is usually much smaller than the depth, \( h \), at mean sea level, its influence is small (Hess, 4). Thus, values of \( c_z \) are computed at the start of each run (for \( \eta = 0 \)), and are
not changed afterward.

The selection of the Manning factor \((N \text{ in } \text{ft}^{1/6})\) poses a somewhat more difficult problem, due to the lack of extensive studies for rivers and bays. Masch and Brandes (49), for example, use values between 0.018 and 0.054, which corresponds to "rubble set in cement" and "natural river channels: winding, with pools and shoals", respectively, in a table given by Henderson (50). The essential concept is bottom roughness, which varies considerably in an area as large as Narragansett Bay. For approximation, then, the Manning factor was taken as a linear function of \(m\), the north-south section number:

\[
N(m) = N_{\text{avg}} (1.3 - 0.6m/\text{max})
\] (4.2)

which varies from 1.3 \(N_{\text{avg}}\) in the Providence River to 0.7-\(N_{\text{avg}}\) at the mouth of the Bay. The average value, \(N_{\text{avg}}\), was determined from comparisons of predicted and observed velocities, and was taken as 0.020.

B.6. Rhode Island Sound Boundary

The primary driving force at the mouth of Narragansett Bay is the astronomical tide, and thus is entered as a water level boundary condition at that location, grids \(m = 48, n = 8, 9, 11, 12, 13\). The coast and Geodetic Survey regularly collects and analyzes tidal elevations at
several locations around the Bay. The primary stations are at Newport, Bristol, and Providence, and the data obtained is used to calculate the amplitude and phase angle of the twenty or so largest tidal constituents (51). A number of secondary stations have been occupied, and the times of high and low water relative to Newport are given for them in reference 51.

The tidal forcing function may be represented by the sum of several sinusoidally varying terms, each with a specified amplitude, angular speed, and phase angle (52). The phase angle is taken relative to Greenwich, England; the amplitude is modified by a function of lunar position, $f_{\bar{\kappa}}$. The equation for the water level, $\eta$, is

$$\eta(t) = H_O + \sum f_{\bar{\kappa}}(t) H_{\bar{\kappa}} \cos \left[ w_{\bar{\kappa}} t + (V_0 + u)_{\bar{\kappa}} - k_{\kappa} \right]$$

(4.3)

where

$H_O$ - the height of the mean sea level above the datum (mean low water)

and for each constituent, $\bar{\kappa}$,

$f_{\bar{\kappa}}(t)$ - amplitude factor depending on the position of the moon's line of nodes

$H_{\bar{\kappa}}$ - amplitude of the constituent

$w_{\bar{\kappa}}$ - angular speed (degrees per hour) of the constituent
$(V_0 + u)$ - value of the equilibrium argument when $t = 0$

$k_r$ - epoch (angular phase difference from Greenwich)

$t$ - time (hours) from reference time

The values of $H_o$, $H_m$, and $k_r$ are calculated for each tide station. The angular speed ($\omega$), lunar node function $f$, and equilibrium argument $(V_0 + u)$, can be calculated from knowledge of astronomical motions, and are tabulated in reference 52. (See Hess (4), Subroutine KURIH).

The tide at the lower boundary is calculated at each of the end grids ($m = 48$, $n = 8$, 9, 11-13) by an equation of the form 4.3. The tide at the intermediate grids is obtained by linear interpolation. The amplitude and epoch of each constituent used at the boundary is derived from the analysis of tidal data taken at three previously mentioned stations. The tidal values will be improved by data obtained from the Ocean Engineering Department's, Whale Rock tide gauge.

Several other types of boundary conditions are included in the model, and can be used in various hydrodynamic experiments. (See Hess (4), Chapter II).

B.7. Providence River Boundaries

The boundaries located in the northern part of
the Bay represents river flows and are velocity boundary conditions in the model. The Providence Harbor is the sum of several rivers, while the Pawtuxet River joins the Providence River further down the Bay. Several smaller river flows into the Bay are neglected because their discharge flow rates would have no noticeable affect on local fluid motions.

The total volumetric flow rate from the Blackstone-Seekonk, Moshassuck, and Woonasquatucket Rivers is entered at boundary grid m = 1, n = 3 and 4 to simplify the model grid system in that region. The mean annual flow rate, about 890 cfs including discharge from the City of Providence, is fairly small compared to tidal flowrate so that local velocities do not differ significantly in the area as a result. The daily average flowrate may either be obtained from surface water records (53) or estimated from the ratio of monthly to yearly mean discharges.

The Pawtuxet River boundary (m = 10 and 11, n = 4) is handled in the same manner as the Providence Harbor boundary.

B.8. The Mt. Hope Boundary

The boundary at the entrance to Mt. Hope Bay probably is the most difficult to model accurately. The
local geography does not permit the use of the Bristol Harbor tide as a water level boundary condition, so a tidal velocity, based upon the volumetric flowrate, is used.

The total flow under the Mt. Hope Bridge is determined by tidal differences, river discharges, and wind effects. The tidal flow results from water level variations between the Narragansett and Mt. Hope Bays where the Mt. Hope Bay is also connected to the Rhode Island Sound by the Sakonnet River. Also, a certain fraction of the fresh water discharge into the Mt. Hope Bay, primarily from the Taunton River (mean annual flowrate of 660 cfs), passes under the bridge. Local winds may contribute to daily variations in the flow, but they are neglected since no data on wind currents is available.

The earliest available measurement of the flow under the bridge were reported by Haight (54), who used a 7 foot pole and three current meters on August 7 and 8, 1930. Recent measurements, Binkerd (55), (August 5 and 18, 1971) were taken by using several poles spaced across the section under the bridge. The general approach of analyzing the data used by Haight was applied to the newer observations.

Due to the nature of the bay geometry, Haight (54)
showed that the currents due to the lunar (M₂, M₄, and M₆) constituents of the tide accounted for most of the obtained current. The flowrate can then be approximated by

\[
q = \sum_{k=1}^{3} q_k \cos \left[ \frac{2 \pi f \tau_k}{12.42} (t - \tau_k) \right]
\]

where \( q \) is the flowrate, and \( \tau \) the time to first flood after high water. The flowrate was deduced from the 1930 data by integrating the velocity over the depth, and multiplying by a weighted area under the bridge (90,600 ft²).

The flowrates for the other observations were calculated by summing the products of the pole velocity and the incremental area; the resultant values were adjusted for the tidal range and smoothed. A weighted average was then analyzed, by a least squares technique, using an equation similar to 4.4. The results are shown in Table 4.1.

<table>
<thead>
<tr>
<th>k</th>
<th>Lunar Constituent</th>
<th>Period (hr.) T</th>
<th>Time to First Flood (hrs)</th>
<th>Current (kts)</th>
<th>( q_k ) (10³ cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M₂</td>
<td>12.42</td>
<td>9.87</td>
<td>1.12</td>
<td>150.5</td>
</tr>
<tr>
<td>2</td>
<td>M₄</td>
<td>6.21</td>
<td>6.29</td>
<td>0.29</td>
<td>33.2</td>
</tr>
<tr>
<td>3</td>
<td>M₆</td>
<td>4.14</td>
<td>3.32</td>
<td>0.15</td>
<td>35.4</td>
</tr>
</tbody>
</table>

**TABLE 4.1. LUNAR CONSTITUENT ANALYSIS OF FLOW UNDER MT. HOPE BRIDGE**
The tidal velocity is obtained by dividing the flowrate, q, by the area at the boundary.

The portion of the Taunton River discharge passing under the bridge is obtained from Hicks, (57), who estimated the river outflow from the ebb flowrates through each Bay passage. The value used here is 72% of the annual mean flow or 475 cfs.

C. MODEL APPLICATIONS FOR NARRAGANSETT BAY - THERMAL SECTION

C.1. Boundary Conditions

As previously mentioned in the hydrodynamic section, the river flow rates are small compared to tidal flow and as a consequence the river temperature boundary conditions around the bay have no noticeable affect on spatial heat variations. Nevertheless, a constant value of 22.20°C was chosen to represent mid-summer conditions at all river outfall areas. The Mt. Hope boundary condition is important because the flow under the bridge is of the order of 10-20% of the tidal flow. From data available at this time (37) a constant value of 21.75°C was chosen. Finally, at the Rhode Island Sound boundary condition, a constant value of 18.5°C is used (31). It is quite obvious that the fixed Rhode Island Sound boundary condition will represent
the greatest source of inaccuracy in the model. A proposed improvement would be to vary the boundary condition as a function of tidal velocity across lower east and west passage as shown in Equation 4.5:

\[
\text{Rhode Island temperature boundary condition} = 18.65 + \frac{\text{Ampl} \times \text{Vel}}{\text{Vel}_{\text{max}}} \quad (4.5)
\]

where

- 18.65 is now the average value of the boundary condition
- Ampl = .15°C - half temperature tidal excursion
- Vel - tidal velocity (yds/sec)
- Vel\text{max} - maximum tidal velocity - taken as .125 yds/sec

Temperature excursion was determined by plotting at a typical North-South temperature profile shown in Figure 4.3.

The use of Equation 4.5 would help model boundary condition by taking into account, in an approximate way, the flow of warm water back into the bay.

C.2. Thermal Model Modes

The model can operate under various schemes that are shown in Table 4.2. These were formulated to help isolate the various heat transfer processes involved in simulating both natural and man-made conditions. Mode I is most commonly used.
FIGURE 4.3. NORTH-SOUTH TEMPERATURE PROFILE
<table>
<thead>
<tr>
<th>DELTAT CONDITIONS</th>
<th>RDCNP</th>
<th>TBNB</th>
<th>BOUNDARY CONDITIONS</th>
<th>NET HEAT EXCHANGE</th>
<th>POWER PLANT</th>
<th>MODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>False</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HTOT</td>
<td>No</td>
</tr>
<tr>
<td>Ambient</td>
<td>True</td>
<td>Not Used in Model</td>
<td>Same as AA Above</td>
<td>HTOT</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Deployed</td>
<td>True</td>
<td>Not Used in Model</td>
<td>Same as AA Above</td>
<td>HTOT</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>True</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HTOT</td>
<td>Yes</td>
</tr>
<tr>
<td>Ambient</td>
<td>False</td>
<td>.00001°C</td>
<td>Same as BB Above</td>
<td>HTOT</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Deployed</td>
<td>True</td>
<td>Not Used in Model</td>
<td>Same as BB Above</td>
<td>HTOT</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

* Adiabatic Surface Condition

**TABLE 4.2. THERMAL MODEL MODES**
c.3. Net Heat Exchange

The value of $HTOT$, the net heat exchange transfer rate, is obtained from Equation 3.37. This is read into the model by the following formulation:

$$HTOT \times AREA = \frac{Btu}{ft^2 \text{-day}} \times GSA \times \frac{yd^2 \times 9 \text{ ft}^2/\text{yd}^2}{(24 \text{ hr/day}) (3600 \text{ sec/hr})}$$

(4.6)

Heat into box = $\frac{9 \times GSA}{24 \times 3600}$ Btu/sec $= Q$ (4.7)

where $GSA$ = grid surface area

but $Q = mc_p DT$ (4.8)

and

$Q$ = heat transfer rate per unit time

$c_p$ = specific heat of water at constant pressure

$DT$ = temperature change in box per unit time

Combining 4.7 and 4.8 and solving for $DT$ we have:

$$DT = \frac{Q}{mc_p} = \frac{9 \times GSA}{24 \times 3600} \times$$

$$\frac{1 lbm}{64 \text{ ft}^3} \frac{[GSA \text{ yd}^2 \times \frac{9 \text{ ft}^2}{\text{yd}^2}]}{\text{ Depth (yd) } \times \frac{3 \text{ ft}}{\text{yd}}}(4.9)$$

Consolidating, the result is

$$DT = \frac{HTOT}{24 \times 3600 \times 64 \times 3 \times \text{Depth}} = ^\circ_F/\text{sec}$$

(4.10)

for a depth of 30 feet the final result is
\[ T = \frac{HTOT}{1.66 \times 10^7} \text{ °F/sec} \quad (4.11) \]

For a value of HTOT = 10 Btu/ft\(^2\)-day, the net heat flux, we have

\[ DT = \frac{10 \times 86,400}{1.66 \times 10^7} \quad (4.12) \]
\[ = \frac{8.6 \times 10^5}{1.66 \times 10^7} = 0.052 \text{ °F/day} \quad (4.13) \]

For one year we would have

\[ T = 0.052 \times 365 = 19 \text{ °F} \quad (4.14) \]

which is of the order of the annual variation in the Narragansett Bay area.

The read in variables required for computing Equation 3.37 are the following:

- **TA** - temperature of the air, °F (T.F. Green Airport, (56))
- **RH** - Relative humidity, percent (T.F. Green Airport, (56))
- **HS2(1)** - Hourly solar radiation parameter (grm-cal/cm\(^2\))
  (scale factor of .2 from Eppley Laboratory, Unpublished)
- **WA** - Wind speed, miles per hour (T.F. Green Airport, (56))
- **ANG** - Direction that wind blows from, degrees (T.F.}
C.4. Power Plant

To determine power plant requirements, the cooling water rate per unit power must be known (see Figure 4.4).

![Power Plant Schematic](image)

**FIGURE 4.4. POWER PLANT SCHEMATIC**
A straightforward calculation is presented using the steady flow energy equation

\[
q - px = \dot{W}_{cw} \left[ (h_6 + \frac{V_6^2}{2} + z_6) - (h_5 + \frac{V_5^2}{2} + z_5) \right]
\]  

(4.15)

\[
q_{out} - 0 = \dot{W}_{cw} \left[ h_6 + 0 + 0 \right] - \left( h_5 + 0 + 0 \right)
\]  

(4.16)

\[
q_{out} = \dot{W}_{cw} (h_6 - h_5)
\]  

(4.17)

where

\( q_{out} \) - heat removed from working fluid after it has passed through turbine

\( \dot{W}_{cw} \) - cooling water flow rate

\( h \) - enthalpy of fluid

Transforming Equation 4.17 we have

\[
\frac{p \cdot q_{out}}{p} = p \cdot \left[ \frac{q_{in}}{p} - p \right] \cdot \frac{1}{q_{in}} = \dot{W}_{cw} (h_6 - h_5)
\]  

(4.18)

\[
\frac{p (1 - E)}{E} = \dot{W}_{cw} (h_6 - h_5)
\]  

(4.19)

where \( E = \frac{p}{q_{in}} \) - efficiency

for \( h = c_p DT_{cw} \)

and \( DT_{cw} \) - temperature increase, °F, in cooling water through heat exchanger
Equation 4.19 becomes, after a little rearranging

\[
\frac{W_{cw}}{P} = \frac{1-E}{E} \frac{1}{c_p DT_{cw}}
\]  

(4.20)

Assuming

\[ E = \text{plant efficiency} = 40\% \]
\[ c_p = 1 \text{ Btu/lb}^{\circ}\text{F} \]
\[ DT_{cw} = 20^{\circ}\text{F} \]

Equation 4.20 is now

\[
\frac{W_{cw}}{P} = \frac{1-.4/.4}{\text{Btu/hr}} \cdot \frac{1\text{ lb}^{\circ}\text{F}}{1 \text{ Btu} \times 20^{\circ}\text{F}} \cdot \frac{3413 \text{ Btu/hr}}{\text{Kw}} \cdot \frac{10^3 \text{kw}}{M_w}
\]

(4.21)

which results in

\[
\frac{W_{cw}}{P} = 255.97 \cdot 10^3 \frac{\text{lb}}{\text{hr Mw}} \cdot \frac{\text{ft}^3}{64 \text{ lb} \text{m}} + \frac{\text{hr}}{3600 \text{ sec}}
\]

(4.22)

\[
= 1.1 \frac{\text{cfs}}{M_w}
\]

(4.23)

For a plant with an 1800 megawatt capacity we would need approximately 2000 cfs for a rated efficiency of 40%.

The data used in the model is summarized as follows:

\[ W_{cw} = 2000 \text{ cfs} = Q_{IN} \]

\[ DT_{cw} = 12^{\circ}\text{C} = T_{IN} \]

(4.24)

These two values represent reasonable values but certain engineers might prefer to use a cooling water rate
based on 1500 cfs/1,000 megawatts or a DT\textsubscript{cw} = 25\textdegree F. There are so many possible choices of flow rates, temperature increases and site locations that the model is structured to handle these many personal preferences in user production runs.

Also, it should be kept in mind, that a power plant generally has an average power production rate below the 95% maximum output rate under peak load conditions to further complicate environmental studies.

C.5. Bay Zonal Divisions

The bay was divided into six major geographically similar sections each with various subsections that comprise the main hydrodynamic elements of the model. This is seen in Figure 4.5. The Rome Point area will affect primarily zone 1.

C.6. Rome Point Area

An enlarged section of Narragansett Bay map Figure 4.10 for the Rome Point area is seen in Figure 4.6. In the prediction portion of this report, isotherms will be drawn in, with average temperature values included in each box.
FIGURE 4.5. NARRAGANSETT BAY ZONAL DIVISIONS
FIGURE 4.6. ROME POINT AREA
V. GENERAL STUDIES OF TEMPERATURE MODEL BEHAVIOR

A. EFFECT OF THE DIFFERENCES

As mentioned in Chapter II and Appendix D the differencing schemes will affect the computed values. The central differencing scheme is preferred because it does not alter the natural dispersion coefficient in the model and is insensitive to the divergent flow patterns. It should be kept in mind that for the dispersion coefficient value of 5.0 \( \text{yd}^2/\text{sec} \) used by Sapulding (16) and considered realistic there is a transient response in the model of several days and with a heat source causes wild computational behavior that propagates near discharge.

B. VERIFICATION PROCEDURE

The most logical first step is to have a uniform temperature for the Bay and its exits and entrances with no heat exchange across the air-water interface. This was done and the results of this are shown graphically in Figure 5.1. A value of the dispersion constant, UPCON, was chosen as 500 for rapid mixing and convergence to the steady state bay temperature. This procedure required two hours of computer time.

The energy loss is only 0.03/21.00 or 0.14 percent drop
FIGURE 5.1. ENERGY BALANCE FOR BAY, UNIFORM TEMPERATURE CASE

DISPERSION COEFFICIENT = 350 YD²/SEC
UPCON = 500
in almost four days but the maximum rate of decrease is of the order of 0.05 percent for the four day period. This is quite acceptable when compared to the findings of Leendertse (2) and establishes the primary verification of the model.

C. **STARTING TRANSIENT**

When the computations during first few hours of simulation are made, it is assumed that the model will tend toward equilibrium from some arbitrary initial temperature field. The transient response for the forced temperature rise apparently follows two and possibly three phases for the shallow water region selected for a possible power plant site. These phases are shown in Figure 5.2.

**Figure 5.2.** Phases of transient response for forced temperature rise and tidal averages
phase I is primarily the rapid increase in the temperature to within 80-90 percent of the steady state value. Steady state means that the apparent temperature average from tidal cycle to tidal cycle is at most a gradual but regular change. Phase II will consist of the alignment of the temperature peaks and dips with some sort of tidal regularity. Finally, Phase III, not always distinct from II, will represent the level at which we have established some steady state value for the forced temperature rise. Further investigation is necessary to determine how steady state values vary over an average monthly variation of tidal cycles. The steady state is emphasized as the apparent average of the temperature oscillation that may itself have a much larger period of oscillation. Each grid has its own transient response characteristics so reference here is made only to grid m = 35, n = 5. Figure 5.3 gives general guidelines for reaching steady state forced temperature rise as a function of dispersion coefficient.

Once a general understanding of the temperature transient response is obtained it is a simple matter of adding it onto the ambient condition provided one stays within the bounds of the linearization assumptions explained in Chapter III, Section L.
FIGURE 5.3. THE ESTABLISHMENT OF THE STEADY STATE TIDALY AVERAGED VALUES OF FORCED TEMPERATURE RISE AS A FUNCTION OF DIFFUSION COEFFICIENT FOR GRID m = 35, n = 5
In summary, the transient response is of the order of 5-10 tidal cycles for the lower range of dispersion coefficient; requiring careful preliminary investigation before making any evaluations of forced temperature rise.

D. DISPERSION COEFFICIENT

In the following discussion, the Rome Point location \( m = 36, n = 5 \) was chosen because its shallow depth and local interest make it a good example. As is seen from Figure 5.3, a diffusion coefficient of the order of 5-20 \( \text{yd}^2/\text{sec} \) in the vicinity of grid \( m = 36, n = 5 \), will force the model into computational difficulty, that is, a forced temperature rise greater than \( DT_{cw} \) of condenser. Figure 5.3 shows the general temperature increases for the various dispersion coefficients that may be used as a guide for determining the average tidal temperature increases in the outfall area.

The dispersion coefficient enhancing technique, elaborated in Chapter II, Section D, and Appendix D, would enable one to use a value of 5-20 \( \text{yd}^2/\text{sec} \) in the model and would be as close to the real conditions as possible. At this stage in the development of the model, it was decided to use the value of 50 \( \text{yd}^2/\text{sec} \) throughout the bay as a
FIGURE 5.4. GRAPHICAL REPRESENTATION OF MINIMUM VALUE OF DISPERSION COEFFICIENT FOR ROME POINT,  

\[ m = 36, \, n = 5 \]

first estimate in determining the general isotherm pattern around the discharge. With a grid size of about 1000 yards and the model interest in the far field it is felt that the results for a dispersion coefficient of the order of 50
yd²/sec (UPCON = 100) would be satisfactory.

A. BACKGROUND

Given the necessary meteorological data, salinity inputs, and boundary conditions, it is feasible to predict the key temperature field through thermal model calculations. In any model verification procedure, the comparison between measured and computed values is difficult because of the small area encompassed by measurements versus the larger 1/3 by 1/2 practical grid area of the model grid. Since model averages vertical water temperature column, surfaces to bottom temperature measurements continuously taken over area with walls are required to achieve more realistic verification criterion. Being realistic, the reference period July 1957 was chosen to give insight on where the model and measurements are most divergent because of the dissimilar nature of the model and the historical measurements.

This does not mean that the model has little value, which it does have for large scale simulation, but rather that measurements should be taken on a length and time scale comparable to the model. The summer of 1957 was chosen for comparison because it contains the heaviest concentration of temperature data taken in instrumented bay.
VI. COMPARISON OF CALCULATED RESULTS AND HISTORICAL DATA

A. BACKGROUND

Given the necessary meteorological data, solar inputs, and boundary conditions it is feasible to predict the bay temperature field through thermal model calculations. In any model verification procedure, the comparison between measured and computed values is difficult because of the small area encompassed by measurements versus the larger 1/2 by 1/2 nautical mile area of the model grids. Since model averages vertical water temperature column, surface to bottom temperature measurements continuously taken on area wide basis, are required to achieve more realistic verification criterion. Being realistic, the reference period July, 1957 was chosen to give insight on where the model and measurements are most divergent because of the dissimilar nature of the model and the historical measurements.

This does not mean that the model has little value, which it does have for large scale simulation, but rather that measurements should be taken on a length and time scale comparable to the model. The summer of 1957 was chosen for comparison because it contains the heaviest concentration of temperature data taken in Narragansett Bay.
B. **MODEL SIMULATION CONDITIONS**

The following conditions were adopted for comparison procedure (see next page).

C. **NARRAGANSETT BAY DATA**

C.1. Narragansett Marine Lab Pier

The data obtained from Hicks (37) and Day (38) is plotted in Figure 6.1 along with the computer results. In addition, the lower boundary condition derived from the average of July measurements at Brenton's Reef (31) was changed arbitrarily from 18.5 to 19.5°C and this result is also shown in Figure 6.1.

It is quite clear that the model grid predictions are between 1.0°C and 2°C too low.

C.2. Newport, Rhode Island

The Newport Data (41) as presented in Table 6.1 shows reasonable agreement with data.

<table>
<thead>
<tr>
<th>DATE</th>
<th>TIME</th>
<th>MEASURED</th>
<th>MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 16</td>
<td>11:30</td>
<td>20.0°C</td>
<td>19.85°C</td>
</tr>
<tr>
<td>July 17</td>
<td>11:30</td>
<td>20.0°C</td>
<td>19.90°C</td>
</tr>
<tr>
<td>July 18</td>
<td>14:10</td>
<td>21.67°C</td>
<td>20.20°C</td>
</tr>
</tbody>
</table>

(Table Continued)
DATE

MEASURED

MODEL

Monthly Average  Morning  20.1°C  20.0°C

TABLE 6.1. NEWPORT TEMPERATURE DATA, (41) GRID LOCATION  n = 15, m = 40

C.3. Bay Data

Hicks (37) undertook Cruise III between July 15 to July 19, 1957 with a total of 19 stations around the bay. In most cases at least four depth measurements were taken at each station and the average of these was used as a comparison with the model as shown in Table 6.2.

The agreement is good for stations where the temperature in the water column is rather uniform. For the Rhode Island Sound station, where the bottom temperatures go as low as 15.3°C, 3.2°C cooler than any temperature in the bay thermal field, the average of measured values are about 0.5°C too low.

C.4. Meteorological Data

The air temperature measurements taken at T.F. Green Airport (56) can be seen in Figure 6.2 and they show no extreme activity for this period. Although the monthly
<table>
<thead>
<tr>
<th>VARIABLE NUMBER</th>
<th>CONDITIONS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>YEAR (YR)</td>
<td>57.</td>
</tr>
<tr>
<td>2</td>
<td>DAY</td>
<td>195.</td>
</tr>
<tr>
<td>3</td>
<td>THR (HOUR)</td>
<td>17.</td>
</tr>
<tr>
<td>4</td>
<td>Tmin (MINUTE)</td>
<td>48.</td>
</tr>
<tr>
<td>5</td>
<td>TMHOPE (Temperature Mt. Hope Bay)</td>
<td>21.75°C</td>
</tr>
<tr>
<td>6</td>
<td>TRIVER (Temperature of Rivers)</td>
<td>22.2°C</td>
</tr>
<tr>
<td>7</td>
<td>TSOUND (Temperature of R.I. Sound)</td>
<td>18.50°C</td>
</tr>
<tr>
<td>8</td>
<td>TBNB (Temperature Field)</td>
<td>21.0°C</td>
</tr>
<tr>
<td>9</td>
<td>IMODES (1-Upstream; 2-Central Differencing)</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>RDCNP (Temperature Read In, °C)</td>
<td>False</td>
</tr>
<tr>
<td>11</td>
<td>UPCON (Dispersion Coefficient Constant)</td>
<td>500 x Elder's Value/5.93</td>
</tr>
<tr>
<td>12</td>
<td>QIN (Source Flow Rate CFS, i.e. Power Plant)</td>
<td>0.0</td>
</tr>
<tr>
<td>13</td>
<td>TIN (Cooling Water Temperature Increase)</td>
<td>12°C</td>
</tr>
<tr>
<td>14</td>
<td>SITE (Power Plant Output and Input)</td>
<td>100 (Flow Out: n=5, m=36. Flow In: n=6, m=37)</td>
</tr>
<tr>
<td>15</td>
<td>Plotting Time</td>
<td>96 Hours</td>
</tr>
<tr>
<td>16</td>
<td>Program No.</td>
<td>12271</td>
</tr>
<tr>
<td>17</td>
<td>Date of Run</td>
<td>1/26/73</td>
</tr>
</tbody>
</table>

**EXPERIMENTAL RUN 1 (NATURAL CONDITIONS FOR MODEL-MEASUREMENT COMPARISON WITH NO POWER PLANT EFFECTS)**
L.I. SOUND
BOUNDARY CONDITION 19.5°C
OR
18.5°C

START 18:00 JULY 24
HOURS OF COMPUTER SIMULATION

FIGURE 6.1. NARRAGANSETT MARINE LAB PIER LOCATION (8, 43)
<table>
<thead>
<tr>
<th>DATE</th>
<th>TIME</th>
<th>STATION</th>
<th>GRID</th>
<th>°C DEPTH AVERAGED MEASUREMENT</th>
<th>°C MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 15</td>
<td>Morning</td>
<td>5</td>
<td>(3, 21)</td>
<td>23.00</td>
<td>22.9</td>
</tr>
<tr>
<td>July 15</td>
<td>0855</td>
<td>10</td>
<td>(9, 28)</td>
<td>21.40</td>
<td>21.8</td>
</tr>
<tr>
<td>July 15</td>
<td>0810</td>
<td>13</td>
<td>(8, 33)</td>
<td>20.60</td>
<td>21.7</td>
</tr>
<tr>
<td>July 16</td>
<td>0850</td>
<td>14</td>
<td>(13, 38)</td>
<td>18.5</td>
<td>20.2</td>
</tr>
<tr>
<td>July 16</td>
<td>1058</td>
<td>15</td>
<td>(8, 41)</td>
<td>18.75</td>
<td>18.50</td>
</tr>
<tr>
<td>July 16</td>
<td>1012</td>
<td>16</td>
<td>(8, 48)</td>
<td>17.90</td>
<td>18.50</td>
</tr>
<tr>
<td>July 16</td>
<td>0950</td>
<td>17</td>
<td>(12, 48)</td>
<td>17.10</td>
<td>18.50</td>
</tr>
<tr>
<td>July 17</td>
<td>1445</td>
<td>Narragansett Marine Lab</td>
<td>(8, 43)</td>
<td>21.0</td>
<td>19.50</td>
</tr>
</tbody>
</table>

**TABLE 6.2. CRUISE III, HICKS (37) TEMPERATURE MEASUREMENTS**
average was 1.0°C above normal, wind speeds were in the 10-12 M.P.H. normal range and relative humidity was about 67 percent or within normal range for this measurement period.

Solar input, as recorded at the Eppley Laboratory, Newport, Rhode Island can be seen in Figure 6.3.

The solar input for this period is about 25 percent
FIGURE 6.3. SOLAR INPUT, EPPLEY LABORATORY, NEWPORT, RHODE ISLAND

above the average monthly value of 1920 Btu/ft$^2$-day.

D. EVALUATIONS

With the discrepancies in the predicted versus actual values of water temperature, it is certainly not clear that this form of verification is realistic or profitable. With regard to Masch et al (57), where comparisons between
detailed prototype, physical, and computer predictions were in error by 10 to 25 percent, the thermal model variances, of this magnitude, do not seem disappointing at all.

Let's begin with the discrepancies that occur at the Narragansett Marine Lab Pier. A referral to Figure 6.4 will clearly show general geographical area and the model grid system overlay.

![Figure 6.4](image)

**FIGURE 6.4. NARRAGANSETT MARINE LAB PIER.**

**GENERAL LOCATION AND DEPTHS**
The model can include grid (7,43) with a depth of 7.2 yards which would be a much better representation for the Narragansett Marine Lab than the originally chosen grid (8,43), with a depth of 15.6 yards. The temperatures in grid (7,42), directly north of a more desirable grid (7,43), averaged 0.5°C above those in grid (8,43). Since the proposed box would also be a corner box, the dispersion coefficient will strongly influence western diffusion of cooler Rhode Island Sound water during flow up the bay. This verification run has a high value of dispersion to insure a well mixed bay. Unfortunately, this inflated value increases the effect of the cool Rhode Island Sound flow past Narragansett Marine Lab Pier area.

In addition, the fixed boundary temperature for Rhode Island Sound is an approximation that complicates the prediction. It is felt that extensive development of the model with regard to a variable boundary condition for one tenth the dispersion coefficient used is necessary to improve comparison.

Although not certain, Dr. Hicks, by letter, has expressed a belief that the water temperature data at Marine Lab (38) was taken by a Bristol Recorder from a source at an unspecified depth below the surface and possibly flushed
through a holding tank with a capacity of several hundred gallons. It is interesting to note that the temperature data obtained by Hicks (37) shows that temperature differences at Narragansett Marine Lab Pier between top and bottom water for the period February 1952 to January 1958 averages 0.2°C. Referring back to Day (38) we also observe that temperature variations of a 4°C during the day at Narragansett Marine Lab Pier appear to be larger than common sense tidal flushing estimates. In Figure 6.5, it is seen for July 9 and 13 that with low solar input, temperature maximum decreases about 0.5°C while minimum temperature is unaffected. It appears that with this low solar input, we should be able to estimate depth of the water column if the solar energy is considered evenly distributed. We have,

\[
\text{Solar Input} = 2000 \text{ Btu/ft}^2 \text{(half day)}
\]

\[= \text{Mass} * C_p * DT\]  \hspace{1cm} (6.1)

\[\text{where } DT = 0.5^\circ \text{C}\]

\[
\frac{1000 \text{ Btu}}{\text{ft}^2 \text{(full day)}} = \text{Depth} \times \text{Unit Area} \times \frac{64 \text{ lb}_m}{\text{ft}^3}
\]

\[
\times \frac{1 \text{ Btu}}{\text{lb}_m^\circ \text{OF}} \times \frac{9^\circ \text{F}}{\text{Day}}\]  \hspace{1cm} (6.3)

after rearranging
FIGURE 6.5. NARRAGANSETT MARINE LAB TEMPERATURES (38)
Depth = 20 ft

With a measured depth of about 20 feet, we conclude that the water temperature variations do follow the above simplistic formulation. Also note in Figure 6.5 the unexplainable $2^\circ C$ temperature increase of minimum temperature on July 17. This sudden increase of $2^\circ C$, in mean water temperature at the Narragansett Marine Lab Pier contributes substantially to the disagreement between the model and measurements because it increases the average water temperature by $1.5^\circ C$. This sudden change in water temperature shows the variability of taking measurements in shallow, inshore water.

This lengthy discussion on the Narragansett Marine Lab Pier temperature measurements can only be resolved by first conducting an extensive detailed area survey around the pier in conjunction with accurate Rhode Island Sound temperature boundary condition measurements. As will be true for all temperature measurements to be discussed, we would have to establish a meteorological station closer to the bay, preferrably on the Narragansett Marine Lab Pier to more accurately represent the input conditions.

For the Newport Data (41) agreement was good while for Hicks (37) the data agreed if the vertical structure
was homogenous. It should be noted that if the 15-16°C bottom water temperatures for Rhode Island Sound stations were not included in vertical average the agreement between predicted and actual values would be closer.

E. CONCLUSION

This attempt at thermal model verification with field measurements while enlightening for general temperature variation shows quite clearly how formidable a task it is to have grid locations agree with temperature measurements to a ±5 percent. Since the desired type of measurements for improved verification work would entail about 10 continuously operating data stations which are beyond the scope of department capability no further verification attempts were initiated. Dr. Eidinger (5) discusses the seemingly impossible task of the model verification with field measurements, an undertaking that no one has yet done successfully.

The lack of detailed model spatial agreement with measured temperature data should not detract from the information the model does predict of a more general nature.
VII. THERMAL MODEL PREDICTIONS

A. POWER PLANT LOCATION

The thermal model can place a heat source simulating an electric generating plant in any of the 314 non-boundary grids. The selection of the Rome Point area was made because the area is of local interest and the relative shallow water depth of 10 feet provides a good indication of the computational effectiveness of the model for a specific value of the dispersion coefficient. From a utility viewpoint, the surface discharge in the Rome Point grid, \( n = 5, m = 36 \), is inexpensive to construct and the land boundary at \( n = 6, m = 36 \) affords reentrainment protection from the intake grid located at \( n = 6, m = 37 \) or southeast of the intake.

The general geometry at the Rome Point site can be seen in Figure 7.1. The shaded area covers the most likely intake and discharge locations.

B. INTRODUCTION TO EXPERIMENTAL RUNS

The following experimental sections will contain various results that clearly show the effectiveness of the thermal model in predicting isothermal patterns around
FIGURE 7.1. ROME POINT AREA WITH MODEL GRIDS, DISCHARGE LOCATIONS AND DEPTHS
a particular heat source. The natural or non-power plant predictions show the thermal patterns that can be measured in the bay. The natural plus power plant predictions are an indication of the thermal pattern that would occur with a power plant in operation for the specified data.

The above ambient or natural condition that occurs if the effect of the power plant is isolated results in valuable plant siting information. To clearly demonstrate the effect of the power plant on the bay the natural temperature state is subtracted from the temperature state including the power plant. This shows quite clearly the effects of the power plant alone. This technique was formulated into a 'forced temperature rise above ambient' condition, where one sees only the effect of the power plant on the natural temperature state predicted by the model.

C. EXPERIMENTAL RUN 1 (THE NATURAL CONDITIONS IN NARRAGANSETT BAY AS PREDICTED BY THE THERMAL MODEL)

This first experimental run contains a listing of all variables in the program that must be defined. For experimental run 1, these are used to determine the natural temperature condition that occurs from July 14 to July 18, 1957 with no heat source included. In an effort to simplify
the discussion of the following experimental runs only
the variables that are different from run 1 are listed.

TABLE 7.1. PROGRAM VARIABLES

<table>
<thead>
<tr>
<th>VARIABLE NUMBER</th>
<th>CONTROL PARAMETER</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>YEAR</td>
<td>57.</td>
</tr>
<tr>
<td>2</td>
<td>DAY</td>
<td>195.</td>
</tr>
<tr>
<td>3</td>
<td>THR (HOUR)</td>
<td>17.</td>
</tr>
<tr>
<td>4</td>
<td>Tmin (MINUTE)</td>
<td>48.</td>
</tr>
<tr>
<td>5</td>
<td>TmHOPE (Temperature for the Mt. Hope Bay Boundary Condition, (B.C.))</td>
<td>21.75°C</td>
</tr>
<tr>
<td>6</td>
<td>TRIVER (Temperature for the River B.C.)</td>
<td>22.2°C</td>
</tr>
<tr>
<td>7</td>
<td>TSOUND (Temperature for the Rhode Island Sound B.C.)</td>
<td>18.50°C</td>
</tr>
<tr>
<td>8</td>
<td>TBNB (Temperature Field in the Bay)</td>
<td>21.0°C</td>
</tr>
<tr>
<td>9</td>
<td>IMODES (1-Upstream; 2-Central Differencing)</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>RDCNP (Temperature field read in, False °C)</td>
<td></td>
</tr>
<tr>
<td>VARIABLE NUMBER</td>
<td>CONTROL PARAMETER</td>
<td>SPECIFICATION</td>
</tr>
<tr>
<td>-----------------</td>
<td>-------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>11</td>
<td>UPCON (Dispersion Coefficient Constant Times Elder's Value)</td>
<td>500</td>
</tr>
<tr>
<td>12</td>
<td>QIN (Source Flow Rate, cfs)</td>
<td>0.0</td>
</tr>
<tr>
<td>13</td>
<td>TIN (Cooling Water Temperature Increase Through Plant)</td>
<td>12.0°C</td>
</tr>
<tr>
<td>14</td>
<td>SITE (Power Plant Output and Input Grids Specified)</td>
<td>100 (Flow Out: n=5, m=36. Flow In: n=6, m=37)</td>
</tr>
<tr>
<td>15</td>
<td>DELTAT (Logical Variable. If true the model calculates forced temperature rise, if false it calculates natural condition with or without power plant)</td>
<td>True</td>
</tr>
<tr>
<td>16</td>
<td>Plotting Time</td>
<td>68 Hours</td>
</tr>
<tr>
<td>17</td>
<td>Program Number</td>
<td>12271</td>
</tr>
<tr>
<td>18</td>
<td>Date of Run</td>
<td>1/26/73</td>
</tr>
</tbody>
</table>

C.I. Comments

The temperature fields, as shown in Figure 7.2 and Figure 7.3, represent a typical display pattern. The relative similarity of isotherms with regard to shape and
| AVERAGED TEMP. (DEGREES C TIMES 1000) FOR TIMEStep 1020 AT TIME = 68.00 HAS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1  | 0 | 22199 | 22199 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2  | 0 | 22633 | 22412 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3  | 0 | 22468 | 22421 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4  | 0 | 22057 | 22054 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5  | 0 | 22036 | 21998 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6  | 0 | 21936 | 21862 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 21612 | 21500 | 21495 | 21481 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 0 | 21421 | 21288 | 21218 | 21118 | 20775 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 0 | 21471 | 21338 | 21167 | 21023 | 20701 | 20570 | 20357 | 20170 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FIGURE 7.2. RUN 1 BAY TEMPERATURE AT 68 HOURS
Given: \( Q = 2000 \text{ cfs} \), \( TIN = 0.0^\circ C \)

**Figure 7.3.** RUN 1, NATURAL THERMAL FIELD AT 68 HOURS NEAR OUTFALL

ALL TEMPERATURES \( ^\circ C \times 100 \)
position reveal important thermal characteristics of the bay. Spatial temperature variations after 68 hours of simulated time are minor between grids, with the highest values in the shallowest grids. Isotherm values agree spatially with general summer profiles one would expect for the July time period (Hicks, 58).

In addition, the temperature variations in the bay are strongly influenced by tidal flushing and meteorological conditions. Plotting selected temperature values versus time clearly shows the expected oscillatory behavior. The predicted change in temperature over time ratio for selected grids would aid the environmentalist in determining power plant impact.

D. EXPERIMENTAL RUN 2 (THE NATURAL CONDITIONS IN THE BAY WITH A POWER PLANT AS THE HEAT SOURCE)

The heat source is included by specifying a flowrate for the variable number 12. As previously mentioned, only the control parameters that are changed from Table 7.1 will be listed.

<table>
<thead>
<tr>
<th>VARIABLE NUMBER</th>
<th>CONTROL PARAMETER</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>QIN (Source Flow Rate cfs)</td>
<td>2000</td>
</tr>
<tr>
<td>VARIABLE NUMBER</td>
<td>CONTROL PARAMETER</td>
<td>SPECIFICATION</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>17</td>
<td>Program Number</td>
<td>11770</td>
</tr>
<tr>
<td>18</td>
<td>Date of Run</td>
<td>1/25/73</td>
</tr>
</tbody>
</table>

D.1. Comments

A typical model predicted heat source distribution in the natural environment can be seen in Figure 7.4. If one subtracts the natural conditions shown in Figure 7.3 from the power plant condition in Figure 7.4 one then obtains Figure 7.5 which shows the forced temperature rise resulting from the heat source in the model.

E. EXPERIMENTAL RUN 3 (THIS PREDICTS ONLY THE TEMPERATURE INCREASE DUE TO HEAT LOAD FROM A POWER PLANT OR FORCED TEMPERATURE RISE)

This run calculates only temperature excess above natural conditions by the variable changes listed below. If the formulation is correct, the thermal field prediction for run 3 should equal the difference in thermal fields between runs 2 and 1.
<table>
<thead>
<tr>
<th>VARIABLE NUMBER</th>
<th>CONTROL PARAMETER</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>TMHOPE (Temperature Mt. Hope Bay)</td>
<td>0.00°C</td>
</tr>
<tr>
<td>6</td>
<td>TRIVER (Temperature of all Rivers)</td>
<td>0.00°C</td>
</tr>
<tr>
<td>7</td>
<td>TSOUND (Temperature for the Rhode Island Sound)</td>
<td>0.00°C</td>
</tr>
<tr>
<td>8</td>
<td>TBNB (Temperature Field in the Bay)</td>
<td>0.00°C</td>
</tr>
<tr>
<td>12</td>
<td>QIN (Source Flow Rate, cfs)</td>
<td>2000</td>
</tr>
<tr>
<td>15</td>
<td>DELTAT (Logical Variable. If true the model calculates forced temperature rise, if false it calculates natural conditions with or without power plant)</td>
<td>True</td>
</tr>
</tbody>
</table>

E.1. Comments

Figure 7.6 shows the result of the forced temperature rise without the natural conditions included. These values are nearly identical to Figure 7.5 and serve to prove the correctness of the forced temperature rise formulation in run 3.
| AVERAGED TEMP (DEGREES C TIMES 1000) FOR TIMESTEP 1020 AT TIME = 68.00 HRS |
|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| 1                | 2                | 3                | 4                | 5                | 6                | 7                | 8                | 9                | 10               | 11               | 12               | 13               | 14               | 15               | 16               |
| 24               | 0                | 0                | 22199            | 26199            | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                |
| 25               | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                |
| 4                | 22027            | 22027            | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                |
| 5                | 0                | 22027            | 21970            | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                |
| 7                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                |
| 12               | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                |
| 13               | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                |
| 14               | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                |
| 15               | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                |
| 16               | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                |
| 17               | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                |
| 18               | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                |
| 19               | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                | 0                |

**FIGURE 7.4. RUN 2 THERMAL FIELD WITH HEAT SOURCE AT 68 HOURS FOR NARRAGANSETT BAY**
Given: \( Q = 2000 \text{ cfs}, \) \( T_{IN} = 12.0^\circ C \)

![Diagram of Rhode Island Sound with temperature rise from runs 1 and 2](image)

**Figure 7.5.** Forced temperature rise from runs 1 and 2
The same procedure indicated for runs 1 through 3 was carried out for a forced temperature rise in the power plant outfall box of 6.5°C and again all the predictions for the forced temperature rise were equal to the difference between the natural plus heat source and natural conditions.

F. EXPERIMENTAL RUN 4 (FORCED TEMPERATURE RISE)

Same as run 3 with the following exceptions:

<table>
<thead>
<tr>
<th>VARIABLE NUMBER</th>
<th>CONTROL PARAMETER</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>Plotting Interval</td>
<td>128-140 Hours</td>
</tr>
</tbody>
</table>

F.1. Introductory Comments

In this section, a detailed graphical presentation of seven predicted thermal fields is made. The purpose of this is to determine the tidal variations of the heat distribution in comparison with the tidally averaged field for all seven predictions.

The tidally averaged plot was obtained by adding the values at 130, 132, 134, 136, and 138 hours to one half the values at 128 and 140 hours and dividing by six. This weighting procedure was chosen because it allowed the
Given: \( Q_{IN} = 2000 \text{ cfs}, T_{IN} = 12^\circ \text{C} \)

All temperatures \( ^\circ \text{C} \)

Figure 7.6. Forced temperature rise from run 3
desired velocity profile, shown in Figure 7.15, to be incorporated in the tidal average.

F.2. Graphical Presentation

The following series of figures (7.7 through 7.14) show the tidal influences on the thermal pattern for 1.0, 0.5, 0.4, 0.3, and 0.2°C. This is done by dividing all values in Figures 7.6 through 7.13 by 1000. The general area of Rome Point, as defined for these figures, encompasses 53 grids or about 17% of the total model area for Narragansett Bay.

F.3. Interpretation of the Graphical Output

The general tidal pattern during this interval can be seen in Figure 7.14. Comparison with Figure 7.15 of Hess (4) shows the peculiar but similar flow conditions for the west passage. In Table 7.1 one can see the pertinent physical variations that occur in the thermal field. Note that the approximate net non-tidal transport obtained from averaging representative velocity grids is of the order of +0.02 ft/sec (0.6 cm/sec) where "+" means up the bay. For a length scale of 3.5 nautical miles it would take a heated particle from Rome Point roughly two weeks to pass out of the Rome Point area if we assumed a net
Given: QIN = 2000 cfs, TIN = 12°C

FIGURE 7.7. RUN 4, THERMAL FIELD AT 128 HOURS

All temperatures °C × 1000
Given: \( Q_{IN} = 2000 \text{ cfs}, T_{IN} = 12{}^\circ C \)

<table>
<thead>
<tr>
<th>QUONSET POINT</th>
<th>UPPER BOUNDARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>339</td>
</tr>
<tr>
<td>958</td>
<td>376</td>
</tr>
<tr>
<td>1025</td>
<td>536</td>
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<tr>
<td>1237</td>
<td>1089</td>
</tr>
<tr>
<td>1924</td>
<td>900</td>
</tr>
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<td>5184</td>
<td>1642</td>
</tr>
<tr>
<td>1274</td>
<td>666</td>
</tr>
<tr>
<td>2000</td>
<td>300</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INFLOW</th>
<th>LOWER BOUNDARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1274</td>
<td>666</td>
</tr>
<tr>
<td>236</td>
<td>247</td>
</tr>
<tr>
<td>203</td>
<td>193</td>
</tr>
</tbody>
</table>

\[ a = b = 0.5 \text{ NAUTICAL MILES} \]

**RHODE ISLAND SOUND**

**ISOTHERM \( ({}^\circ C \times 1000) \)**

**FIGURE 7.8. RUN 4, THERMAL FIELD AT 130 HOURS**

**ALL TEMPERATURES \( {}^\circ C \times 1000 \)**

137
Given: \( Q_{IN} = 2000 \) cfs, \( T_{IN} = 12^\circ C \)

**Figure 7.9.** Run 4, thermal field at 132 hours

All temperatures \( ^\circ C \times 1000 \)
Given: \( Q_{IN} = 2000 \text{ cfs}, T_{IN} = 12\,^\circ\text{C} \)

**QUONSET POINT**

- 903
- 453
- 343
- 233
- 169
- 100

**OUTFALL**

- 980
- 1032
- 569
- 363
- 273
- 243

**INFLOW**

- 2141
- 974
- 574
- 420
- 352

**ROME POINT AREA**

**LOWER BOUNDARY**

- 5483
- 982
- 660
- 491
- 430

- 568
- 498
- 457

- 408
- 444
- 395

- 380
- 397
- 340

- 348
- 339
- 299

- 341
- 304
- 247

**RHODE ISLAND SOUND**

- 566
- 519
- 462

**ISOTHERM \((^\circ\text{C} \times 1000)\)**

**FIGURE 7.10. RUN 4, THERMAL FIELD AT 134 HOURS**

**ALL TEMPERATURES \(^\circ\text{C} \times 1000\)**
Given: \( Q_{IN} = 2000 \text{ cfs}, T_{IN} = 12^\circ \text{C} \)

**Figure 7.11.** Run 4, Thermal Field at 136 Hours

All Temperatures \( ^\circ \text{C} \times 1000 \)
Given: \( Q_{IN} = 2000 \text{ cfs}, T_{IN} = 12^\circ C \)

**Figure 7.12.** Run 4, Thermal Field at 138 Hours

All temperatures \( ^\circ C \times 1000 \)
Given: QIN = 2000 cfs, TIN = 12°C

**FIGURE 7.13. RUN 4, THERMAL FIELD AT 140 HOURS**

ALL TEMPERATURES °C x 1000
Given: \( Q_{IN} = 2000 \text{ cfs}, \ T_{IN} = 12^\circ C \)

**Figure 7.14.** Run 4, Tidal Averaged Thermal Field, 128-140 Hours

All temperatures \( ^\circ C \times 1000 \)
FIGURE 7.15. RUN 4, TIDAL MOTION IN THE WEST PASSAGE
<table>
<thead>
<tr>
<th>Length of Simulation (Hours)</th>
<th>Ft/Sec Tidal Velocity</th>
<th>Grids Within 1°C Isotherm</th>
<th>Grids Within 0.5°C Isotherm</th>
<th>Grid (9,36) °C</th>
<th>Average North Boundary at Row 31 °C</th>
<th>Average South Boundary at Row 42 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>128</td>
<td>-0.065</td>
<td>7</td>
<td>14</td>
<td>0.344</td>
<td>0.286</td>
<td>0.129</td>
</tr>
<tr>
<td>130</td>
<td>+1.12</td>
<td>8</td>
<td>17</td>
<td>0.353</td>
<td>0.243</td>
<td>0.179</td>
</tr>
<tr>
<td>132</td>
<td>+0.36</td>
<td>9</td>
<td>19</td>
<td>0.327</td>
<td>0.201</td>
<td>0.289</td>
</tr>
<tr>
<td>134</td>
<td>-0.55</td>
<td>8</td>
<td>19</td>
<td>0.430</td>
<td>0.199</td>
<td>0.284</td>
</tr>
<tr>
<td>136</td>
<td>-0.31</td>
<td>7</td>
<td>17</td>
<td>0.437</td>
<td>0.220</td>
<td>0.231</td>
</tr>
<tr>
<td>138</td>
<td>-0.44</td>
<td>7</td>
<td>17</td>
<td>0.421</td>
<td>0.234</td>
<td>0.186</td>
</tr>
<tr>
<td>140</td>
<td>-0.24</td>
<td>8</td>
<td>17</td>
<td>0.375</td>
<td>0.264</td>
<td>0.141</td>
</tr>
<tr>
<td>Tidal Average 128-140</td>
<td>+0.02</td>
<td>8</td>
<td>17</td>
<td>0.445</td>
<td>0.23</td>
<td>0.220</td>
</tr>
</tbody>
</table>

Grid Area = 1/4 (nautical mile)²
average transport north of 0.02 ft/sec. In Rose (10) figures 7a, 7b, and 7c, pages 13-15, one can see that net transport is variable and of the order of $\pm 0.14$ ft/sec (4 cm/sec) depending on wind direction and magnitude. A net transport of 4 cm/sec would reduce particle residence time in Rome Point area to one or two days.

Evaluation of Table 7.2 leads to the following conclusions:

1. $1^\circ C$ isotherm encompasses an area of 2 square nautical miles (S.N.M.).
2. $0.5^\circ C$ isotherm encompasses an area of 4.25 S.N.M.
3. Average temperature for entire Rome Point area (13.25 S.N.M.) is $0.6^\circ C$ above natural condition.
4. The average value of the upper and lower Rome Point area boundaries is $0.23^\circ C$.
5. Tidal variations cause minor variations in locations of isotherms (See Figure 7.16) below $1.0^\circ C$.

G. **LONG TERM VARIATIONS IN SURFACE DISCHARGE BOX FOR A HIGH DISPERSION COEFFICIENT**

The complexity of the flow pattern around the Rome Point area causes very interesting tidal variations in heat content for box $n = 5$, $m = 36$. Referring to Figure 7.17
one can appreciate the value of computer modeling especially when with large variations in temperature of the grid due to sudden high velocity conditions at the 78 hour mark.

H. EXPERIMENTAL RUN 5 (FORCED TEMPERATURE RISE WITH 50% INCREASE IN FLOWRATE)

Run 5 is the same as run 3 with the following exceptions:

<table>
<thead>
<tr>
<th>VARIABLE NUMBER</th>
<th>CONTROL PARAMETER</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>QIN (Source Flow Rate, cfs)</td>
<td>3000</td>
</tr>
<tr>
<td>15</td>
<td>Plotting Interval (Hours)</td>
<td>36</td>
</tr>
<tr>
<td>16</td>
<td>Program Number</td>
<td>33225</td>
</tr>
<tr>
<td>17</td>
<td>Date of Run</td>
<td>6/2/73</td>
</tr>
</tbody>
</table>

H.1. Discussion

The thermal pattern for grid n = 5, m = 36, run 4, is compared with run 5 (Figure 7.18) to see what effect there will be in temperature field for a 50 percent increase in flowrate, from 2000 to 3000 cfs, for the same temperature increase through the condenser.

One can see from Figure 7.18 that the estimated
steady state value is +9.0°C or an 80 percent increase in forced temperature rise for grid n = 5, m = 36. Surrounding grid locations show a similar increase in heat content to balance the warmer input grid.

I. EXPERIMENTAL RUN 6, (FORCED TEMPERATURE RISE UPCON EQUALS 50)

Run 6 is the same as run 1 with the following exceptions:

<table>
<thead>
<tr>
<th>VARIABLE NUMBER</th>
<th>CONTROL PARAMETER</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>UPCON (Dispersion Coefficient Constant Times Elders' Value)</td>
<td>50/93</td>
</tr>
<tr>
<td>16</td>
<td>Plotting Interval (Hours)</td>
<td>36</td>
</tr>
<tr>
<td>17</td>
<td>Program Number</td>
<td>33374</td>
</tr>
<tr>
<td>18</td>
<td>Date of Run</td>
<td>6/5/73</td>
</tr>
</tbody>
</table>

I.1. Discussion

The dispersion coefficient constant (control parameter) was lowered by 50 percent to see what effect this would have on the temperature field. The results have been plotted in Figure 7.18 and are of the same
Given: \( Q_{IN} = 2000 \text{ cfs}, T_{IN} = 12^\circ C \)

**Figure 7.16. Tidal Effects on the 0.4°C Isotherm**
Given: $Q_{IN} = 2000$ cfs, $T_{IN} = 12^\circ$C

**Figure 7.17. Run 2, Temperature Variations for Grid n = 5, m = 6**
FIGURE 7.18. RUN 4, QIN = 2000 CFS, UPCON = 100; RUN 5, QIN = 3000 CFS, UPCON = 100; RUN 6, QIN = 2000 CFS, UPCON = 50
J. **INTERPRETATION OF AVERAGE AND WORST BAY CONDITIONS ON THE SITING OF THE POWER PLANT**

Average conditions for the bay might be summarized as some number of the following occurring:

1. Natural water temperature variations during year.
2. Expected marine population densities can be found by sampling.
3. Normal weather conditions.
4. Average water quality levels.
5. Average activity by fisheries and pleasure interests.
6. No major or unexpected fish kills.

Worst bay conditions would follow some of the following criteria occurring:

1. Extreme or biologically harmful temperatures in bay.
2. Unusual marine populations and unexpected migrations.
3. Very unusual weather patterns, storms, heat or cold spells, etc.
4. Very poor water quality levels.
5. Unusual activity of bay users.
6. Unexpected major fish kills.

K. GENERAL COMMENTS

In the presentation of the computational results this report has stressed the forced temperature rise method because it would be applicable for any period of the year. The warm water temperatures during mid summer coupled with peak power production by utility would create the highest temperatures in the outfall area. Whether the highest temperature and the worst temperature are synonymous remains a judgment for the biologist who must evaluate the thermal affects of the power plant on marine life throughout the year. The point here is to determine the need, if any, for temperature limitations that would be imposed on power plant operations for various air and water temperature values. Once the operating specifications have been determined, the environmental engineer can utilize his options to meet these criteria. Some engineering options available are:

1. Reduce plant output.
2. Increase flow rate through the plant.
3. Increase dilution in the discharge channel.
4. Change the outfall location by moving discharge into deeper water.

5. Dissipating heat near power plant through cooling towers or ponds.

Except for 1, these techniques do not reduce or "dissolve" the heat load on the bay environment but rather soften the impact by increasing the total area affected.

The upper temperature limit in the discharge grid would be the total temperature increase of condenser flow water for the entire grid. This value is somewhat fictitious, because with dilution in the normal tidal environment this value is not attainable. As a "worst case" it would be used in conjunction with the forced temperature rise analysis for any part of the year. With the 1800 megawatt sample plant at maximum output, the tidally averaged value for the discharge grid is approximately half the condenser temperature rise. This prediction was made with a value of the dispersion constant coefficient, UPCON, set at 50.
VIII. CONCLUSIONS

A. GENERAL

The thermal model can predict the general spatial temperature distribution in Narragansett Bay for either natural or man made conditions. When isotherms are sketched in by interpolation between grid temperatures, the effect of tidal flushing and heat sources are quite evident. The isotherms drawn for the forced temperature rise above ambient case serve as a valuable guide for environmental impact statements, because they dramatically display the effect of the heated effluent from a power plant. The heat content in a grid is vertically averaged but the Rome Point area is shallow enough to assume a high degree of vertical mixing for good model simulation. This mixing is further added by the variable current direction and magnitude during most of the tidal cycle.

Another challenging area comes from thermal field prediction or the attempt of the model to simulate bay boundary conditions in the form of a boundary value problem for temperature field calculation. The results obtained for the period of simulation, July 14-18, 1957, were of the same order of accuracy as those obtained by MASCH (57).
Long computer simulation runs of the order of a month would be required to pursue this verification procedure for the empirical heat exchange formulas and the variable boundary conditions. Verification improvements could be made by adjusting the empirical heat exchange formulas and the necessary variable boundary conditions.

When the Rome Point discharge grid temperature is plotted against time, one can observe the characteristic peaks and valleys of tidal flushing but the variations within a tidal cycle are most irregular. The sudden changes in temperature of the discharge grid, as seen in Figure 7.17, are important for physical impact studies. Knowing the general isothermal patterns around the discharge grid, the oceanographer now can make biological observations and recommendations.

The basic model can predict the spatial distribution of any dissolved constituent. For instance, the salinity distribution in the bay would be very valuable for biological models now being developed.

In general summary, the thermal model produces valuable temperature distribution information for both natural and man made conditions. The ability to predict thermal plume patterns for various input and output sites is of great
value to both the ecologist and the electric utility.

B. SPECIFIC

The verification of the model indicates no gross or unreasonable values are produced when the approximations used to formulate the model are evaluated. This model has been used to predict Jamaica Bay flushing characteristics and verification accuracy is comparable.

To limit this study, only one specific site at m = 36, n = 5 was chosen. This site enabled a verification of the forced temperature rise criterion. It is felt that this technique produces the most usable output for thermal impact studies.

In Chapter VII, the tidally averaged thermal field shown in Figure 7.14 clearly shows the scale of the spreading of the heat. The 0.5°C isotherm encompasses about eight to nine square nautical miles of bay. The tidally varying patterns appear to have surprising similarity beyond the 0.5°C isotherm mark. As discussed in earlier chapters, the higher the diffusion coefficient the less variation in heat content from box to box especially near the outfall area. In conclusion, the ground work has been laid for extensive development. Various physical
testing must be undertaken to pinpoint near field dispersion. This must of course be done in conjunction with computer runs that vary dispersion coefficient and site location.
IX. RECOMMENDATIONS

This thesis has established the value of the thermal model to make realistic spatial temperature distribution predictions. Before attempting to develop a better model that would more closely represent the three dimensional structure of Narragansett Bay, one should make salinity predictions. This would establish the ability of the difference scheme to predict the concentration of salinity without the use of the semi-empirical heat balance that occurs at the air-water interface.

As a prelude to a more sophisticated model, one should perform dye dispersion studies in conjunction with model predictions. These studies would indicate the importance of vertical structure on overall bay mixing. Finally, one could develop a two-dimensional width averaged vertically layered model. This would then reveal the importance of the vertical bay structure, especially in the deeper water grids.

It should be noted that Hess (59) is developing a three dimensional tidally averaged model for Narragansett Bay that shows considerable promise for understanding non-reacting constituent distribution of salt.

Research should be planned to bridge the gap between
the non-reacting concentration models to determine the differences predicted by vertical averaging, width averaging and time averaging on, for example, spatial distribution of salinity.
APPENDIX A

A. INTRODUCTION

The physical limitations on the amount of computer core and time available on the present operating computer required a reworking of the computer model into more manageable segments. This reworking enabled one to use a special storage unit, called a disk pack, to facilitate handling. In addition, the introduction of H level Fortran during the development stage offered a reduction of at least 50 percent in execution time, if the current batch processing mode was upgraded. That is to say, the program in its entirety exceeded the core requirement for Fortran H, optimization level 2, for the long runs, making segmentation and disk pack utilization a necessity.

B. TERMINOLOGY

To understand the workings of the disc pack a review of the technical language (I.B.M., (1) and Clayton, (3)) is presented.

Data Sets: A data set is a named, organized, logical collection of records. Generally, this consists of the main control segment,
subroutines, and the input data for starting model. A disk pack is used for the storage of data set records.

Sequential: Means an organized data set that is arranged in a logical, physical order of computational need. This is done to facilitate debugging by the user.

Direct: Each record in the model has independent address.

Partitioned: Combination of the sequential and direct organization. The grouping of these records is sequentially arranged into collections called "members".

OCEPAK: Name of the disk pack used for all computation.

Library: Sum of all the sets of partitioned data sets available in the disk pack that facilitate job execution.

OCESMODS: Name of all the partitioned data sets containing many members which are the source input.

OCECOMP: Name of all partitioned data sets containing compiled modules from OCESMODS.
OCEDATAS: Name of all the partitioned data sets that contain initialization and data information required for execution of the program. You do not compile this information. It is just read by the model.

C. DISK PACK USE

The job control language (JCL) for the library creation (IBM, la, lb) is as follows:

```
//LIBRARY JOB (IN0100, 256, 5, 500), 'J.J.A.',
    MSGLEVEL=1 (A-1)
//BLDSTEP EXEC PGM=IEBFBR14 (A-2)
//NEWSRCE DD DS=OCESMODS (A-3)
//   DISP=(NEW,CATLG), VOL=SER=OCEPAK (A-4)
//   UNIT=2314, SPACE=(CYL, (15, 5, 20)), (A-5)
//   DCB=(RECFM=FB, LRECL=80, BLKSIZE=3440) (A-6)
//ADDSTEP EXEC PGM=IEBUPDTE (A-7)
//SYSPRINT DD SYSOUT=A (A-8)
//SYSUT1 DD DSN=OCESMODS, DISP=OLD, UNIT
    =2314, VOL=SER=OCEPAK (A-9)
//SYSUT2 DD DSN=OCESMODS, DISP=OLD, UNIT
    =2314, VOL=SER=OCEPAK (A-10)
//SYSIN DD * (A-11)
```
The following data cards for execution appear after the input program JCL:

```
./ ADD NAME=AMAIN, LIST=ALL
./ NUMBER INCR=100, NEW=100
DIMENSION.....
  AMAIN
  FORTRAN CARDS
END

./ ADD NAME=AINVAL, LIST=ALL
./ NUMBER INCR=100, NEW=100
SUBROUTINE AINVAL(.....
  AINVAL
  FORTRAN CARDS
END
```

One repeats the above procedure for the remaining modules: APRINT, AHEATN, AOPBD, AUPNFH, AVPMFH, AVPMSH, AUPNSH, AWTDEP, AWTIND, AAZ, AKURIH, ADIVE, AFIND, ADEPTH, ACHEZY, AANLZE, ACHECK, APLOT and ADISPLY. This makes a total of 21 model modules.

To enter data for initialization of the model a partitioned data set, called OCEDATAS was created and filled in the same manner as OCESMODS with the following specific changes:
on line A-3, OCESMODS to OCEDATAS
A-5, SPACE=(CYL, (15, 5, 20))
A-9, OCESMODS to OCEDATAS
A-10, OCESMODS to OCEDATAS

OCEDATAS module names are: ADATA1, ADATA2, ADATA3, ADATA4, AD191, AD192, AD193, for a total of seven.

To change or update the library the following is done:
on line A-7, ADDSTEP to CHNGSTEP
A-12, ADD replaced by CHANGE
A-13, Fortran statement(s) on IBM card(s) with module line number is columns 73 to 80, for the specified change in module. It is important to list the line numbers in ascending order.

For obvious ease in handling changes it is desirable to stay in the CHNGSTEP mode once modules have been added to the library. For any data change or update one should do the following:
on line A-9, OCESMODS to OCEDATAS
A-10, OCESMODS to OCEDATAS
A-17, Specific changes desired
As an example, a typical deck layout for updating the library would be as follows:

lines A-1, LIBRARY JOB(.....

  A-7, //CHNGSTEP ..... 
  A-8, //SYSPRINT .... 
  A-9, //SYSUT1 .. OCESMODS .. 
  A-10, //SYSUT2 .. OCESMODS .. 
  A-11, // SYSSIN DD * 
       ./ CHANGE .. AMAIN 
       COL: 7 GO TO 10 .. 73 G04688 
       10 CONTINUE 004698 
       etc.

  A-7, //CHNGSTEP ..... 
  A-8, //SYSPRINT .... 
  A-9, //SYSUT1, .. OCEDATAS .. 
  A-10, //SYSUT2, .. OCEDATAS .. 
  A-11, // SYSSIN DD * 
       ./ CHANGE .. ADATAL .. 
       COL: 10 0010 .. 20 0020 .. 73 000778 

       ..

       etc.

JCL FOR REMAINING PROGRAM
After creation of the input partitioned data sets, the next step is to create a third partitioned data set called OCECOMP. This is done by making the following changes:

on line A-3, OCESMODS to OCECOMP

\[ \text{A-5, SPACE} = (\text{CYL}, (2, 2, 2)) \] \hspace{1cm} (A-19)

\[ \text{A-6, final line} \]

The primary function of this data set is to store all the compiled modules after they have been updated. Once a program has been compiled it need not be recompiled unless a change is made in the structure of the module. This results in a great saving in compilation time for each run. The necessary JCL is:

\[ \text{// EXEC FORTHOL, PARM.FORT-'OPT=2', PARM.LKED} \]
\[ = '\text{LET, LIST, NCAL, XREF} \] \hspace{1cm} (A-20)

\[ \text{//FORT.SYSIN DD DSN=OCESMODS(AMAIN), DISP} \]
\[ = \text{SHR} \] \hspace{1cm} (A-21)

\[ \text{//LKD.SYSLMOD DD DSN=OCECOMP(MAIN), DISP} \]
\[ = \text{OLD} \] \hspace{1cm} (A-22)

Repeat set A-23 for as many modules as needed in OCESMODS that have just been updated for a maximum of 21 compilations. Note here that AMAIN is the uncompiled module in OCESMODS while MAIN is the same module compiled and stored in OCECOMP.
Now that after all the modules are compiled they must be included in the object (functional) library through the LINK Editor as follows:

```plaintext
//LKED EXEC PGM=IEWL,PARM=(MAP,LET,LST,OVLY,XREF)
            \(A-24\)
//SYSLIB DD DSN=SYS1.FORTLIB,DISP=SHR
            \(A-25\)
// DD DSN=URI.SSPLIB,DISP=SHR \(A-26\)
// DD DSN=URI.OPOTLIB,DISP=SHR \(A-27\)
//SYSPRINT DD SYSOUT=A \(A-28\)
//SYSLIN DD DDNAME=SYSIN \(A-29\)
//SYSLMOD DD DSN=&GOSET(MAIN),UNIT=SYSDA,DISP=(I,PASS),
           \(A-30\)
            SPACE\(=(3\,72,\,3\,1\,1)\) \(A-31\)
//SYSLMOD DD DSN=&SYSUT1,UNIT=SYSDA,SPACE
           \(=(1\,24,\,2\,2)\),SEP=SYSLMOD \(A-32\)
//LKED.OBJLIB DD DSN=OCECOMP,DISP=SHR,VOL=SER
           \(=OCEPAK,UNIT=2314\) \(A-33\)
//LKED.SYSIN DD * \(A-34\)
```

Since the core restriction of 256 K is imposed on the fastest turn-around class it is necessary to follow up with the Overlay feature (IBM, (2)) that is specified in A-24. The modules in the program must be organized
into usable groups that minimize the core demand for any one executing group. See Figure A-1, Overlay Flow Chart, for details. Directly after A-34 are the instructions.

The final JCL required for reading in the initialization values is:

```plaintext
//GO EXEC PGM=*.LKED.SYSLMOD
//FT06F01 DD SYSOUT=A
//FT07F01 DD SYSOUT=B
//FT05F01 DD DSN=OCEDATAS(ADATA2),DISP=SHR,VOL=SER=OCEPAK
//UNIT=2314,LABEL=(),,,IN
```
BEGIN

PART 1, MAIN INPUT

PART 2, MAIN EXECUTION

COMPUTATIONAL SCHEME SECOND OVERLAY
OPENED UPNFHT VPMFHT VPMSHT UPNSHT WATDEP WATIND AZ PRINT DISPLAY

PART 3, MAIN OUTPUT

END

INITIALIZATION FIRST OVERLAY KURIH HEATIN DIVE FIND DEPTH CHEZY INVAL

TIDAL COMPARISON THIRD OVERLAY ANALYZE

FIGURE A.1. OVERLAY FLOW CHART
where A-55 represents the physical end of the job deck.

D. DISK PACK UTILITIES

When using a disk pack it is necessary, on occasion, to compress (IBM, (lc)) or eliminate the old modules that have accumulated on the disk pack. The following deck should be submitted about once a week exactly as shown.

//COMPRESS JOB (INØ1Ø, 256, Ø5, Ø1), 'USERNAME'.
MSGLEVEL=1 (A-56)

// EXEC PGM=IEBCOPY (A-57)

//SYSPRINT DD SYSOUT=A (A-58)

//INOUT1 DD DSN=OCESMODS, DISP=OLD (A-59)

//INOUT2 DD DSN=OCECOMP, DISP=OLD (A-60)

//INOUT3 DD DSN=OCEDATAS, DISP=OLD (A-61)
From time to time it is convenient to have a total print and punch (IBM, (ld)) of the disk pack. The programs that will perform this function are described below.

```
//PTWOH JOB (IN01ØØ, 128, Ø1, 1Ø, 35ØØ), 'USERNAME',
   MSGLEVEL=1
// EXEC PGM=IEBPTPCH
//SYSPRINT DD SYSOUT=A
//SYSUT1 DD DSN=OCESMODS, DISP=(OLD, KEEP), VOL=
   =SER=OCEPAK, UNIT=2314
//SYSUT2 DD SYSOUT=A [Gives Printed Output -Choose One]
   B [Gives Punched Output]
//SYSIN DD *
   COL: 7
   [Choose One -PRINT, PUNCH]
   TYPORG=PO, MAXFLDS=1
   TITLE ITEM=(' PRINT AND PUNCH ALL
   MEMBERS', 1Ø)
   RECORD FIELD=(8Ø, , 5)
/*
```
Note that one can obtain either punched or printed output (but not both) by picking the "A PRINT", or "B PUNCH" options.

E. ACKNOWLEDGMENT

Now that the model is fully operational in all modes it would be a great injustice not to cite the very valuable and timely assistance given to me by the entire computer center staff. Specifically, Dave "I can solve your problem" Clayton was undoubtedly the individual in the staff I must cite as instrumental in bringing the computer hardware into line. In addition to his daily assistance, he formalized all the above information into a special class especially for the Ocean Engineering Bay Model group.

F. SELECTED BIBLIOGRAPHY


<table>
<thead>
<tr>
<th>TITLES</th>
<th>PAGES</th>
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<tbody>
<tr>
<td>IEBUPDAT</td>
<td>173-198</td>
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<td>IEBCOMPR</td>
<td>51-58</td>
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APPENDIX B

HYDRODYNAMIC FINITE DIFFERENCE EQUATIONS

A. HYDRODYNAMIC MODEL

The three basic equations, 2-32 through 2-35, may be expressed in finite difference form, using the notation outlined in Equations 2-36 through 2-44. The results are:

A.1 First Half Timestep

X - Momentum:

\[ u^t + 1/2 = u^t + \frac{1}{2} DT \frac{\partial}{\partial t} \vec{v}^t - \frac{1}{2} DT \frac{\partial}{\partial L} u^t + 1/2 \delta_x u^t \]

\[ - \frac{1}{2} DT \frac{\partial}{\partial L} u^t + 1/2 \vec{v}^t \delta_y u^t - \frac{1}{2} DT \frac{\partial}{\partial L} g \delta_x \eta^t + 1/2 \]

\[ - \frac{1}{2} DT R^t (x) - \frac{1}{2} T F^t + 1/2, \]

at \( X_c + 1/2 DL, Y_c \).

Conservation of Mass:

\[ \eta^t + 1/2 = \eta^t - \frac{1}{2} DT \frac{\partial}{\partial L} \delta_x \left[ (h^x + \eta^x)^t + 1/2 u^t + 1/2 \right] \]

\[ - \frac{1}{2} DT \frac{\partial}{\partial L} \delta_y \left[ (h^y + \eta^y)^t \nu^t \right], \]

at \( X_c, Y_c \).
**Y-Momentum:**

\[
\frac{\nu^t}{v^t} + \frac{1}{2} = v^t - \frac{1}{2} \frac{D\nu}{DL} \delta^x v^t \frac{\partial u^t}{\partial + \frac{1}{2}} - \frac{1}{2} \frac{D\nu}{DL} \delta^y \nu^t v^t v^t + \frac{1}{2} \\
- \frac{1}{2} \frac{D\nu}{DL} \delta^y \eta^t - \frac{1}{2} \frac{D\nu}{DL} R^t_{x(y)} + \frac{1}{2} - \frac{1}{2} \frac{D\nu}{DL} F^t_{(y)}
\]

at \(X_c, Y_c + \frac{1}{2} DL\).

**A.2 Second Half Time step**

**X-Momentum:**

\[
\frac{u^t}{u^t} + 1 = u^t + \frac{1}{2} + \frac{1}{2} \frac{D\nu}{DL} \delta^x v^t + \frac{1}{2} - \frac{1}{2} \frac{D\nu}{DL} u^t + \frac{1}{2} \delta^x u^t + \frac{1}{2} \\
- \frac{1}{2} \frac{D\nu}{DL} \delta^x v^t + \frac{1}{2} \delta^x u^t + \frac{1}{2} - \frac{1}{2} \frac{D\nu}{DL} v^t + \frac{1}{2} \\
- \frac{D\nu}{DL} R^t_{x(y)} + \frac{1}{2} - \frac{D\nu}{DL} R^t_{y} + \frac{1}{2}
\]

at \(X_c + \frac{1}{2} DL, Y_c\).

**Conservation of Mass:**

\[
\eta^t + 1 = \eta^t + \frac{1}{2} - \frac{D\nu}{DL} \delta^x \left[(\bar{h}^y + \bar{\eta}^x) + \frac{1}{2}\right] u^t + \frac{1}{2} \\
- \frac{1}{2} \frac{D\nu}{DL} \delta^y \left[(\bar{h}^x + \bar{\eta}^y) + \frac{1}{2}\right] v^t + 1
\]

at \(X_c, Y_c\).
Y - Momentum:

\[ v^{t+1} = v^{t} + \frac{1}{2} \left( \frac{Dv^{t}}{D\tau} + \frac{1}{2} \right) - \frac{1}{2} \frac{Dv^{t}}{D\tau} f u^{t} + \frac{1}{2} - \frac{1}{2} \frac{Dv^{t}}{D\tau} g \delta_y n^t + \frac{1}{2} \]

\[ - \frac{1}{2} \frac{Dv^{t}}{D\tau} v^{t+1} \delta_y v^{t+1} - \frac{1}{2} \frac{Dv^{t}}{D\tau} g \delta_y n^t + \frac{1}{2} \]

\[ - \frac{1}{2} \frac{Dv^{t}}{D\tau} R^{t+1/2} - \frac{1}{2} \frac{Dv^{t}}{D\tau} R^{t+1} \]  

(B.6)

at \( X_c, Y_c + \frac{1}{2} L \)

where the bottom stress term, \( R \), is defined as:

\[ R_x^t = g u^t \left[ (u^t)^2 + (\bar{v}^t)^2 \right]^{1/2} \]  

(B.7)

\[ R_y^t + 1/2 = g v^t + 1/2 \left[ \frac{(\bar{u}^t + 1/2)^2 + (\bar{v}^t)^2}{(\bar{h}^y + \bar{n}^x)^t (\bar{c}^y)^2} \right]^{1/2} \]  

(B.8)

\[ R_x^t + 1 = g u^t + 1 \left[ \frac{(u^t + 1/2)^2 + (\bar{v}^t + 1)^2}{(\bar{h}^y + \bar{n}^x)^t + 1/2 (\bar{c}^y)^2} \right]^{1/2} \]  

(B.9)

\[ R_y^t + 1/2 = g v^t + 1/2 \left[ \frac{(\bar{u}^t + 1/2)^2 + (\bar{v}^t + 1/2)^2}{(\bar{h}^y + \bar{n}^x)^t + 1/2 (\bar{c}^y)^2} \right]^{1/2} \]  

(B.10)
and the surface stress terms, \( f \), are defined as

\[
\begin{align*}
F_x^t + 1/2 &= K \frac{(\omega_x^t + 1/2)^2}{(\eta_y^t + \eta_x^t)^t} \\
F_y^t &= K \frac{(\omega_y^t)^2}{(\eta_y^t + \eta_x^t)^t} \\
F_x^t + 1/2 &= K \frac{(\omega_x^t + 1/2)^2}{(\eta_y^t + \eta_x^t)^t + 1/2} \\
F_y^t + 1 &= K \frac{(\omega_y^t + 1)^2}{(\eta_y^t + \eta_x^t)^t + 1/2}
\end{align*}
\]

where

\[
K = \frac{k \rho_{air}}{\rho_{water}}
\]

The conservation of mass equations, B.2 and B.6, contain the non-linearities \((\eta_x^t)^t + 1/2\) and \((\eta_y^t)^t + 1\), respectively, which are at the same time level as \( \eta \) on the left-hand side of the equations. In the solution, these terms are taken at the lower time level in the first approximation and at the same time level in succeeding iterations. The hydraulic portion of model does contain iterative procedure but is not used because the improvement in accuracy was negligible.
Appendix C

Method of Solution

The implicit method of solution for \( n \) and \( u \) in the first half of the time step is first presented. The solution of \( n \) and \( v \) in the second is analogous. Starting with equations B.2 and B.1 (in Appendix B), and writing out the finite-difference approximations, we have

\[
-r_{m-1/2} \frac{u_m}{m-1/2} + n_m + r_m + 1/2 \frac{u_m}{m+1/2} = A_m
\]

\[
-r_m n_m + u_m + 1/2 + r_m + 1 n_m + 1 = B_m + 1/2
\]

where the coefficients \( r \) are

\[
r_m \pm 1/2 = \frac{1}{2} \frac{DT}{DL} (\tilde{h}^Y \pm \tilde{h}^X)_m \pm 1/2
\]

\[
r_m = \frac{1}{2} \frac{DT}{DL} g
\]

and \( A_m, B_m \) are the remaining terms in equations C.2 and C.1, respectively. Both \( n \) and \( u \) are at the \( t + 1/2 \) time level (except for \( \tilde{h}^X \) in C.3, which is at time \( t \)).

Suppose the first computational grid is at \( m = 2 \), and the last is \( m = J \). Then the values of \( n \) occur with subscripts \( m = 2, 3, \ldots J \), while \( u \) values have subscripts of \( m = 1^{1/2}, 2^{1/2}, \ldots J + 1/2 \) (see Figure C.1).
Solving eq. C.1 for \( \eta_m \) at \( m = 2 \), gives

\[
\eta_2 = A_2 + r_{12} u_{12}^* - r_{22} u_{22}^* \tag{C.5}
\]

where \( u_{12}^* \) is the velocity at the boundary. For the case of a land boundary, \( u_{12}^* \) is zero. Equation C.5 may be rewritten as

\[
\eta_2 = -p_2 u_{22} + u_2 \tag{C.6}
\]

where

\[
p_2 = r_{22} \tag{C.7}
\]

and

\[
\eta_2 = A_2 + r_{12} u_{12}^* \tag{C.8}
\]

Equation C.2 at \( m = 2 \) is

\[
u_{22} = B_{22} + r_2 \eta_2 - r_3 \eta_3 \tag{C.9}
\]

Taking the expression for \( \eta_2 \) from eq. C.6, and substituting into the above,

\[
u_{22} = B_{22} + r_2 (-p_2 u_{22} + u_2) - r_3 \eta_3 \tag{C.10}
\]

or

\[
u_{22} = -R_2 \eta_3 + S_2 \tag{C.10a}
\]

where

\[
R_2 = \frac{r_3}{1 + r_2 p_2} \tag{C.11}
\]

\[
S_2 = B_{22} + r_2 u_2 \frac{1}{1 + r_2 p_2} \tag{C.12}
\]
The next water level, \( \eta_3 \), is (from eq. C.1 at \( m = 3 \))

\[
\eta_3 = A_3 + r_{22} u_{22} - r_{32} u_{32} \tag{C.13}
\]

and substituting the expression for \( u_{22} \) from eq. C.10a,

\[
\eta_3 = A_3 + r_{22} (-R_2 \eta_3 + S_2) - r_{32} u_{32} \tag{C.14}
\]

or

\[
\eta_3 = -p_3 u_{32} + \eta_3 \tag{C.15}
\]

where

\[
\rho_3 = \frac{r_{32}}{1 + r_{22} h_2} \tag{C.16}
\]

The velocity \( u_{32} \) is obtained from eq. C.2 at \( m = 3 \):

\[
u_{32} = B_{32} + r_3 \eta_3 - r_4 \eta_4 \tag{C.17}
\]

or

\[
u_{32} = -R_3 \eta_4 + S_3 \tag{C.18}
\]

where

\[
R_3 = \frac{r_4}{1 + r_3 \rho_3} \tag{C.19}
\]

\[
S_3 = \frac{B_{32} + r_3 Q_3}{1 + r_3 \rho_3} \tag{C.20}
\]
This procedure (calculation of $p_m$, $Q_m$, $R_m$, and $S_m$) is repeated for all $m$ up to $m = J$, where, for a land boundary at $J + \frac{1}{2}$,

$$\eta_J = - p_J u_J^* + \frac{1}{2} + Q_J$$  \hspace{1cm} (C.21)

and $\eta_J$ is easily computed since $u_J^* + \frac{1}{2}$ is zero.

Suppose, however, that instead of land boundaries, the first ($m = 1$) and last ($m = J + 1$) are water boundaries, with either velocity or water level values given. For a first grid water level value, $\eta_1^*$, eq. C.2 gives

$$u_{1\frac{1}{2}} = B_{1\frac{1}{2}} + r_1 \eta_1^* - r_2 \eta_2 = - R_1 \eta_2 + S_1$$  \hspace{1cm} (C.22)

where $R_1 = r_2$  \hspace{1cm} (C.23)

and $S_2 = B_{1\frac{1}{2}} + r_1 \eta_1^*$  \hspace{1cm} (C.24)

For a first grid velocity, $u_{1\frac{1}{2}}^*$, eq. B.5 will suffice. For the case of a last grid water level value, $\eta_{J+1}^*$, eq. C.2 leads to

$$u_{J + \frac{1}{2}} = B_{J + \frac{1}{2}} + r_J \eta_J - r_J + 1 \eta_{J+1}^*$$

$$= - R_J \eta_{J+1}^* + 1 + S_J$$  \hspace{1cm} (C.25)

There are three methods of specifying the last grid ($m = J + 1$) velocity. The first is to specify the value $u_{J + 1}^* + \frac{1}{2}$, and

$$\eta_{J+1} = - p_J + 1 u_{J + 1}^* + \frac{1}{2} + Q_J$$  \hspace{1cm} (C.26)

which involves the calculation of $\eta$ at the boundary grid ($\sigma = J$).
Secondly, it is possible to calculate \( u_J + \frac{1}{2} \) from \( u_J + 1 + \frac{1}{2} \) using a flowrate conservation law. Finally, the velocity at \( J + \frac{1}{2} \) could be specified and eq. C.21 used directly. This last method is the most efficient, and is the one used in the present model calculations.

In general, the coefficients can be written as:

\[
P_m = \frac{r_m + \frac{1}{2}}{1 + r_m - 1 R_m - 1}
\]

\[
u_m = \frac{A_m + r_m + \frac{1}{2} S_m - 1}{1 + r_m - \frac{1}{2} R_m - 1}
\]

\[
P_m = \frac{r_m}{1 + r_m - 1 P_m}
\]

\[
S_m = \frac{B_m + \frac{1}{2} + r_m u_m}{1 + r_m - 1 P_m}
\]

Starting at the lower boundary (\( m = 1 \)), \( R_m \) and \( S_m \) are calculated, (from C.23 and C.24 for a water level boundary; \( R_1 = S_1 = 0 \) for a land boundary; \( R_1 = 0 \), \( S_1 = u_1 + \frac{1}{2} \) for a velocity boundary). Then at the computational levels (\( m = 2 \) to \( m = J \)) \( A_m, P_m, u_m, B_m, R_m \), and \( S_m \) are calculated in that order for each \( m \). At \( m = J \), \( u_J + \frac{1}{2} \) assumes its appropriate value (zero for a land boundary; the specified value for a velocity boundary; or computed from eq. C.25 for a water level boundary). The remaining values of \( \eta \) and \( u \) are then obtained from the recursive relations

\[
\eta_m = -P_m u_m + \frac{1}{2} + Q_m
\]
\[ u_m - \lambda_2 = -R_m \eta_m + S_{m-1} \]  

for \( m \) decreasing from \( m = J \) to \( m = 2 \).
FIGURE C-1: SPATIAL ARRANGEMENT OF VARIABLES ON GRIDS
APPENDIX D

MASS TRANSPORT MODEL

A. GENERAL

The solution of Eqs. (B.1) and (B.2) yields the \( x \) component of the water velocity and the water levels at the time level \( n + \frac{1}{2} \).

These values, along with the \( y \) component of the water velocity at time level \( n \), are then used in Eq. (B.3) to solve for the constituent concentration at time level \( n + \frac{1}{2} \). For the constituent, three unknown values are found at adjacent grid points in Eq. (B.3), and numerical procedures similar to those in the flow computation can be used to solve for these unknowns. This procedure is described in detail below.

B. EXPANSION OF THE FINITE-DIFFERENCE EQUATION

In the first operation at the time level going from \( t \) to \( t + \frac{1}{2} \) \( \Delta t \), the constituents are computed in both directions. This information is used in the computation of the concentration for the second half time step. The finite-difference equation for the constituent, Eq. (B.3), can then be expanded in the form:

\[
\begin{align*}
\left[ \tilde{c}^{t+\frac{1}{2}}_{j,k} \right] & \left( h_{j-\frac{1}{2}, k-\frac{1}{2}} + h_{j-\frac{1}{2}, k+\frac{1}{2}} + h_{j+\frac{1}{2}, k-\frac{1}{2}} + h_{j+\frac{1}{2}, k+\frac{1}{2}} + 4n^{t+\frac{1}{2}}_{j,k} \right) \\
- \left[ c_{j,k} \right] & \left( h_{j-\frac{1}{2}, k-\frac{1}{2}} + h_{j-\frac{1}{2}, k+\frac{1}{2}} + h_{j+\frac{1}{2}, k-\frac{1}{2}} + h_{j+\frac{1}{2}, k+\frac{1}{2}} + 4n_{j,k} \right) \frac{1}{2\Delta t} \\
- \left[ \tilde{n}_{j-1, k} \right] & \left( c_{j-1, k}^{t} + c_{j, k}^{t} \right) \left( c_{j-1, k}^{t+\frac{1}{2}} + c_{j, k}^{t+\frac{1}{2}} \right) u_{j-\frac{1}{2}, k}^{t+\frac{1}{2}} \left( c_{j-1, k}^{t+\frac{1}{2}} + c_{j, k}^{t+\frac{1}{2}} \right) \\
- \left[ n_{j, k} \right] & \left( c_{j-1, k}^{t} + c_{j, k}^{t} \right) \left( c_{j-1, k}^{t+\frac{1}{2}} + c_{j, k}^{t+\frac{1}{2}} \right) u_{j-\frac{1}{2}, k}^{t+\frac{1}{2}} \left( c_{j-1, k}^{t+\frac{1}{2}} + c_{j, k}^{t+\frac{1}{2}} \right)
\end{align*}
\]

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\[- (n^t_j, k + n^t_{j+1}, k + h_{j+\frac{1}{2}}, k-\frac{1}{2} + h_{j-\frac{1}{2}}, k+\frac{1}{2}) v^{t+\frac{1}{2}}_{j, k} (c^{t+\frac{1}{2}}_{j, k} + c^{t+\frac{1}{2}}_{j+1, k}) \left( \frac{1}{4D_x} \right) \]

\[- [n^t_j, k - 1 + n^t_j, k + h_{j-\frac{1}{2}}, k-\frac{1}{2} + h_{j+\frac{1}{2}}, k-\frac{1}{2}) v^{t}_{j, k-\frac{1}{2}} (c^{t}_{j, k-1} + c^{t}_{j, k}) \]

\[- (n^t_j, k + n^t_{j+1}, k + 1 + h_{j-\frac{1}{2}}, k+\frac{1}{2} + h_{j+\frac{1}{2}}, k+\frac{1}{2}) v^{t}_{j, k+\frac{1}{2}} (c^{t}_{j, k+1} + c^{t}_{j, k}) \left( \frac{1}{4D_x} \right) \]

\[+ [n^{t+\frac{1}{2}}_{j-1}, k + n^{t+\frac{1}{2}}_{j}, k + h_{j-\frac{1}{2}}, k-\frac{1}{2} + h_{j+\frac{1}{2}}, k+\frac{1}{2}) D^{t+\frac{1}{2}} x_{j-\frac{1}{2}, k} (c^{t+\frac{1}{2}}_{j, k} - c^{t+\frac{1}{2}}_{j-1, k}) \]

\[- (n^{t+\frac{1}{2}}_{j}, k + n^{t+\frac{1}{2}}_{j+1}, k + h_{j+\frac{1}{2}}, k-\frac{1}{2} + h_{j+\frac{1}{2}}, k+\frac{1}{2}) D^{t+\frac{1}{2}} x_{j+\frac{1}{2}, k} (c^{t+\frac{1}{2}}_{j+1, k} - c^{t+\frac{1}{2}}_{j, k}) \left[ \frac{1}{2 (D_x)^2} \right] \]

\[+ (h_{j+\frac{1}{2}}, k+\frac{1}{2} + h_{j-\frac{1}{2}}, k-\frac{1}{2} + h_{j-\frac{1}{2}}, k+\frac{1}{2} + h_{j-\frac{1}{2}}, k-\frac{1}{2} + 4n^t_j, k) \left[ \frac{S^t_{\frac{1}{4}, k}}{2} \right] = 0 \]

where \( c^{t+\frac{1}{2}}_{j, k} \) is the concentration of constituent at the grid point \( j, k \) for time level \( t + \frac{1}{2} \). The dispersion coefficients \( D_x \), \( D_y \) and the source of constituent \( S \) can be both space- and time-varying functions in this formulation. Point sources of constituents, such as occur at a power plant outfall, can be included. These procedures used for this part of the computation are described in Leendertse(2).

There are only three unknown variables in Eq. (D.1). They are:

\[ c^{t+\frac{1}{2}}_{j, k} ; c^{t+\frac{1}{2}}_{j-1, k} \text{; and } c^{t+\frac{1}{2}}_{j+1, k} \]  (D.2)

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Thus, rewriting Eq. (D.1) after multiplying through by $\tan = t/2$
yields

$$a_j C_{j-1, k} + b_j C_{j, k} + c_j C_{j+1, k} = D_j$$  \hspace{1cm} (D.3)

where:

$$a_j = -(n_{j-1}^{t}, k + n_j^{t}, k + h_{j-\frac{1}{2}}, k-\frac{1}{2} + h_{j-\frac{1}{2}}, k+\frac{1}{2}) u_j^{t}, k \left(\frac{\tan}{4 \, Dt}\right)$$

$$- (n_{j-1}^{t+\frac{1}{2}}, k + n_j^{t+\frac{1}{2}}, k + h_{j-\frac{1}{2}}, k-\frac{1}{2} + h_{j-\frac{1}{2}}, k+\frac{1}{2}) D_{x_{j-\frac{1}{2}}, k}^{t+\frac{1}{2}} \left[\frac{\tan}{2 (Dt)^2}\right]$$  \hspace{1cm} (D.4)

$$c_j = - \left[(n_j^{t}, k + n_{j+1}^{t}, k + h_{j+\frac{1}{2}}, k-\frac{1}{2} + h_{j+\frac{1}{2}}, k+\frac{1}{2}) (-u_j^{t+\frac{1}{2}}, k)ight.$$

$$+ (n_{j}^{t+\frac{1}{2}}, k + n_{j+1}^{t+\frac{1}{2}}, k + h_{j+\frac{1}{2}}, k-\frac{1}{2} + h_{j+\frac{1}{2}}, k+\frac{1}{2}) D_{x_{j+\frac{1}{2}}, k}^{t+\frac{1}{2}} \left(\frac{\tan}{4 \, Dt}\right)\left(\frac{\tan}{4 \, Dt}\right) \left[\frac{\tan}{2 (Dt)^2}\right]\right]$$  \hspace{1cm} (D.5)

$$b_j = \frac{1}{k} (h_{j-\frac{1}{2}}, k-\frac{1}{2} + h_{j-\frac{1}{2}}, k+\frac{1}{2} + h_{j+\frac{1}{2}}, k-\frac{1}{2} + h_{j+\frac{1}{2}}, k+\frac{1}{2}) + n_j^{t+\frac{1}{2}}$$

$$- (n_{j-1}^{t}, k + n_j^{t}, k + h_{j-\frac{1}{2}}, k-\frac{1}{2} + h_{j-\frac{1}{2}}, k+\frac{1}{2}) w_{j-\frac{1}{2}, k}^{t+\frac{1}{2}} \left(\frac{\tan}{4 \, Dt}\right)$$

$$+ (n_{j}^{t+\frac{1}{2}}, k + n_{j+1}^{t+\frac{1}{2}}, k + h_{j+\frac{1}{2}}, k-\frac{1}{2} + h_{j+\frac{1}{2}}, k+\frac{1}{2}) w_{j+\frac{1}{2}, k}^{t+\frac{1}{2}} \left(\frac{\tan}{4 \, Dt}\right)$$

$$+ (n_{j-1}^{t+\frac{1}{2}}, k + n_j^{t+\frac{1}{2}}, k + h_{j-\frac{1}{2}}, k-\frac{1}{2} + h_{j-\frac{1}{2}}, k+\frac{1}{2}) D_{x_{j-\frac{1}{2}}, k}^{t+\frac{1}{2}} \left[\frac{\tan}{2 (Dt)^2}\right]$$

$$+ (n_{j}^{t+\frac{1}{2}}, k + n_{j+1}^{t+\frac{1}{2}}, k + h_{j+\frac{1}{2}}, k-\frac{1}{2} + h_{j+\frac{1}{2}}, k+\frac{1}{2}) D_{x_{j+\frac{1}{2}}, k}^{t+\frac{1}{2}} \left[\frac{\tan}{2 (Dt)^2}\right]$$  \hspace{1cm} (D.6)
$$D_j = C_j^t,_{k} \left[ \frac{1}{h} (h_j,_{k-1} + k,_{-1} + h_j,_{k+1} + k,_{-1} + h_j,_{k+2} + k,_{1} + \eta_j^t,_{k} ) \right]$$

$$+ \left[ \eta_{j-1},_{k-1} + \eta_{j-1},_{k} \right] v_j,_{k-1} (c_j,_{k-1} + c_j,_{k} )$$

$$- \left[ \eta_{j+1},_{k+1} + \eta_{j+1},_{k} \right] v_j,_{k+1} (c_j,_{k+1} + c_j,_{k} )$$

$$\left( \frac{\tan}{4 \Delta x} \right)$$

$$= \left[ \eta_{j-1},_{k-1} + \eta_{j-1},_{k} \right] v_j,_{k-1} (c_j,_{k-1} + c_j,_{k} )$$

$$- \left[ \eta_{j+1},_{k+1} + \eta_{j+1},_{k} \right] v_j,_{k+1} (c_j,_{k+1} + c_j,_{k} )$$

$$\left( \frac{\tan}{2 \Delta x^2} \right)$$

$$- \left[ \frac{1}{h} (h_j,_{k-1} + k,_{-1} + h_j,_{k+1} + k,_{1} + h_j,_{k+2} + k,_{1} + h_j,_{k+3} + k,_{1} + \eta_j^t,_{k} ) \right] s_j,_{k}$$

For each row $k$, Eq. (D.7) can be written as:

$$a_j c_{j-1} + b_j c_j + e_j c_{j+1} = D_j$$

where the subscripts $k$ and superscript $t + \frac{1}{2}$ are dropped for convenience.

Equation (D.8) can be solved for the concentration of constituent at each grid point along row $k$ by a process of elimination of unknowns.

To illustrate the method, a closed left-hand boundary is assumed at some value of $j = J-1$, $k = K$, as shown in Figure D-1.

![Figure D-1: Left Closed Boundary](image-url)
For this case, both the advective and dispersive transport of constituent through the cross section between grid points \( J-1 \) and \( J \) is zero. Thus \( a_J = 0 \), and Eq. (D.8) can be written as:

\[
b_J C_J + e_J C_{J+1} = D_J
\]  

(D.9)

For the next point, \( j = J+1 \), along row \( k = K \), Eq. (D.8) is written as:

\[
a_{J+1} C_J + b_{J+1} C_{J+1} + e_{J+1} C_{J+2} = D_{J+1}
\]  

(D.10)

Solving Eq. (D.9) for \( C_J \) yields

\[
C_J = E_{J+1} C_{J+1} + Q_{J+1}
\]  

(D.11)

where

\[
E_{J+1} = - \frac{e_J}{b_J} \quad ; \quad Q_{J+1} = \frac{D_J}{b_J}
\]  

(D.12)

Substituting Eq. (D.9) for \( C_J \) into Eq. (D.10) gives

\[
a_{J+1} (E_{J+1} C_{J+1} + Q_{J+1}) + b_{J+1} C_{J+1} + e_{J+1} C_{J+2} = D_{J+1}
\]  

(D.13)

Solving for \( C_{J+1} \) yields

\[
C_{J+1} = E_{J+2} C_{J+2} + Q_{J+2}
\]  

(D.14)

where

\[
E_{J+2} = - \frac{e_{J+1}}{b_{J+1} + a_{J+1} E_{J+1}} \quad ; \quad Q_{J+2} = \frac{D_{J+1} - a_{J+1} Q_{J+1}}{b_{J+1} + a_{J+1} E_{J+1}}
\]  

(D.15)
In general, the following recursion formulas are valid:

\[ P_j = E_{j+1} C_{j+1} + Q_{j+1} \]  \hspace{1cm} (D.16)

where

\[ E_{j+1} = -\frac{e_j}{b_j + a_j E_j} \]  \hspace{1cm} (D.17)

\[ Q_{j+1} = \frac{D_j - a_j Q_j}{b_j + a_j E_j} \]  \hspace{1cm} (D.18)

It is assumed that the right-hand boundary at \( j = M, k = K \) is also a closed boundary, as shown in Figure D-2.

The advective and diffusive transport of constituent through the cross section between \( j = M \) and \( j = M + 1 \) is zero for this case, and therefore \( e_M \equiv 0 \). Equation (D.8) for \( j = M \) then becomes

\[ a_M C_{M-1} + b_M C_M = D_M \]  \hspace{1cm} (D.19)
and solving for $C_{M-1}$ yields

$$M-1 = -\frac{b_M}{a_M} C_M + \frac{D_M}{a_M}$$  \hspace{1cm} (D.20)

Writing the general recursion formula given by Eq. (D.17) for $j = M-1$ leads to

$$C_{M-1} = E_M P_M + Q_M$$  \hspace{1cm} (D.21)

Using Eq. (D.21) in Eq. (D.22) gives

$$E_M C_M + Q_M = -\frac{b_M}{a_M} C_M + \frac{D_M}{a_M}$$  \hspace{1cm} (D.22)

and solving for $C_M$ yields

$$M = \frac{D_M - a_M Q_M}{b_M + a_M E_M} \equiv Q_{M+1}$$  \hspace{1cm} (D.23)

The recursion factors $E$ and $Q$ are calculated in ascending order, starting with $E_{j+1}$ and $Q_{j+1}$, given by Eq. (D.13). Equations (D.17) and (D.18) are used to calculate the remaining recursion factors to $j = M$, noting that $E_{M+1} = 0$ since $e_M = 0$. The concentrations are then computed in descending order, starting with $j = M$, using Eq. (D.16).

If instead of a closed boundary at either end of the computational field, the geography of the region to be modeled requires an open boundary, then the above procedure must be modified slightly. As in the example given for the flow model, it is assumed that part of the left-
hand boundary, $j = 1$, of the computational field contains an open boundary, as shown in Figure D-3. For this case, $E_2$ is set equal to zero and $Q_2$ is set equal to the concentration of constituent $i$ at the open boundary, $C_1$. This concentration is a given input variable and is usually a function of time. The methods used to obtain $C_1$ for the sample calculations are explained in the next section.

\[ \begin{array}{ccc}
  * & - & - \\
  o & - & o \\
  k=K & * & - \\
  o & - & o \\
  j - 1 & 2 & 3 \\
\end{array} \]

Concentration of constituent at open boundary (function of time)

FIGURE D-3: LEFT OPEN BOUNDARY

The rest of the recursion factors and concentrations are then calculated in the same way as for a closed boundary.
APPENDIX E

DIFFERENCING SCHEMES AND THEIR EFFECTS

Consider the one-dimensional convective-dispersion equation

\[
\frac{\partial C}{\partial t} + \frac{\partial}{\partial x} (UC) = \frac{\partial}{\partial x} (D \frac{\partial C}{\partial x}) = 0
\]  

(E-1)

For the case of constant velocity and dispersion coefficient, the finite difference formulation is

\[
\frac{DC_m}{Dt} = \frac{Dx}{L^2} [C_{mp} - 2C_m + C_{mm}] - \frac{U}{L} [C_{mp} (1-A) + (A-B) C_m - C_{mm} (1-B)]
\]  

(E-2)

where \( L \) is the grid length, \( A \) and \( B \) are parameters with possible values of 0, 1/2, or 1, \( mm = m-1 \) and \( mp = m+1 \).

Let us suppose a constant depth and width channel with unit concentration at grid \( m \), and zero elsewhere in Figure E.1.

\[\text{FIGURE E.1. ONE DIMENSIONAL DIFFERENCING SCHEME}\]
Using a central spatial derivative in the convective term \((A = B = 1/2)\), the rate of change of concentration, \(DC/DT\), may be computed as follows:

\[
\text{at } M \quad \frac{DC_m}{Dt} = \frac{D_x}{L^2} [C_{mp} - 2C_m + C_{mm}] - \frac{u}{2L} [C_{mp} - C_{mm}]
\]

(E-3)

which becomes, upon substitution of values of \(C\) from Figure E-1,

\[
\frac{DC_m}{Dt} = \frac{D_x}{L^2} [-2C_m] = -\frac{2D_x}{L^2}
\]

(E-4)

\[
\begin{array}{cccc}
A & B & \frac{DC_{mm}}{Dt} & \frac{DC_m}{Dt} & \frac{DC_{mp}}{Dt} \\
1/2 & 1/2 & \frac{D_x}{L^2} - \frac{u}{2L} & -\frac{2D_x}{L^2} & \frac{D_x}{L^2} + \frac{u}{2L} \\
1 & 0 & \frac{D_x}{L^2} & -\frac{2D_x}{L^2} - \frac{u}{L} & \frac{D_x}{L^2} + \frac{u}{L} \\
0 & 1 & \frac{D_x}{L^2} - \frac{u}{L} & -\frac{2D_x}{L^2} - \frac{u}{L} & \frac{D_x}{L^2}
\end{array}
\]

(E-5)

**TABLE E.1. DIFFERENCING SCHEMES ON SPATIAL CONCENTRATION GRID**
The results for grids M, MM, and MP are given in the table. If the dispersion coefficient, $D_x$, is small (less than 25 yd$^2$), this scheme results in a negative concentration at the grid immediately upstream from the grid with unit concentration.

To overcome this, the upstream differencing technique may be used to advantage. That is, instead of using a central difference in the spacial term, a backward difference is used (with velocity in (+) - x direction), which is obtained by setting $A = 1$, and $B = 0$. Applying this at M, we have

$$\frac{DC_m}{Dt} = \frac{D}{L^2} \left[ -2C_m \right] - \frac{u}{L} \left[ C_m - C_{mm} \right]$$  \hspace{1cm} (E-5)

$$= - \frac{2D}{L^2} - \frac{u}{L}$$  \hspace{1cm} (E-6)

The results for M, MM, and MP are shown in Table E.1. The upstream concentration is now positive. However, this scheme results in an increase in effective dispersion. This may be seen by making the substitution for $A = 1$, $B = 0$ into Equation E-1.

Consider the consequences of using a mixture of the two schemes. By adding the rates of increase of concentration for the three grids M, MM, MP for the upstream scheme
(A = 1, B = 0), the sum is zero, indicating that mass is conserved. However, if a central derivative is used at grid MP, its increase is

\[ \frac{D C_{MP}}{D t} = \frac{D X}{L^2} + \frac{U}{2L} \]  

(E-7)

The sum for the three grids is then

\[ - \frac{1}{2} \frac{U}{L} \]  

(E-8)

indicating that mass is lost. Thus a mixture of the two schemes is to be avoided. For the velocity conditions below

Case u greater than 0; \( A = 1, B = 0 \)  

(E-9)

Case v greater than 0; \( A = 1, B = 0 \)

Case u less than 0; \( A = 0, B = 1 \)  

(E-10)

Case v less than 0; \( A = 0, B = 1 \)

the upstream differencing would be

Case A \( \frac{d C}{d X} = \frac{1}{2L} [2C_m - 2C_{m-1}] \)  

(E-11)

Case B \( \frac{d C}{d X} = \frac{1}{2L} [2C_{m+1} - 2C_m] \)  

(E-12)

where \( L = \) is length of grid

The second term in Equation E-4, \( \frac{d}{dX} (UC) \) is now analyzed for \( U \frac{d C}{d X} \) according to Figure E.2
and we have

$$u \frac{\partial C}{\partial x} = u[(1 + A) C_{m+1} - 2(A-B) C_m - (1 - B) C_{m-1}] \frac{1}{2L}$$

(E-13)

for centered derivative $A = 1/2$ and $B = 1/2$, we have

$$= (C_{m+1} - C_{m-1}) \frac{u}{2L}$$

(E-14)

A. UPSTREAM DIFFERENCING IN A CONSISTENT DIVERGENT FLOW PATTERN

It was discovered that for the grid point $N = 10$, $M = 32$ the upstream differencing scheme is unstable. This is shown by first referring to Figure E.3., and noting the general divergent flow condition that exists especially with regard to their velocity component.

Since we have Case A, Equation E.1 is supposed to be applicable which it normally would be if the component was
not plus (easterly) over 90% of the time. The result is that the $c_{m-1}$ term is forced to change sign by the differencing scheme, which means that the $\frac{\partial c}{\partial x}$ term is larger than it should be, which in turn increases the net advective transport out of the box, giving the response shown in Figure E.4.

Considering the divergent flow and artificial diffusion enhancing properties of the upstream differencing scheme, it was decided to make initial prediction runs using the central differencing scheme.
B. CONSERVATION OF MASS

An attempt was made to check on the mass-conserving properties of several approximations to the convective-dispersion concentration equation

$$\frac{\partial C}{\partial t} + U \frac{\partial C}{\partial x} - D_x \frac{\partial C^2}{\partial x^2} = 0$$  \hspace{1cm} (E-1.a)

which have been used in mathematical models. The approximations involve the use of various differencing schemes on the convective term, and modifications of the dispersion coefficient, $D_x$, if applicable.

In finite-difference form, the above equation may be written as

$$\frac{C^+ - C^0}{t} + \frac{U}{2L} \left[ 2(1 - A) C^+_{mp} + 2(A - E) C^+_m \right]$$
\[ -2(1 - B) C_{mm}^+ - \frac{D_x}{L^2} [C_{mp}^+ - 2C_m^+ + C_{mm}^+] = 0 \]

(E-16)

where \( U \), the velocity in the (+) \( x \)-direction, and the dispersion coefficient, \( D \), are taken as constant over \( x \) (as they are in the uniform channel).

The terms \( C \) represent the concentrations at the center of each grid, with the superscript (+) denoting the upper time level, and the (0) the lower time level. The subscripts denote the grid number in the \( x \)-direction, with \( MP = M+1 \), \( MM = M-1 \). The above finite-difference equation is written for grid \( M \).

The dispersion coefficient, (refer to Figure E.4), \( D \), is calculated from the velocity, \( u \), the depth, \( H \), and the Chezy coefficient, \( C_z \), in the general form

\[
\frac{\partial C}{\partial t} = - u \frac{\partial C}{\partial x} = - u \left[ (1 - A) C_{mp} + (A - B) C_m \right. \\
\left. - (1 - B) C_{mm} \right] \frac{1}{L} \tag{E-9}
\]

FIGURE E.5. ONE DIMENSIONAL FIVE GRID SCHEME
for \( C_m \neq 0.0 \), and \( E = u/L \)

\[
C_{mp} = C_{mm} = 0 = C_{mpp} = C_{mmm}
\]

**Case I** upstream: all \( M \) \( A = 1, B = 0 \)

\[
\begin{align*}
  m = m & \quad D_C^m = -E(C_m - C_{mm}) = E_m & \text{(E-17)} \\
  m = mp & \quad D_C^{mp} = -E(C_{mp} - C_m) = +E_m & \text{(E-18)} \\
  m = mm & \quad D_C^{mm} = -E(C_{mmm} - C_{mm}) = 0 & \text{(E-19)}
\end{align*}
\]

**Case II** no upstream \( A = B = 1/2 \)

\[
\begin{align*}
  mm & \quad D_C^{mm} = -(E/2) (C_m - C_{mmm}) = -E_m/2 & \text{(E-20)} \\
  m & \quad D_C^m = -(E/2) (C_{mp} - C_m) = 0 & \text{(E-21)} \\
  mp & \quad D_C^{mp} = -(E/2) (C_{mpp} - C_m) = +E_m/2 & \text{(E-22)}
\end{align*}
\]

**Case III** upstream at \( mm \) only

\[
\begin{align*}
  mm & \quad D_C^{mm} = -E (C_{mm} - C_{mmm}) = 0 & \text{(E-23)} \\
  m & \quad D_C^m = -(E/2) (C_{mp} - C_m) = 0 & \text{(E-24)} \\
  mp & \quad D_C^{mp} = -(E/2) (C_{mpp} - C_m) = +E_m/2 & \text{(E-25)}
\end{align*}
\]

For Cases I and II mass is conserved if schemes are consistent, that is either upstream of central differencing is used exclusively in computational procedure. In Case III, one of many that might be tried, mass is not conserved when one applies the upstream scheme at grid \( mm \) only and central differencing in grids \( m \) and \( mp \). It is a matter of judgment whether this loss, especially in the area of a source, will result in significantly less accuracy.
Appendix F

Sample Program For Thermal Model Segments
IEF2371 244 ALLOCATED TO
IEF2371 631 ALLOCATED TO SYSPRINT
IEF2371 244 ALLOCATED TO SYSLMOD
IEF2371 240 ALLOCATED TO SYSLIN
IEF2371 132 ALLOCATED TO SYSUT1
IEF2551 SYS3.FORLIB
IEF2551 VOL SER NOS= MFTRES.
IEF2551 UTILSPL13
IEF2551 VOL SER NOS= MFTLIB.
IEF2551 UTILSPL13
IEF2551 VOL SER NOS= MFTLIB.
IEF2551 SYS3156.T003132.RFO00.LIBRARY.R0000050
IEF2551 VOL SER NOS= OCEPAK.
IEF2551 SYS3156.T003132.RFO00.LIBRARY.OLOAD
IEF2551 VOL SER NOS= CEDISK.

//CHNGSTEP EXEC PGM=IEBUPDTE
//SYSPRINT OD SYSDUMP
//SYSPRINT OD SYSDUMP
//SYSLIN OD *
IEF2361 ALLOC. FOR LIBRARY CHNGSTEP
IEF2371 631 ALLOCATED TO SYSPRINT
IEF2371 244 ALLOCATED TO SYSLIN
IEF2371 244 ALLOCATED TO SYSLIN
IEF2371 244 ALLOCATED TO SYSUT1
IEF2551 SYS3156.T003132.RFO00.LIBRARY.R0000060
IEF2551 VOL SER NOS= OCEPAK.
IEF2551 OCEPAK.
IEF2551 VOL SER NOS= OCEPAK.
IEF2551 SYS3156.T003132.RFO00.LIBRARY.R0000062
IEF2551 VOL SER NOS= OCEPAK.

//CHNGSTEP EXEC PGM=IEBUPDTE
//SYSPRINT OD SYSDUMP
//SYSLIN OD *
IEF2361 ALLOC. FOR LIBRARY CHNGSTEP
IEF2371 631 ALLOCATED TO SYSPRINT
IEF2371 244 ALLOCATED TO SYSLIN
IEF2371 244 ALLOCATED TO SYSLIN
IEF2371 244 ALLOCATED TO SYSLIN
IEF2551 SYS3156.T003132.RFO00.LIBRARY.R0000059
IEF2551 VOL SER NOS= MFTRES.
IEF2551 UTILSPL13
IEF2551 VOL SER NOS= MFTLIB.
IEF2551 UTILSPL13
IEF2551 VOL SER NOS= MFTLIB.
IEF2551 SYS3156.T003132.RFO00.LIBRARY.R0000059
IEF2551 VOL SER NOS= MFTRES.
IEF2551 UTILSPL13
IEF2551 VOL SER NOS= MFTLIB.
IEF2551 UTILSPL13
IEF2551 VOL SER NOS= MFTLIB.
IEF2551 SYS3156.T003132.RFO00.LIBRARY.R0000059
IEF2551 VOL SER NOS= MFTRES.
IEF2551 UTILSPL13
IEF2551 VOL SER NOS= MFTLIB.
IEF2551 UTILSPL13
IEF2551 VOL SER NOS= MFTLIB.
IEF2551 SYS3156.T003132.RFO00.LIBRARY.R0000059
IEF2551 VOL SER NOS= MFTRES.
IEF2551 UTILSPL13
IEF2551 VOL SER NOS= MFTLIB.
IEF2551 UTILSPL13
IEF2551 VOL SER NOS= MFTLIB.
IEF2551 SYS3156.T003132.RFO00.LIBRARY.R0000059
IEF2551 VOL SER NOS= MFTRES.
IEF2551 UTILSPL13
IEF2551 VOL SER NOS= MFTLIB.
IEF2551 UTILSPL13
IEF2551 VOL SER NOS= MFTLIB.
/ CHANGE NAME=AMAIN LIST=ALL

DIMENSION AI(49), BI(49), CJI(49), DI(49), E(49), F(49),
1D(M), N(5), P(M), Q(M), R(M), S(M), T(M), U(M), V(M), W(M),
2X(111), X(111), Y(111), Z(111), I(110), J(110), K(110), L(110),
3M(110), N(110), O(110), P(110), Q(110), R(110), S(110),
4T(110), U(110), V(110), W(110), X(110), Y(110), Z(110),
5A(110), B(110), C(110), D(110), E(110), F(110), G(110),
6H(110), I(110), J(110), K(110), L(110), M(110), N(110),
7O(110), P(110), Q(110), R(110), S(110), T(110), U(110),
8V(110), W(110), X(110), Y(110), Z(110),
9A(110), B(110), C(110), D(110), E(110), F(110), G(110),
10H(110), I(110), J(110), K(110), L(110), M(110), N(110),
11O(110), P(110), Q(110), R(110), S(110), T(110), U(110),
12V(110), W(110), X(110), Y(110), Z(110),
13A(110), B(110), C(110), D(110), E(110), F(110), G(110),
14H(110), I(110), J(110), K(110), L(110), M(110), N(110),
15O(110), P(110), Q(110), R(110), S(110), T(110), U(110),
16V(110), W(110), X(110), Y(110), Z(110),
17A(110), B(110), C(110), D(110), E(110), F(110), G(110),
18H(110), I(110), J(110), K(110), L(110), M(110), N(110),
19O(110), P(110), Q(110), R(110), S(110), T(110), U(110),
20V(110), W(110), X(110), Y(110), Z(110),
21A(110), B(110), C(110), D(110), E(110), F(110), G(110),
22H(110), I(110), J(110), K(110), L(110), M(110), N(110),
23O(110), P(110), Q(110), R(110), S(110), T(110), U(110),
24V(110), W(110), X(110), Y(110), Z(110),
25A(110), B(110), C(110), D(110), E(110), F(110), G(110),
26H(110), I(110), J(110), K(110), L(110), M(110), N(110),
27O(110), P(110), Q(110), R(110), S(110), T(110), U(110),
28V(110), W(110), X(110), Y(110), Z(110),
29A(110), B(110), C(110), D(110), E(110), F(110), G(110),
30H(110), I(110), J(110), K(110), L(110), M(110), N(110),
31O(110), P(110), Q(110), R(110), S(110), T(110), U(110),
32V(110), W(110), X(110), Y(110), Z(110),
33A(110), B(110), C(110), D(110), E(110), F(110), G(110),
34H(110), I(110), J(110), K(110), L(110), M(110), N(110),
35O(110), P(110), Q(110), R(110), S(110), T(110), U(110),
36V(110), W(110), X(110), Y(110), Z(110),
37A(110), B(110), C(110), D(110), E(110), F(110), G(110),
38H(110), I(110), J(110), K(110), L(110), M(110), N(110),
39O(110), P(110), Q(110), R(110), S(110), T(110), U(110),
40V(110), W(110), X(110), Y(110), Z(110),
41A(110), B(110), C(110), D(110), E(110), F(110), G(110),
42H(110), I(110), J(110), K(110), L(110), M(110), N(110),
43O(110), P(110), Q(110), R(110), S(110), T(110), U(110),
44V(110), W(110), X(110), Y(110), Z(110),
45A(110), B(110), C(110), D(110), E(110), F(110), G(110),
46H(110), I(110), J(110), K(110), L(110), M(110), N(110),
47O(110), P(110), Q(110), R(110), S(110), T(110), U(110),
48V(110), W(110), X(110), Y(110), Z(110),
49A(110), B(110), C(110), D(110), E(110), F(110), G(110),
50H(110), I(110), J(110), K(110), L(110), M(110), N(110),
51O(110), P(110), Q(110), R(110), S(110), T(110), U(110),
52V(110), W(110), X(110), Y(110), Z(110),
INMODEL = 1

SET COMPUTATION PARAMETERS

IF DELTAT IS TRUE MODEL WILL CALCULATE TEMPERATURE ABOVE AMBIENT

DELTAT = TRUE.

TINR=21.0

IF (DELTAT) GO TO 2873

GO TO 2875

2873 TIME=0.03001

TIMEOPE=0.0001

TRIVER=0.0001

TSOUND=0.0001

2875 CONTINUE

DIFFUSION CONSTANT IS UPCON

FOR UPCON =500 THE ORDER OF MAGNITUDE OF HIGHEST DIFFUSION COEF

IS ABOUT 350 YDS2/SEC

UPCON=0.50.

POWER PLANT

TIN =0.0 YOU WILL HAVE HYDRODYNAMICS OF POWER PLANT BUT

NO THERMAL LOAD ON BAY. 

IF EFFECTS OF POWER PLANT ARE DESIRED SET TIN EQUAL TO 12.

TIN=12.

QIN=2000.

SITE SELECTION. SEE HEATING FOR DETAILS ON LOCATIONS

SITE=100.

LNL = 0

AMHD=27.91.940*11.00+0.000841*SALRIS-0.000100*TSOUND

NMAX=19

NMAX=40

anglat=41.6

M=1

MOUR1=1001

MOUR2=400091

MOUR3=051171

MOUR4=1422342

MOUR5=0410112

MNORD=6

MNIND=3

NSECT=30

87 CONTINUE

ARG=ANGLAT*3.1415927/180.

FF=3.1415927*SIN(ARG)/21600.
209 N=1.0
    IF=1
    C1=AT#AG/AL
    C2=AT/AL
    C3=AT/4.
    C4=S4/AT#AG
    C5=2.*C2#AL
    CT=4.0#SURFAG)
    C8=1./AL
    C9=1./4(AL#2)
    C10 = 0.
    C11=C1
    C12 = 0.
    C13=1./AT
    C14=1./4.*AL
    DD 8 M=1,NMAX
    DD 6 N=1,NMAX
    SC(N,M)=4.0.
    SEP(N,M)=0.0
    CN(M)=0.0.
    CHP(N,M)=3.0.
    UAVG(N,M)=0.0
    VAVG(N,M)=0.0
    VP(N,M)=0.0
    UP(N,M)=0.0
    V(N,M)=0.0
    U(N,M)=0.0
    C(N,M)=0.0
    M(N,M)=0.0
  6 FINI=FF
  8 CONTINUE
  RA=4.0
  CALL KURHIAKST,AT,INTERM,FCHECK,FR,DAY,TIM,TH1N,T5J
  CALL SIGUE(NMAX,NMAX)
  CALL FIND(MIND,MINS,MMAX,MINDX,MINDX,NSECT)
  CALL DEPEH(NMAX,NMAX)
  CALL CHEFY(NMAX,NMAX,CMNAX)
  CALL CHECK(NMAX,NMAX)
  DO 26 I=1,5
     L=1291
     M=10*(I-1)+1
     CALL READ(5,25) (INPUTI(N),N=N,L)
  25 FORMAT(18I4)
  26 CONTINUE
  DO 62 M=1,NMAX
     DO VAVG(N,M)=0.0
     DD M=1,NMAX
     IF(MN,M.EQ.0.0) GO TO 61

**Comment:**

```plaintext
61 CONTINUE
62 CONTINUE
7 IF (NUM.EQ.0 .AND. J .NE. 0) GO TO 3
```

**Code:**

```plaintext
DAVGIM3 = DAVGIM3 * (1 - HIN * h)
DEP = DEP + h
NUM = NUM + 1
DEP = DEP * 0.0
DEPSQ = DEPSQ + h
GRID1 = 0.0
GRID2 = 0.0
GRID3 = GRID1 * GRID2
GRID4 = GRID1 * GRID2
GRIDN1 = GRIDN1 + GRID4
GRIDN2 = GRIDN2 + GRID1
LIN = (LIN + 1) / MP
K = K + 1
MGRID = L + K - 1
GRIDN1 = GRIDN1 + GRIDN2
GRIDN2 = GRIDN2 + GRID1
GRIDN3 = GRIDN1 * GRIDN2
GRIDN4 = GRIDN1 * GRIDN2
GRIDN5 = GRIDN1 * GRID1
GRIDN6 = GRIDN1 * GRID1
GRIDN7 = GRIDN1 * GRID1
GRIDN8 = GRIDN1 * GRID1
GRIDN9 = GRIDN1 * GRID1
GRIDN10 = GRIDN1 * GRID1
GRIDN11 = GRIDN1 * GRID1
GRIDN12 = GRIDN1 * GRID1
GRIDN13 = GRIDN1 * GRID1
GRIDN14 = GRIDN1 * GRID1
GRIDN15 = GRIDN1 * GRID1
GRIDN16 = GRIDN1 * GRID1
GRIDN17 = GRIDN1 * GRID1
GRIDN18 = GRIDN1 * GRID1
GRIDN19 = GRIDN1 * GRID1
GRIDN20 = GRIDN1 * GRID1
GRIDN21 = GRIDN1 * GRID1
GRIDN22 = GRIDN1 * GRID1
GRIDN23 = GRIDN1 * GRID1
GRIDN24 = GRIDN1 * GRID1
GRIDN25 = GRIDN1 * GRID1
GRIDN26 = GRIDN1 * GRID1
GRIDN27 = GRIDN1 * GRID1
GRIDN28 = GRIDN1 * GRID1
GRIDN29 = GRIDN1 * GRID1
GRIDN30 = GRIDN1 * GRID1
GRIDN31 = GRIDN1 * GRID1
GRIDN32 = GRIDN1 * GRID1
GRIDN33 = GRIDN1 * GRID1
GRIDN34 = GRIDN1 * GRID1
GRIDN35 = GRIDN1 * GRID1
GRIDN36 = GRIDN1 * GRID1
GRIDN37 = GRIDN1 * GRID1
GRIDN38 = GRIDN1 * GRID1
GRIDN39 = GRIDN1 * GRID1
GRIDN40 = GRIDN1 * GRID1
GRIDN41 = GRIDN1 * GRID1
GRIDN42 = GRIDN1 * GRID1
GRIDN43 = GRIDN1 * GRID1
GRIDN44 = GRIDN1 * GRID1
GRIDN45 = GRIDN1 * GRID1
GRIDN46 = GRIDN1 * GRID1
GRIDN47 = GRIDN1 * GRID1
GRIDN48 = GRIDN1 * GRID1
GRIDN49 = GRIDN1 * GRID1
GRIDN50 = GRIDN1 * GRID1
GRIDN51 = GRIDN1 * GRID1
GRIDN52 = GRIDN1 * GRID1
GRIDN53 = GRIDN1 * GRID1
GRIDN54 = GRIDN1 * GRID1
GRIDN55 = GRIDN1 * GRID1
GRIDN56 = GRIDN1 * GRID1
GRIDN57 = GRIDN1 * GRID1
GRIDN58 = GRIDN1 * GRID1
GRIDN59 = GRIDN1 * GRID1
GRIDN60 = GRIDN1 * GRID1
```

**Comment:**

```plaintext
USE ONLY IF NO SE VALUES ARE READ IN
```

```plaintext
GO TO 7
CONTINUE
```

```plaintext
CN (3,1) = TANB
CNP (3,1) = TANB
CN (4,1) = TANB
CNP (4,1) = TANB
CN (19,23) = TANB
CNP (19,23) = TANB
CN (15,24) = TANB
CNP (15,24) = TANB
CN (16,24) = TANB
CNP (16,24) = TANB
CN (11,14) = TANB
CNP (11,14) = TANB
CN (12,48) = TANB
CNP (12,48) = TANB
CN (13,48) = TANB
CNP (13,48) = TANB
```
IF (HA.EQ.0) GO TO 31
M=MOD(NA)/10000
NBUT =MOD(NA)/1000 -M*100
NTOPO =MOD(NA)/100 -M*10000 -NBUT*100
DO 32 NA=NA+1
NA=NA+1
GO TO 5
31 NA=1
32 SEPH,MSEI(N-1,DI/46.I)*HINV
SEPH,MSEI(N-1,DI/46.I)*HINV
33 IF (HA.EQ.4) GO TO 34
M=MOD(NA)/10000
NLIF =MOD(NA)/1000 -M*100
MRIG =MOD(NA)/10 -M*10000 -NLIF*100
GO 35 NA=NA+1
M=NLIF,MRIG
DI=M
DI=DI-1.
SEP(M,)=SEIN(V-1,DI/46.I)*HINV
SEPH,MSEI(N-1,DI/46.I)*HINV
34 CONTINUE
C***************************************************************************
C CALL INVAL(MMAX,NMAX,GRID1,DEP,DEPSQ,READ1,ROCNPA,DAG)
C CALL HEAT(NINS,M57,SIT,TIME,NPRINT,2IN)
C WRITE(6,2050) NS(5),MS(5)
C IF(INST.GT.MAXST) GO TO 501
C***************************************************************************
100 IF (INST.GT.MAXST) GO TO 501
C***************************************************************************
SET OPEN BUJUSOS

CALL OPEN0D(INST,IMODES,EXTRA1,WRIT1,KRT,IMODE1,T1,T2,T4,T5,
INTERn,C5,TRIVER,THMDE,TSOUND,PI,TH,FCHECK,AT,T5,AL,GIN)

COMPUTE UP AND SEP ON ROW N (FIRST HALF TIME STEP)

CALL UPNFHT(NX,NY,C6,C2,C4,AT,AG,KN0,F,N)

COMPUTE VP ON COLUMN N (FIRST HALF TIME STEP)

CALL VPNFHT(C2,C6,NX,NY,C4,AT,DUSAL,IMODES,NSOURC,MSOURC,EL3,
C1,O,T,C4,C6,C1,C5,CHIND,P,N1,NST,NPRI NT,IP,TBMK,KRT,HMAX,HMAX,
ZIO,Y,P1,DAY,FRA,MIN,MTOT,HR,BH,NC,SAVE,NS,MS,SS,
G1N,TIN,NZ,UPCVR,VAR1,DELTA,T,NINPUT,ZIG)

CALL PRINT1(STEP,NST,NPRINT,K,NMAX,HMAX,IP,AT,MTOT,HA,BH,
TMES,NC,SAVE,IPUNCH)

CALL OPEN0D(INST,IMODES,EXTRA1,WRIT1,KRT,IMODE1,T1,T2,T4,T5,
INTERn,C5,TRIVER,THMDE,TSOUND,PI,TH,FCHECK,AT,T5,AL,GIN)

NXT=1LD

IF (NXT.EQ.0) GO TO 200
100 IF (NST.EQ.99) GO TO 2040
     GO TO 2040
2040 WRITE(6,E203)NXT,CNI5,36),CN(5,36),QIN,TIN,N11,N11,NZ,
     INPUN,T511),Z1IN(NXT),Z1B(NXT),ZIC(NXT),Z1D1,NXT),
     Z2A(NXT),Z8N(NXT),SITE,NS15,MS15),NXT
     2030 FORMAT(5X,'NST=',I4,'** CNI5,36) = ',E12.4, ' CN(5,36) = 'E12.4, 
     'QIN = ',E12.4, ' TIN = ',E12.4, ' NS = ',I4, ' MS = ',I4,
     'INPUN = ',E12.4, ' INPUN = ',E12.4, ' SS11 = ',E12.4,
     'Z1IN(NXT) = ',E12.4, ' Z1B(NXT) = ',E12.4, ' ZIC(NXT) = ',E12.4,
     'Z1D1(NXT) = ',E12.4, ' Z2A(NXT) = ',E12.4, ' Z8N(NXT) = ',E12.4,
     'SITE = ',E12.4, ' SS15 = ',I4, ' MS15 = ',I4
     200 CONTINUE

299 ISTEP=2

000030100

000030200
K=2*NST

COMPUTE VP AND SEP ON COLUMN M (SECOND HALF TIME STEP)

CALL VPPSHY(NX,NY,CX,C1,C2,C4,ATFAG,NIND,F,N1)

CALL UPNSH1(C2,C4,AT,NSRCH,D1D5,NSQIND,NSFLMK,NSQURC,C13,
L1C5,C7,C9,C14,C15,NIND,F,N1,NST,NSPRN,IP,TBR,B1R,TMAX,NMAX,
2 IDY,PF,DAY,NS,SS,QIN,TIN,NZ,T1R,TMIN,HTOT,NN,UPCON,VAR1)

SINPUT)

SUM=0,
GRID1=0.0
SUM=0.0

BAY AREA

NUM=1

IF(INUM.EQ.NIND) GO TO 36

NSRCH=NSRCH/1000000
M=NSRCH+10000-N
MF=NSRCH/100
N=NSRCH+10000000-N-100
MF=MF-1

GRIDZ=GRIDZ+1
GRIDT=GRIDT+1
DO 22 N=NF+1,L
PM=M-1
SUMWT=SUMWT+CNPIN(M)+I(25*HIN+M)*HIN+M+H(N,M)+H(N,M)+H(N,M)+SEP1(N,M)

183.0
SUM=SUM+SUMWT
SUM=SUM+CNPIN(M)

22 CONTINUE

NUM=NUM+1
GO TO 36

SUMZIG=SUMZIG/1001+SUMZIG

C

CONSTANT SHOULD EQUAL AL*2*L*#DENS*/5

CONST=1.0
SUMZIG=CONST*SUMZIG

IF(PMOD(IPRINT,IPRINT).EQ.0) GO TO 45

GO TO 47

45 IPRINT=IPRINT
IPRINT=IPRINT+1
GO TO 47

47 ZI01LD=SUMZIG/IPRINT
ZI01LD=SUMZIG/IPRINT
SUMZIG=0.0
POWER PLANT AREA

300 IF(NUM.EQ.7) GO TO 310
312 NSRC = NTP(NUM)/1000000
N = NTP(NUM)/1000-NSRC*100
MF = NTP(NUM)/100-NSRC*10000-MF*100
L = NTP(NUM)-NSRC*1000000-MF*1000
IF(MF.LT.32) MF = 32
IF(L.GT.42) L = 42
NN = 1
NGD = L-MF+1
GRT = NGD
GRID3 = GRID3+GRT4
DO 130 M=MF+L
MM = 1
SUMPT = CNPIN(M)*L.25*(HIN,M)+HIN,N)*HIN,M)+HIN,N)+HIN,M)+SEP(N,M)
130 SUM = SUM+SUMPT
330 SUM = SUM+SUMPT
60 SUMZIF = CNSP*SUM*SUMZIF
SUMZ = CNP*GRID3+SUMZIF
IF(MOVMST,IPRINT).EQ.0) GO TO 65
GO TO 70
65 IPRINT = IPRINT
IF(DELTAF) GO TO 67
IPRINT = IPRINT*10**2
67 ZIF(I) = SUMZIF/IPRINT
ZIH(I) = SUMZIF/IPRINT
SUMZIF = 0.0
SUMZIF = 0.0
70 CONTINUE
GO TO 302
310 CONTINUE

VELOCITY COMPONENTS IN OUTFALL AREA

C C C
C SUM = 0.0
SUM1 = 0.0
316  
INS=NS(I)Z
INS=NS(2)Z
C CHANGE 5 TO NS(2) AND 36 TO NS(1) WHEN YOU RUN POWER PLANT
SUM=SUM+INS+INS
SUM1=SUM+INS
SUM2=SUM+INS
IF(PRIINST,NPRINT,INST).EQ.0 THEN GO TO 75
GO TO 80
75  
AAILD)=SUMA+IPRINT
BLD)=SUMB+IPRINT
SUMAA=SUM+SUM
SUMBB=SUM+SUM
IF(PRIINST,IPRINT).EQ.0 IF(DIDINST,IPRINT).EQ.0 ILO+ILD+1
NXT=ILD-1
IF(DIDINST,IPRINT).EQ.0  
80 CONTINUE
C WRITE(6,277) IZ1(NAT),IZ1(NAT),IZ1(NAT),IZ1(NAT)
C 2070 FORMAT(/,3X,'A1',I12,4X,'A1',I12,4X,'A1',I12,4X,'A1',I12)
C AVERAGE VELOCITY IN WEST PASSAGE
C  
CALL DISPLAYINST,NMAX,TBNB,IF1,ZIF1,Z1M1,IPRINT)
C IF(INST.LT.MAXST) GO TO 60
110 CALL PRINT(ISTEP,NST,NPRINT,NMAX,NMAX,IP,AT,HOT,T,N,BH,
1HE,MC,SAVE,IPUNCH)
C END OF MAIN COMPUTATIONAL SCHEME
C  
501 CONTINUE
C CALL ANALYSISMAXST,INTERM,AT,NST,ZIF1
RETURN
END
.I CHANu E

l ~llUPUll

NCW MASJ[lt

SYS IN
NAHE•AV~HFH,ll~f•All

SU!\ ROUTIN E l/PMF HT cc2. ((J,.o.... Y,(4,Af, O!JSAL,

lll~

PA!.i~

OOlO

00001000
00001100
0 00 01l00
3QC N, Tl 'l t Nl , N ~ ,UPC ON,V AR I, Clf l TAT, N INP UT, l l GI
00001100
COMMUN SE 12 l, 48 I, SE P I 2 l t 48 I , I/ I 2 l, 4 81, \IP I 2 l, 4 ~ I , UI 21 ,481 t UP 12 l ,lt81 , 00001 40 0
0000 15 00
l Cl 2 l t 4 Bl , N iHl l 85 1,M HO I R ~l ,M 080 litl, NOBO l 41tHI 21 oltSl o
2 Wl2uloUl2Jl,ll20l,EllOl,~tPl20l,fPl20loHBl201,Elll201,
000 01 600
3 AR N l2 0 lo4 ~G PllOl,ARG81lOloA~GlBl20l,HLl20ltEll201,
0 000 1700
4llAI O l7 5 J,Zl 8 101751,llCCOl1~1, UAl/Gl2l,48l,l/AVGl2lt481,llEIOl751,0000l 800
5 AC OSMfl61,ASINMTl61,CNl21,it8ltCNPl21t4BI,
00001900
6 I F I ELOl2l,481,HS ll0151,HS210151,llOIOl751,AllOl751tBBIOl751
00002000
DIM ENS I ON Al790l,Bl481,Pl48),Ql481,Rl48l,Sl481,Fl481o
00002 100
lKU /lo V~T llllo NH l2lltNPRINfl2001oDAl/Gl801t
AH0l01481,
Ou002 20 0
2MSllOl,NSllOl,SSllOltZIGlll
00 002300
EXTRAl = l.O
00 002 400
1'•JM =l
000 07.500
NZ • l
000 0260 0
LOGICAL OUSAL,OELTAT
000 02 700
00002800
201 lFINUM .E Q,MINDI GO TO 202
c
• • • •••••••
••
••••••••••• 0 000 2900
1615 CONTINUE
00003UOO
c
••• • •• •
•••••••••••••
00003100
"4SF<Cfl =MBD I N\JMl/ 1000000
000 0320 0
M
=MB DINUMl/10000 -MSRCH•IOO
00003300
NF
= M ~O IN\JHl/100
-"4SRCH•lOOOO -M•lOO
00003400
L
•MRD l'IUMI
-MSRCHt 1000000-M• lOOOO-NF•lOO
0000350 0
lll =L+l
000Ul60 0
ll =L- 1
00003700
NFF=~f- 1
00003 80 0
l"M ~= ~+l
00003900
MM=M-1
•
00004000
IA• l"SRC>t/10
0000 4100
11\ = ~SR C H-IO•l.A
' 0000420 0
2903 CONTINU E
000 0430 0
DO 220 N•~ F,L
OO \l0 44v0
NN =N-l
~
00 00450 0
r..; ~,r~=M +l
,
00 004600
•
00004700
c
00004 d0 0
AL F AC ~ . 5
0 0004900
BET Ar.= . 5
.00005 000
GA :H1AC= . 5
00005100
DELTA C=.5
00005200
IFCN.EQ. NF I GO TO 206
000 05300
IFIN.fQ.LI GO ro 210
00005400
1ll CONTINUE
OOO\l5500
6ETA=0.5
00005600
JEMP4 ~ c2•111.-BETAl•IVINNN,Ml-V(N,Mll•BETl•IV(N,Ml-vlNN,Mll I
OC005700
fEHPl • VCN,Ml••2+11(UPIN,Hl+UPINNN,Ml+UPIN,MHl+UPINNN,MMll••21/
00005ij00
116. I
C0005900
TEMP2• IS EP l 'io Ml +SEP INNN, HI •·H(N,HH I +HIN, Ml I UCIN,MJ+
00006.000
lCINNN,HJ 1.. 2
IM CJ O~S.NSOURC,

lH S~URC ,Cll,Clu,c1,c s ,c 9 , c 14,CltMI NO ,f, N l.N S T, NP~ I N T.IP,TONB,KRT,
2 NMAX, MM AX, lflY, PI , DAY, H •R , 11" l 'l , >il 0 T, H~, RH, HE, HC, SA \IE, NS, HS, SS,

N
f--'

0\

-

~--

,


TEMP1=V(N,MM)
TEMP11=V(N,MM)
IF(TEMP1.EQ.1) TEMP10= V(N,MM)
TEMP111=V(N,MM)
IF(TEMP11.EQ.0) TEMP111= V(N,MM)
TEMP1/T=TEMP11+DELTA*G2*(TEMP10-V(N,MM)+DELTA*G2)

204 (V(N,MM)=TEMP3)
204 (V(N,MM)=TEMP111)
2- C*SECOND HALF TIMESTEP )
C
212 CONTINUE
IF(IGOSAL) GO TO 213
IF(IMOES.EQ.1) GO TO 7096
GO TO 7098
7096 ALFC=0.0
BETAC=1.0
GAMMAC=0.0
DELTAC=1.0
IF(U(N,M) GT 0.0) ALFC=1.0
IF(U(N,M) GT 0.0) BETAC=0.0
IF(U(N,M) GT 0.0) GAMMAC=1.0
GO TO 7099
C
7099 CONTINUE
IF(N.EQ.MS(NZ),OR.M.EQ.MS(NZ)) GO TO 518
518 CONTINUE
IF(N.EQ.MS(NZ)) GO TO 512
GO TO 520
512 CONTINUE
IF(NN.NEQ.MS(NZ)) AND.V(N,M) GT 0.0) GAMMAC=1.0
IF(NN.NEQ.MS(NZ)) AND.V(N,M) LT 0.0) DELTAC=1.0
IF(NN.EQ.MS(NZ)) GO TO 514
514 IF(U(N,M) GT 0.0) BETAC=0.0
IF(U(N,M) LT 0.0) ALFC=0.0
IF(V(N,M) LT 0.0) DELTAC=0.0

GO TO 520
INS = INS(NINPUT)
INS = INS(NINPUT)
IF INS.EQ.0 .AND. INS(2) .EQ. 0 GO TO 525
GO TO 530
525 S(N) = S(N-1) + T(N) + CNP(INS,IMS)
NPLUS = NPRINT(IP) - 29
IF INST.EQ.NPLUS) GO TO TG 1903
IF INST.EQ.11 GO TO 1903
GO TO 1904
1903 ISUM = 0
SDXM = 0
SYNM = 0
SDYMM = 0
1904 SDXM = SDXM + DXNM
SYNM = SYNM + DYNM
SDYMM = SDYMM + DYNMM
ISUM = ISUM + 1
1907 IF INST.EQ.NPRINT(IP) GO TO 1909
IF INST.EQ.MAXST) GO TO 1909
GO TO 1908
1909 SYNM = SYNM + ISUM
SDYMM = SDYMM + ISUM
SOXM = SDXM + ISUM
SOYN = SYNM + ISUM
AMS = NS(IN2)
MSG = NS(IN2)
WRITE(*,7121) NS, IMS, SDXM, SDYN, SDXNM, SDYNN
1908 CONTINUE
530 CONTINUE
IF INST.EQ.INS(AN0 .AND. IMS.EQ. IMS) GO TO 526
GO TO 527
526 S(N) = S(N-1) + SS(NZ) + CNP(INS, IMS)
NZ = NZ + 1
527 CONTINUE
C C HEAT EXCHANGE CALCULATIONS
C EXTRAL = EXTRAL + 1.
IF EXTRAL = Eq.44 + 1 GO TO 1730
GO TO 1732
1730 SAVE = S(N)
1732 IF EXTRAL.EQ.2 + 1 GO TO 3035
GO TO 1508
3035 CONTINUE
C C MORE TEMP CALCULATIONS YEAAAAA
IF INST.EQ.NPRINT(IP) GO TO 1500
IXA = NPRINT(IP) - 15
C C
SYSIN

IF INST = 0, I = X1A I GT 1500
GO TO 1500
1500 IF INST = 0, I = X1A I GT 1502
TEQ = T
TEQ = T + TEO + 32
1500 CONTINUE
CALL WATIND(T, AT, PT, DAY, TPH, TA, HA, WB, WC, FACT, RH)
ICLCVR, ANG, EXTRAPTIME, SC, HA, EA, PMM, NST, EXTRAP, T, THM
1515 TN = CNP(11, T) + CNP(9, 27) + CNP(10, 26) + CNP(8, 37) + CNP(13, 37) / 5
CALL WATSEP(TRNA, TA, TH, EA, EH, ES, EXTRAP, SUMONE, HE, MC, S
INT, EXTRAP, NST, JOY, MA, NA, WC, FACT, ANG, TEMPS, TEMPS + DELTA1)
1500 CONTINUE
C CALL AZIZONE, ZONE2, ZONE3, ZONE4, ZONE5, ZONE6, TBAY, PMMAX, NMAX, NST
C JT1 = 1, 0
WC = ABS(HA * COS(ANG / 180.0))
IF(TEQ, LE, 70.) GO TO 25
GO TO 20
25 RETA = 2.553
CBETA = -20.15
GO TO 40
30 RETA = 2.774
CBETA = -33.60
40 CONTINUE
SUMONE = 73. + 7.39 * (WC * 2 * WB * 2 * WC * 5) * WFACT
X = 10. + 10. - BETAI * SUMONE
EE = ES
TA = 1.07A + 32.
TH = T + 0.8 + 32.
SIGN = EE - EA
IF(SIGN .LE. 0.0) SIGN = 0.0
HR = 1.01 + (TEQ / 60.01 + 1.) * 0.04 + SUMONE * SIGN + 26. * SUMONE * (TEQ - TA)
TEQ = (184.1 / 1 / X) * (1 - 15.71 / X) * 1.26 * TA / (10.26 * BETAI + EA - CBETA) / (1.26 * BETAI)
HTEQ = -.15 + (.26 * BETAI) * (SUMONE) + (TW - TEQ) - .0541 * (TW + 2 * TEQ) / 21.0
THA = (TA - 32.) / 9.
TH = (TH - 32.) + 9.
HTD = HTOE / 10. + 24. + 3000 / 3.1
HTTQ = HTOE / 10.0 + 90.0
IF(NST = 0, I = X1A) GO TO 1533
GO TO 1531
1531 CONTINUE
IF(EXTRAP .NE. 2.) GO TO 1511
1536 CONTINUE
C HTOT = HTOT + 1
WRITE(15, 1535) SC, PMM, EA, WC, SUMONE, X, ES, HTOT, TA, HA, BA, HE, WC, TW
HEAT INPUT
HEAT INPUT CONVERTED INTO TEMPERATURE
HTPRBX = HTOT*CN(M,N)+0.00001/NST1/(TW+0.0001/NST)
HTPRBX = HTOT
SIN = S(N) - HPRBX
CONTINUE
IF(DDGSL) GO TO 1131
GO TO 214
1131 CONTINUE
A(NFF) = CNP(NFF,M)
IF(MSRECH.EQ.0) A(NFF) = 0
BINFF = 0
DO 232 K = 1, NF
IF(N(K) + P(N(K) + 1) + 1) = IF1
IF(N(K) + P(N(K) + 1) + 1) = IF2
CONTINUE
CNP(L,M) = A(L) - R(L)*CNP(LL,L,M)
NR = L - NF
DO 233 J = 1, NR
IF(MSRECH.EQ.0) CNP(L,M) = A(L)
L = L - J
NP = L - 1
CNP(NL,M) = A(NL) - R(NL)*CNP(NFF,M)
233 CONTINUE
GO TO 214
210 CONTINUE
IF(18.EQ.0) TEMPI = 0
IF(18.EQ.2) TEMPI = WP(L,M)
IF(18.EQ.1) GO TO 205
GO TO 209
205 TEMPI = VIL,MMI
IF(VIN(M),GT,0.0) GAMMAC = 1.0
IF(TEMP1.EQ.0.0) TEMPI = VIL,MMI
IF(TEMP1.EQ.0.1) TEMPI = VIL,MMI
933 LL = L - 1
BETA = 0
LL = L - 1
TEMP2 = C2*BETA*(VIL,M)-VILL,M))
TEMP2 = VIL,M) + SEP(L,M) + SEP(LL,M) + HIL,M) + HILL,M) + C(LL,M) + C(L,L,M) + C(L,L,M)
TEMP1 = C2*W2*(SEP(L,M) + SEP(LL,N) + HIL,M) + HILL,M) + C(LL,M) + C(L,L,M)) * 2
TEMP1 = VIL,MMI
200 CONTINUE
IEB0161 MEMBER NAME (AVPMFH ) FOUND IN WM DIRECTORY. TTR IS NOW ALTERED.
SUBROUTINE UPSHFT(C2, Co.WX, WY, CA, AT, DOSAL, IMODES, NSOURC, MSOURC, N)  
    1021 NSRCH=9BDI NUM/100000  
    1=9BDI NUM/1000-NSRCH*1000-NA100  
    I=9BDI NUM-9SRCH*100020-910000-NA100  
    N=A9SRCH/20  
    IF(A9SRCH/20=10+1)  
    NN=1  
    LLL=L-1  
    LLL=1+1  
    MF = MF-1  
    IF(MF=0) GO TO 406  
    MM=M+1  
    MM=M-1  
    DELTAC=.5  
    GAMMAG=.5  
    BETA=.5  
    IF(I=EQ.NF) GO TO 406  
    IF(N=EQ.L) GO TO 410  
    CONTINUE  
    IF(ALPHA=0.5)  
    TEMPA=C2*(I1-ALPHA)*U1+V1+H1+M1+U1+V1+H1+M1)  
    TEMPL=U1+M1+M1+V1+H1+H1+M1)  
    TEMPS=1*SEP(M1, M1, M1)+H1+H1+M1)  
    TEMPS=1*SEP(M1, M1, M1)  
    GAMMA=0.5  
    IF(TEMP1=EQ.U1) TEMPO=U1  
    IF(TEMP1=EQ.0.5) TEMPO=U1  
    IF(TEMP1=EQ.0.0) TEMPO=U1
978  TEMP1 = U(N,N,M)
980  IF (TEMP1.EQ.0.)  TEMP1 = U(N,N,M)
1  = $r_1$.$r_1$ $r_1$.$r_1$ $r_1$.$r_1$ $r_1$.$r_1$ $r_1$.$r_1$ $r_1$.$r_1$
404  UP(N,M) = TEMP1
405  (UP(N,M) = TEMP1)
C
412  CONTINUE
413  CONTINUE
GO TO 413

7196  ALFAC = 0.0
7198  AI = 1.0
A2 = 1.0
C
7199  CONTINUE
GO TO 510
510  CONTINUE
GO TO 512
512  CONTINUE
GO TO 514
514  IF (V(N,M) .GT. 0.0) DELTAC = 1.0
GO TO 523
515  IF (V(N,M) .GT. 0.0) DELTAC = 1.0
GO TO 523

520  CONTINUE
NOTE DISCOVERED ON 31 JULY 72 THAT LINE 0953/3 HAD CNIN, MMM INSTEAD OF CNIN, N,M.

INS = SIN(INPUT)
INS = MS (INPUT)
IF (INS IN Z = EQ. N, AND M, EQ. MS IN Z) GO TO 525
GO TO 530
926 \( S(M) = S(M) - SS(N) + T.IN + CNP(INS,IMS) \)

530 CONTINUE
IF(INS.EQ.INS.AND.M.EQ.IMS) GO TO 526
GO TO 527

526 \( S(M) = S(M) - SS(N) + CNP(INS,IMS) \)
N2=N2+1
527 CONTINUE

C
T=CNP(11,17)+CNP(9,27)+CNP(6,26)+CNP(8,37)+CNP(13,37)/5.
HTPRBX=HTOT*ICNN+INS+IO000001/NSTI/HTW*IO0010/NSTI
HTPRBX=HTOT
SIM=S(M) - HTPRBX

420 CONTINUE
IF(DUSAL) GO TO 1115
GO TO 414

1115 CONTINUE
A(MFF)=CNPN(M,MP)
IF(INS=CH.EQ.0) A(MFF)=0.
R(MFF)=0.
DO 432 M=MFF+1
M=M+1
F1=(M-P(M)*P(M))
A(M)=A(M)+F1*M
R(M)=R(M)+F1

432 CONTINUE
CNPS(L)=A(L)-F(L)*CNPN(L,LLL)
IF(SRCN.CEQ.0) CNPN(L,L)=AIL
P(L)=P(L)+1
DO 433 J=1,P(L)
M=L-J
K=M+1
CNPN(M)=A(M)-F(M)*CNPN(M,MP)

433 CONTINUE
GO TO 414

410 CONTINUE
IF(INS.EQ.2) TEMP=UPLN(L)
IF(INS.EQ.0) TEMP=0.
IF(INS.EQ.1) GO TO 405
GO TO 409

405 TEMPO=UPLN(L)

C
IF(U(L)=GT.0) ALFAC=1.0
IF(TMP1=EQ.0) TEMP1=UPLN(L)

1001 TEMPI=UPLN(L)

C
INSERTED FOLLOWING TWC CARDS 24 AUG
IF(TMP11.EQ.0) TEMP11=UPLN(L)
ALFAC=2.
TEMP4=2*ALFAC*(U(L)+MIN(L))
TEMP1=U(L)+MIN(L);+MIN(L))=2]/10.
TEMP2=(SEP(L)+SEP(l,L)+MIN(L)+MIN(L))=(C(L)+C(L)+C(L))
TEMP2=2*SEP(L)+SEP(l,L)+MIN(L)+MIN(L)
TEMP2=C+MP*TEMP12
TEMP3=1+C4+5QAT(TEMP1/TEMP2*TEMP4+TEMP12

00016300
00016400
00016500
00016600
00016700
00016800
00016900
00017000
00017100
00017200
00017250
00017300
00017400
00017500
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00020000
00020100
00020200
00020300
00020400
00020500
00020600
00020700
00020800
00020900
00021000
00021100
00021200
00021300
SYSIN

NEW MASTER

IEUPDATE LOG PAGE 0021

TEMP1 = TEMP3

GAMMA = 0.5

TEMP1 = 25*(ATAN(N)-1+GAMMA*C2*(TEMP10-U(N,L1)))-GAMMA*C2*

1*(U(N,L1)-TEMP11)

TEMP1 = TEMP3*(U(N,L1)+TEMP1*VP(N,N)+VP(N,N,L1))

1-C1*(SEIN(L,L)-SEIN,L1))

409 UP(N,L) = TEMP1

GO TO 412

406 IF (A.EQ.1) GO TO 407

IF (A.EQ.2) TEMP1 = UP(N,MFF)

IF (A.EQ.0) TEMP1 = 0.

GO TO 408

407 PFF = PF-1

C IF (U(N,M,L) LT 0.0) BETAC = 1.0

TEMP10 = U(NNN,MFF)

IF (TEMP10 .EQ. 0.0) TEMP10 = U(NNN,MFF)

1006 TEMP1 = U(NNN,MFF)

IF (TEMP1 .EQ. 0.0) TEMP1 = U(NNN,MFF)

1008 ALPHA = 1.

TEMP4 = C*(1.-ALPHA)**1*(U(N,MFI)-U(N,MFI))

TEMP1 = U(N,MFI)**2*(E(N,N,MFI)**2**21/16.)

TEMP2 = SEPIN(N,MFI)*SEPIN(N,MFI)**2**1+H(N,N,MFI)**10*IC(N,MFI)*IC(N,MFI)

1**2

TEMP12 = TEMP12**2/TEMP12

TEMP3 = 1.+C4*SQRT(TEMP11)/TEMP4*TEMP12

TEMP3 = 1./TEMP3

GAMMA = 0.5

TEMP1 = 25*(ATAN(N)-1+GAMMA*C2*(TEMP10-U(N,N,MFI))-GAMMA*C2*

1*(U(N,MFI)-TEMP11)

TEMP1 = TEMP3*(U(N,MFI)+TEMP1*VP(N,MFI)+VP(N,N,MFI))

1-C1*(SEIN(MFI)-SEIN,MFI))

408 UP(N,MFI) = TEMP1

GO TO 411

414 NUM = NUM + 1

GO TO 340

402 CONTINUE

RETURN

END

IEB9161 MEMBER NAME (AUPNSH) FOUND IN NN DIRECTORY. TTR IS NOW ALTERED.
**SYSSN**

- CHANGE NAME=ANTDEP
- LIST=ALL
- NUMBER INCR=100,NEW=1000

**NEW MASTER**

- SUBROUTINE ANTDEP
- TA,TW,EA,BH,ES,EXTRA,SMONE,HE,HC,S

1HM=EXTRA,4,ST,4Y=MA,MC,W,FACT,HA,ANG,TEMPS,TEMPE,DELTAT

2 COMMON SE(1,4),SEP(21,4),VP(21,4),UP(21,4),JP(21,4)

IC(21,4),NRI(81),PAC(81),MRD4(41),NORD(41),HP(21,4)

3 ARN(4),ARGP(4),ARGB(4),ARGL(4),HL(4),EL(4)

4 ZIA(41,75),ZIB(41,75),ZIC(41,75),VAVG(21,48),VAVG(21,48),ZIE(41,75)

5 ACCSMN(6),ASINMT(6),CH(21,48),CN(21,48),CNP(21,48)

6 IF(IIFL(21,48),HS(1,15),HS2(315),ZIE(41,75),AA(41,75),BB(41,75)

DIMENSION S(40)

LOGICAL DELTAT

C TEMP CALCULATIONS

WB = WIND FROM Y DIRECTION

WC = WIND FROM X DIRECTION

MC = ABS(WC*COS(ANG/57.11))

WB = ABS(WB*SIN(ANG/57.11))

EXTRA= 0.0

100 TW = 1.874 TW

GO TO 100

100 TW = 1.874 TW

GO TO 200

200 AM(51,9)

TW = 1.874 TW

BM = 0.97426 - 0.0400(459.7003)*TM

BETA = 0.0

SUMNE=11.49 WA

HE = SUMONE*BETA*TM

IF(H<.01,HE=0.0)

HC=.26*SUMONE*TM

HA = 0.0

ES=0.0

HS2(105) = 0.0

TM=TW*0.9/9.0

GO TO 300

300 CONTINUE

400 AM(31,9)

TW = 1.874 TW

BM = 0.97426 - 0.0400(1/TW*100)

C

ES=0.9999,COS(T*(1/100)+33.17)/(1+0.1033+7.1/180.)

SUMNE=7.3 + 7.3(12C**2W**2)*S*5**WFACT

SUMNE=11.49 WA

HC=.26*SUMONE*(TM*TA)

C

HE=SUMONE*(ES-EA)

SIGN = ES-EA

IF(SIGN.LT.0.0) HE=0.0

TM=(11/10.0)*9.0

CONVERTING HTOT INTO DEG CENT

HTOT = HS2(1105) + HA - BM - HE =HC


C
<table>
<thead>
<tr>
<th>Line</th>
<th>Code</th>
<th>Description</th>
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</thead>
<tbody>
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<td>SUBP</td>
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<td>ICLO</td>
<td>CALLING PARAMETERS</td>
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<td>5-6</td>
<td>CCNN</td>
<td>DEGREES OF FREEDOM</td>
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<td>FNL</td>
<td>FORTRAN IV NAME</td>
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</tbody>
</table>

**Notes:**
- The code snippet seems to be a part of a larger program, possibly related to heat transfer or thermal systems.
- The program includes functions like `SUBP`, `CALL`, and `IF` statements.
- The purpose of the code is not immediately clear without additional context.
- The comments within the code may provide more insights into its functionality.
**SYSIN**

**NEW MASTER**

**IEBUPDTE LOG PAGE 0025**

GO TO 5240

5210 IFI NOT ((TA.GE.80.00 AND TA.LE.89.99)) GO TO 5222

5222 PMH = 94.5-90.*COS(PI*(((TA-30.1/70.1)*61.-3.1)/180.1))

5240 EA = (PMM-((TA-30.1/70.1)*3.5+1.1))*RH-10.1/90.1*(TA-30.1/70.1)*3.5+

11.

BC = .74=(1 3.5*(96.-TA)**1.671/100*(4.+3.9*CLODVR))

HA=1.5E-8)*((TA+460.)**4)*(8C+.081*(EA**.5))

TA =TA - 32.1* 5.6/9.0

200 CONTINUE

RETURN

END

IEBIB16I MEMBER NAME (ANTIND) FOUND IN NN DIRECTORV. TTR IS NOW ALTERED.
<table>
<thead>
<tr>
<th>Statement</th>
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</tbody>
</table>

**Note:** The table contains a series of data points related to various parameters and values, which seem to be part of a larger program or system. Each row represents a specific instance or configuration, with columns indicating different attributes or measurements.
NEW MASTER

IF Field1(N,M),EQ.01 GO TO 10

MM = N-1
MM = M-1
10 CONTINUE
GO TO 300

IF INST.GT.11 GO TO 300
300 CONTINUE

IF IFKRT.EQ.01 GO TO 400
400 CONTINUE
RETURN
END

IEB016I MEMBER NAME IAAZ ) FOUND IN AN DIRECTORY. TTR IS NOW ALTERED.
* / CHANGE NAME = ADIVE, LIST = ALL

SYNIN

NEW MASTER

IEBUPDTE LOG PAGE 0028

C

SUBROUTINE DIVE

SUBROUTINE DIVE(NMAX, NMAX)

COMMON XI(21), Y(21), Z(21), W(21)

IC(21), NMAX, MMAX, MMAX, MMAX, MMAX, MMAX, MMAX, MMAX

DO 1 N = 1, NMAX

T = S(J)

WRITE(6,5) N, N

END

5 FORMAT(2I3)

WRITE(5,5) N, N

CONTINUE

WRITE(6,4) N, N

RETURN

4 FORMAT(1H, 1X, 4H, 1X, 4H)

5 FORMAT(1H, 1X, 4H, 1X, 4H)

6 FORMAT(1H, 1X, 4H, 1X, 4H)

END

IE88161 MEMBER NAME = ADIVE FOUND IN AN INIT DIRECTORIES, TTA IS NOW ALTERED.
SUBROUTINE PLOT((NO,A,N,NL,NS))
COMMON SE(1,4),SEF(1,4),VI(1,4),VIl(1,4),VPl(1,4),WPl(1,4)
1 C(1,4),V1(1,4),F(1,4),V(1,4),H(1,4),K(1,4),L(1,4)
2 W1(20),F2(20),E2(20),C2(20),H2(20),L2(20),I2(20)
3 ARN(20),ARGP(20),ARKL(20),AL(20),EL(20)
4 Z(1,175),Z1(1,175),Z2(1,175),V(1,48),V1(1,48),V2(1,48)
5 AGC(6),ASMT(6),CN(1,4),CN1(1,4),CN2(1,4),CN3(1,4),CN4(1,4)
6 IF(I(21,48),H5(1,159),H5(1,159),Z1(1,175),AA(1,175),BB(1,175))

SUBROUTINE PLOT

PURPOSE
PLOT SEVERAL CROSS-VARIABLES VERSUS A BASE VARIABLE

USAGE
CALL PLOT((NO,A,N,NL,NS))

DESCRIPTION OF PARAMETERS
NO - CHART NUMBER (1 DIGITS MAXIMUM)
A - MATRIX OF DATA TO BE PLOTTED. FIRST COLUMN REPRESENTS BASE VARIABLE AND SUCCESSIVE COLUMNS ARE THE CROSS-VARIABLES (MAXIMUM IS 99).
N - NUMBER OF ROWS IN MATRIX A
M - NUMBER OF COLUMNS IN MATRIX A EQUAL TO THE TOTAL NUMBER OF VARIABLES. MAXIMUM IS 10.
NL - NUMBER OF LINES IN THE PLOT. IF 0 IS SPECIFIED, 50 LINES ARE USED.
NS - CODE FOR SORTING THE BASE VARIABLE DATA IN ASCENDING ORDER. 0 SORTING IS NOT NECESSARY (ALREADY IN ASCENDING ORDER). 1 SORTING IS NECESSARY.

REMARKS
NONE

SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
NONE

DIMENSION OUT(101),YP(111),ANG(91),A11

1 FORMAT(',//',62X,TH,CHART +13,//' ')
2 FORMAT(1H,F11.4,9X,10A11)
3 FORMAT(1H )
4 FORMAT(10H 123456789)
5 FORMAT(10A11)
6 FORMAT(1H +16X,10H )
7 FORMAT(1H +16X,10H )
SORT BASE VARIABLE DATA IN ASCENDING ORDER
10 DO 15 I=1,N
   DO 14 J=1,N
      IF(A(I,J)) 14,14,11
11 L=I-N
   LL=I-J
   DO 12 K=1,N
      L=L+N
      LL=LL+N
      F=A(I,L)
      AIJ=A(I,L)
12 AIJ=F
14 CONTINUE
19 CONTINUE

TEST NLL
16 IF(NLL) 20,18,20
18 NLL=50

PRINT TITLE
20 WRITE(6,110)

DEVELOP BLANK AN DIGITS FOR PRINTING
REWIND 13
WRITE (13,4)
REWIND 13
READ (13,5) BLANK,ANG(11),I=1,9
REWIND 13

FIND SCALE FOR BASE VARIABLE
XSCALE=(A(N)-A(I))/FLOAT(NLL-1)
WRITE(6,100) XSCALE
100 FORMAT(9X,3E12.4)

FIND SCALE FOR CROSS-VARIABLES
M1=N+1
```plaintext
YMIN=A(1)
YMAX=YMIN
M2=M1+1
DO 40 J=M1,M2
IF(A(J)-YMIN) 26,26,26
26 IF(A(J)-YMAX) 40,40,30
28 YMIN=A(J)
GO TO 40
30 YMAX=A(J)
40 CONTINUE
YSCALE=(YMAX-YMIN)/100.0
WRITE(6,110) YSCALE
110 FORMAT(5X,YSCALE=11,E12.4,/) 
C FIND BASE VARIABLE PRINT POSITION
C XN=A(I)
L=1
MY=Y-1
C IF(I-1)
45 IF(I=1)
XPR=XB+F×YSCALE
IF(A(I))=XPR) 50,50,70
50 OUT(I)X=1101
55 OUT(I)X=BLANK
DO 60 J=1,MY
LL=L+J*H
JP=(LL+YMIN)/YSCALE+1.0
OUT(JP)ANG(J)
60 CONTINUE
C PRINT LINE AND CLEAR OR SKIP
C WRITE(16,2)XPR,(OUT(I))I2=1,101
L=1
GO TO 80
70 WRITE(16,3)
80 IF(I=1) 85,84,86
84 XPR=A(I)
GO TO 50
C PRINT CROSS-VARIABLES NUMBERS
C WRITE(16,7)
YPR[I]=YMIN
DO 90 KN=1,9
90 YPR(KN)=YPR(KN)+YSCALE×10.0
YPR(I)=YMAX
```
NEW MASTER

WRITE(1,0) (YPKLIP, IP=1:11)
RETURN
END

IEB8161 MEMBER NAME ['APLOT '] FOUND IN KM DIRECTORY. TTR IS NOW ALTERED.
SUBROUTINE DISPLAY(INST,MAKST,TMA0,FLF,ZIG,ZIH;IPRIND)
C
COMMON SE(12),EF(12),VP(21,48),UI(21,48),UP(21,48)
LC(21,48),NI(1651),MO(51),MOND(4),NORD(4),HI(21,48)
1 2 (120),F(120),E(120),HI(201),EP(201),EB(201),
3 ARA(20),ARB(20),CAR(20),CH(20),E(20),
4 K(1600),ZIG(1750),ZIE(1750),ZIE(1750),UAVG(21,48),VAVG(21,48),MCI(21,48),
5 ACOSI(61),ASINHT(61),CN(21,48),CNP(21,48),
6 IFIELD(21,48),HS(10151),HS(10151),ZID(10151),MAT(1751),MM(1751),
5 DIM I NC T 5363(125),T363(125),T636(125),T635(125),T635(125),
7 T351(125),T351(125),T351(125),T351(125),T351(125),T351(125),
8 T341(125),T341(125),T341(125),T341(125),T341(125),T341(125),
9 T331(125),T331(125),T331(125),T331(125),T331(125),T331(125),
10 T321(125),T321(125),T321(125),T321(125),T321(125),T321(125),
11 T311(125),T311(125),T311(125),T311(125),T311(125),T311(125),
C
C INNER TEMPERATURES AROUND ROME PT

MO=NST
IF(INST.EQ.1) MD=1
CONTINUE
IF(MOD(INST,IPRIND).EQ.1) GO TO 409
GO TO 600
KST=MD
IF(ITBHM.EQ.0) RONB=1.0
5363(INST)=CNP(15,36)/TNB
6363(INST)=CNP(16,36)/TNB
637(INST)=CNP(16,37)/TNB
735(INST)=CNP(15,35)/TNB
733(INST)=CNP(16,33)/TNB
773(INST)=CNP(17,37)/TNB
773(INST)=CNP(17,37)/TNB
5363(INST)=CNP(17,36)/TNB
737(INST)=CNP(17,37)/TNB
5334(INST)=CNP(15,33)/TNB
6334(INST)=CNP(16,33)/TNB
7334(INST)=CNP(17,33)/TNB
7334(INST)=CNP(17,33)/TNB
7334(INST)=CNP(17,33)/TNB
7334(INST)=CNP(17,33)/TNB
7334(INST)=CNP(17,33)/TNB
7334(INST)=CNP(17,33)/TNB
C
C OUTER TEMPERATURES AROUND ROME PT

CONTINUE
IF(MOD(INST).EQ.0) GO TO 301
GO TO 400
301 CONTINUE
KST=1
ND=4
M=0
N=NST
ML=NST

C
NEW MASTER

IEBPUPD TE LOG PAGE 0034

N=0
DO 100  I=1,NST
N1=NST+N
N2=NST+2+N
N3=NST+3+N
N4=NST+4+N
N5=NST+5+N
N6=NST+6+N
N7=NST+7+N
N8=NST+8+N
A(N)+N
A(N1)=T363(N)
A(N2)=T363(N)
A(N3)=T375(N)
A(N4)=T355(N)
A(N5)=T354(N)
A(N6)=T375(N)
A(N7)=T363(N)
A(N8)=T377(N)
100 CONTINUE
WRITE(6,120)
120 FORMAT(1H1,5X,'ALL OF THE FOLLOWING TEMPERATURES ARE ON THE INNER RADIUS OF THE KEMT PT AREA')
WRITE(6,125)
125 FORMAT(1H1,5X,'ALL OF THE FOLLOWING TEMPERATURES ARE IN DEG C')
DIVIDED BY T0NB IF T0NB NE 0. T0 /5X,*1 = TEMP IN (5,36) , 10X;
2 = TEMP IN (6,36) , 10X; 3 = TEMP IN (6,37) , 10X; 4 = TEMP IN (6,35) , 10X;
5 = TEMP IN (7,35) , 10X; 6 = TEMP IN (7,35) , 10X;
7 = TEMP IN (7,36) , 10X; 8 = TEMP IN (7,36) , 10X;
9 = TEMP IN (7,37) , 10X;
N=NST
CALL PLOT (N,N, N,N, N, N, N)
DO 200  I=1,NST
N1=NST+N
N2=NST+2+N
N3=NST+3+N
N4=NST+4+N
N5=NST+5+N
N6=NST+6+N
N7=NST+7+N
N8=NST+8+N
A(N)+N
A(N1)=T363(N)
A(N2)=T363(N)
A(N3)=T375(N)
A(N4)=T355(N)
A(N5)=T354(N)
A(N6)=T375(N)
A(N7)=T363(N)
A(N8)=T377(N)
200 CONTINUE
WRITE(6,240)
240 CONTINUE

240 FORMAT(1H1,25X) 'ALL OF THE FOLLOWING TEMPERATURES ARE ON THE OUTDOOR:
1' RADIUS OF THE rome PT AREA:1
WRITE(6,230)
250 FORMAT(5X,'ALL OF THE FOLLOWING TEMPERATURES ARE IN DEG C,
1DIVIDED BY TANH IF TANH NE 0 '+/5X,'1 = TEMP IN (5,34)*10X,
2*2 = TEMP IN (6,34)*10X,'3 = TEMP IN (7,34)*10X,'4 = TEMP IN
3(8,34)*10X,'5 = TEMP IN (8,35)*10X,'6 = TEMP IN (8,36)*
4,7 = TEMP IN (8,37)*11X,'8 = TEMP IN (8,38)*1
N=NST
ND=2
CALL PLOTINO(ND,A,N,M,FL,0)
WRITE(6,350)
350 FORMAT(1H1,5X) 'WEIGHTED AVERAGE ALL TEMP IN BAY (DEG C)*/5X,
1*2 = WEIGHTED AVG. OF ALL TEMP AROUND ROME PT (DEG C/10,1)*/'
25X,'3 = AVERAGE UP VELOCITY IN WEST PASSAGE IN YDS/SEC,
3/5X,'4 = AVERAGE UP VELOCITY IN OUTFALL AREA BOXS
4/5X,'5 = AVERAGE VP VELOCITY IN OUTFALL AREA/5X,
5/6X,'7 = AVERAGE TEMP IN BAY (DEG C)*100,'1
6 ROME PT AREAIDEG C*100.1)
ND=3
N=NST
N=8
FL=NST
DO 340 N=1,NST
M=NST+N
N2=2*NST+N
N3=3*NST+N
N4=4*NST+N
N5=5*NST+N
N6=6*NST+N
N7=7*NST+N
AIN1=N
AIN2=ZID(N)
AIN3=ZIF(N)/10.
AIN4=LE(E(N)
AIN5=AA(N)
AIN6=B(N)
AIN7=ZID(INST#10.
AIN8=ZID(INST#100.
N=NST
CALL PLOTINO(ND,A,N,M,FL,0)
C BB=TBAY THEN TGB
C AA=HTOT THEN HTGE
C ZID = AVERAGE HT IN EACH BOXMAIN), ZIE= VELOCITY AT MOUTH OF
C WEST PASSAGE (YPHFHT)
C NOTE THAT AAIN(N) IS DIVIDED BY 100=3
C NOTE THAT ZIE(N) IS DIVIDED BY 100.
400 CONTINUE
600 AST=MIST
IF(TBNOD.EQ.1,1) TANB=0.00001
RETURN
END
SUBROUTINE ANALYZE(MAXST, NTERM, AT, NST, ZIF)

COMMON SE(21,48), SEP(21,48), VI(21,48), VP(21,48), UI(21,48), UP(21,48)

1 11(21,48), HBD(85), HBE(105), HBDI(43), HBDI(43), HI(21,48)

2 A(21,48), F2(21,48), E(21,48), HI(21,48), E(21,48), HBE(21,48)

3 A(21,48), ARG(21,48), ARG(21,48), H(21,48), H(21,48), E(21,48)

4 ZIA(0175), ZIB(0175), ZIC(0175), UVACG(21,48), UVACG(21,48), ZIE(0175)

5 COSMT(61), ASINMT(63), CN(21,48), CN(21,48), CN(21,48)

6 IF IE(0175), HS(0175), J(0175), AA(0175), BB(0175)

DIMENSION XIA(0175), ALINE(65), ZIF(11)

DATA BLANK, DPT, STAN, */*,**,**/

NSTEP=1803./AT

DO 10 K=1,61

10 ALINE(K)=BLANK

C

T=0.

IF (MAXST.GT.175) MAXST=175

DO 30 N=1,MAXST,NSTEP

S=0.

DO 20 J=1,17

20 S=F2(J)*Z(11)*COS(W(11)*T+AR(J))*S

XIA(N)=S

T=T+1.0

Z=0.

DO 40 N=1,MAXST,NSTEP

IIFSABS(ZIA(N)).GT.ZA) ZABS(ZIA(N))

40 IIFSABS(ZIA(N)).GT.ZB) ZABS(XIA(N))

ZS=Z

WRITE(6,45)

WRITE(6,46)

DO 80 N=MAXST,NSTEP

ALINE(J)=DPT

J=31.+ZIA(N)/ZS)*30.

JS=31.+XIA(N)/ZS)*30.

ALINE(JM)=STAR

ALINE(JS)=DPT

WRITE(6,50) N,ZIA(N),XIA(N),ALINE(J),J=1,61

ALINE(JM)=BLANK

ALINE(JS)=BLANK

60 CONTINUE

C

T=0.0

DO 90 N=1,MAXST,NSTEP

S=0.0

DO 80 J=1,17

80 S=F2(1)*HB1*IDT+AR(J))*S

XIA(N)=S

90 T=T+1.0

Z=0.

DO 100 J=1,MAXST,NSTEP

100 IIFSABS(ZIA(N)).GT.ZA) ZABS(ZIA(N))

IIFSABS(XIA(N)).GT.ZA) ZABS(XIA(N))

00001000

00001100

00001200

00001300

00001400

00001500

00001600

00001700

00001800

00001900

00002000

00002100

00002200

00002300

00002400

00002500

00002600

00002700

00002800

00002900

00003000

00003100

00003200

00003300

00003400

00003500

00003600

00003700

00003800

00003900

00004000

00004100

00004200

00004300

00004400

00004500

00004600

00004700

00004800

00004900

00005000

00005100

00005200

00005300

00005400

00005500

00005600

00005700

00005800

00005900

00006000
C 110 CONTINUE
   IF (T .eq. 0.0).
   DO 150 N = 1, MAXST, NSTEP
      SP = 0.0
      DO 140 J = 1, 17
         140 SP = SP * FZ(N) + HP(N) * COS(NI(N)) * T + ARGP(I) * SP
                        XI(N) = SP
      150 T = T + 1.0
   END
   ZA = 0.0
   DO 160 J = 1, MAXST, NSTEP
      IF (ABS(ZIC(N)) .gt. ZA) ZA = ABS(ZIC(N))
      160 Z = ZA
   WRITE (6, 40)
   WRITE (6, 40) N, XI(N), AL(N), J, 61
   AL(N) = BLANK
   C 170 CONTINUE
   C 45 FORMAT (1H1, 12X, *MODEL(1)*, 4X, *SERIES(J)*, 10X, *WATER LEVEL AT*), 00000000
   46 FORMAT (5X, *NEWPORT*/)
   48 FORMAT (5X, *PROVIDENCE*/)
   60 FORMAT (5X, *BRISTOL*/)
   50 FORMAT (5X, 45X, ZF0.2, 3X, XI(N), *1+61AL*, *M*)
   RETURN
END

IEB816 MEMBER NAME (AANLCE ) FOUND IN NP DIRECTORY. TTR IS NOW ALTERED.
IEB816 HIGHEST CONDITION CODE WAS 00000000
IEB819 END OF JOB IE8UPDATE.
LEVEL 20.1 (AUG 71) US/360 FORTRAN H

COMPILER OPTIONS - NAME= #AIN CP#02, LINESMT=60, SIZE=6000K
SOURCE= EBCDIC, NULIST, NODEC, ISAD, MAP, NODEC, NTOD, NOREF

ISN 0002
DIMENSION A(I+8),B(I+8),C(I+8),D(I+8),E(I+8),F(I+8),G(I+8),H(I+8)
1K0N4RT[2],11H[21],NPRIN[72001],DAVG[80],AH0[648],M11[10] 20NS110.1, HS110,55110, Z1F101751, NPI110, Z1P101751, Z1G101751

ISN 0003
COMMON SE[21,48],SEP[21,48],V[21,48],VP[21,48],U[21,48],UP[21,48],UC0011400
1 C[21,48],ND[183],MD[183],NBD[41],NBD[41],H[21,48]
2 W2[201],F2[201],E2[201],H2[201],EP2[201],MB2[201],EB2[201]
3 ARN2[201],ARG2[201],ARG2[201],ML2[201],EL2[201]
4 ZIA1[0175],ZIO1[0175],Z1C1[0175],ZIAV[21,48],ZAVG[21,48],Z1E[0175]
5 AC08NT[210],AS1NT[210],CX[21,48],CMN[21,48]
6 IF1[21,48],HS1[0175],S1Z1[0175],A1[0175],BB1[0175]

ISN 0004
LOGICAL READIN, DOSAL, RCNP, DELAT

ISN 0005
DATA YR, DAY, HR, TMN /57, 195, 17, 48/ 00002400
DATA MDURC, MDURC /1, 1/ 00002500

ISN 0006
DATA AL, AG, SALIR, TMOPR, TRTHK, TSOUND /10, 7, 10, 7, 32, 5, 21, 75

ISN 0007
DATA HNV, HENV, PV, CNMN, WX, WY, COKAG, CRMO /0, 0, 3, 14, 19, 27
1, 0, 5, 0, 0, 0025, 0, 0114/

SET EXECUTION PARAMETERS

IMODES = 1 UPSTREAM DIFFERENCING
IMODES = 2 CENTRAL DIFFERENCING
SIMODES = 3 UPSTREAM DIFFERENCING

ISN 0009
IMODES = 2

ISN 0100
PL1PUNCH=540

ISN 0111
AT = 120.

ISN 0112
EXTRA3=AT 00003000

ISN 0113
IPRMND WILL SPECIFY TIME THAT VARIABLES ARE DISPLAYED

ISN 0114
IPRMND=15

ISN 0115
IL0=1

SET M0DES REQUIRED FOR DISPLAYS

ISN 0115
SUM1G=0.0

ISN 0116
SUM1D=0.0

ISN 0117
SUM1F=0.0

ISN 0118
SUM1H=0.0

ISN 0119
SUM1K=0.0

ISN 0120
SUM1L=0.0

ISN 0121
MAX=540

ISN 0122
NM= MAX+1

ISN 0123
I0Y=1

ISN 0124
HS1DD0Y) = 2000.0

ISN 0125
RCNP=FALSE

SET RCNP FOR READING IN PREVIOUS VALUES OF CNP

ISN 0026
READIN=TRUE

ISN 0027
DOSS=TRUE

ISN 0028
IRMS=1000

ISN 0029
IMODEL = 1

SET COMPUTATION PARAMETERS

ISN 0030
H/RCP\=FALSE

ISN 0031
US/360 FORTRAN H

DATE 73.156/04.43.34

244
IF DELTAT IS TRUE MODEL WILL CALCULATE TEMPERATURE ABOVE AMBIENT

DELTAT = TRUE.
TIN = 21.0

2873
TIN = 2875

2875
CONTINUE

DIFFUSION CONSTANT IS UPCON
FOR UPCON = 500 THE ORDER OF MAGNITUDE OF HIGHEST DIFFUSION COEFFICIENT IS ABOUT 350 YD SQ/SEC

UPCON = 050.
POWER PLANT
TIN = 0.0 YOU WILL HAVE HYDRODYNAMICS OF POWER PLANT SITE BUT NO THERMAL LOAD ON BAY
IF EFFECTS OF POWER PLANT ARE DESIRED SET TIN EQUAL TO 12.

TIN = 12.

SITE SELECTION. SEE HEATING FOR DETAILS ON LOCATIONS
SITE = 100.

LNL = 0
ARH0 = 27.091400
SALRIS = 0.000100
TSOUND = 0.000100

NMIX = 19
MMAX = 48

ANGLAT = 41.6
NI = 1

NBOI11 = 0103042
NBOI23 = 4860691
NBOI31 = 5111131
NBOI11 = 1923242

NBOI23 = 0410112
NBOI31 = 4810050
NBOI31 = 3000003

NSECT = 00
87 CONTINUE

ART = ANGLAT * 3.1415927 / 180.

FF = 0.691527 * SIN ( ART ) / 21600.

2080
N SI = 0

C 2T IS FOR CFT TO CYRDS CONVERSION AND 2 IS FOR DISPLAYING
ACTUAL CROSSFECIONAL FLOW EK FOR RIVER

C6 = 1.940110 + 0.000841 * SARIS - 0.000120 * TSOUND

C7 = 0.000059

C8 = 1.940110 + 0.000841 * SARIS - 0.000120 * TSOUND

C9 = 0.000059

C10 = 1.940110 + 0.000841 * SARIS - 0.000120 * TSOUND

C11 = 0.000059
GRIZN2=AGR2D
GRDN1=GRDN1+GRIZN2

USED ONLY IF NO SE VALUES ARE READ IN

DO 2 M=1.L
ISE=DEP*HIN,M
DEPS=DEPS+SQRT(HIN,M)
DIM=M
1M=1M-1.
CNI,M,J=TNBN
CNP,J,M,J=TNBN
SEP,HJ,M=SEINV*(1.-DIM/M)*HINV
2 SEIN,M= SEINV*(1.-DIM/M)*HINV
NUM=NUM+1
GO TO T

GO TO T
CONTINUE
CN J1,1) = TANB
CNP61,1) = TANB
CPN64,1) = TANB
CN (19,23) = TANB
CNP(J9,23) = TANB
CNI,9) = TANB
CNP(j9,48) = TANB
CN (109,48) = TANB
CNP90,48) = TANB
CN 90,48) = TANB
CNP90,48) = TANB
CN 90,48) = TANB
CNP90,48) = TANB
CNP109,48) = TANB
CN 109,48) = TANB
CNP109,48) = TANB
CN 109,48) = TANB
CNP109,48) = TANB
CNP109,48) = TANB
CNP109,48) = TANB
CNP109,48) = TANB
UPE=3.*DEP/GRI
DEPS=DEPS/GRIDNI
DEPS*3*DEP**2)
NA=1
9 IF(INA.EQ.MIN) GO TO 31
NA=N=HOB/DINAI/1000
NBNT =HOB/DINAI/1000 -H100
NTOP =HOB/DINAI/10 -H1000 -HOB*100
DIN =HOB/NTOP
DIM=M
1M=1M-1.
SEP,HJ,M=SEINV*(1.-DIM/M)*HINV
32 SEIN,M= SEINV*(1.-DIM/M)*HINV
NA=NA+1
GO TO 5

31 NA=1
33 IF(NA.EQ.MIN01) GO TO 34
NA=N=HOB/DINAI/100000
NLEF =HOB/DINAI/100000 -H10000
N=HOB/NTOP
DIM=M
1M=1M-1.
NA=NA+1
GO TO 5

34 NA=1
35 IF(NA.EQ.MIN02) GO TO 34

SEP(N,M1) = SEINV•LL-M1/46+HINV
NA = NA+1
SU TO 33
ISN 0191
C
34 CONTINUE
C
ISN 0192
C
CALL INVAL(NMAX,NNMAX,GRIDM1,DEP,DEPSW,READIN,ROCMTX,DAYG)
C
ISN 0193
C
CALL HEAT(KN5,MS,SS,TIN,NZ,SITE,NINPUT,QIN)
C
ISN 0194
WRITE(6,2050) NS5,MS5
C
ISN 0195
2050 FORMAT(5X,5X,NS5 = 'I4, MS5 = 'I4)
C
ISN 0196
40 ISTEP = 2
C
ISN 0197
C
CALL PRINT(ISTEP,NST,NPRINT,K,NMAX,IP,HTAT,HA,BH,
IHE,H+SAVE,(PUNCH)
C
ISN 0198
88 ISTEP = 1
ISN 0199
NST = NST + 1
ISN 0200
K = 2 NST - 1
ISN 0201
2001 IF (NST.GT.MAXST) GO TO 501
C
ISN 0202
SFT OPEN BOUNDS
C
ISN 0203
CALL OPENB(OINST,IMODES,EXTRAL,KWRITE,K,KRT,MODEL,T1,T2,T4,T5,
INTERM,C5,TRIVER,TMOP,E,T1,T2,T4,T5,P1,TMA,FCHECK,AT,T,SAL,QIN)
C
ISN 0204
COMPUTE UP AND SEP Cm RCW N (FIRST HALI TIMESTEP)
C
ISN 0205
CALL UPHIT(X,WY,CS1,C2,C4,AT,AG,NIND,P,N1)
C
ISN 0206
COMPUTE VP Cm COLUMN M (FIRST HALI TIMESTEP)
C
ISN 0207
CALL VPMLHC(T2,C5,CS,AT,DOSAL,IMODES,MSOURC,MSOURC,C13,
C10,C7,C8,C9,C14,C1,MIND,F,NI,NST,NPRINT,IP,IBNB,KRT,NMAX,NNMAX
200,PT,DAY,THR,TMH,HTOT,HA,BH,HE,HC,SAVE,NS,MS,SS
301,N1,NZ,NW,UPCON,YAR1,DELTAT,NINPUT,ZIG)
C
ISN 0208
CALL PRINT(ISTEP,NST,NPRINT,K,NMAX,NNMAX,IP,HTAT,TA,BH,
IHE,H+SAVE,(PUNCH)
CALL OPENBDINST(INST,IMODES,EXTRAL,KWRITE,K,XRT,I,MODE1,T1,T2,T4,T5, 
INTDIM,C1,TRIVER,TMOPE,T5MOND,P1,TMA,FCHECK,K,AT,TS,AL,QIN) 00295000
C
**...........................................................................**
C ISN 0209
C IF(NXT<0.0) GO TO 2020 00299000
C ISN 0210 2010 IF(INST=LT,901) GO TO 2020 00299100
C ISN 0211 GO TO 2020 00299200
C ISN 0213 ISN 0211
C 2040 WRITE(16,2039) NXT,NL,CNP(5,361),QIN,TNS(11),MS(1),NE,
INPUT,SLT1,JAINST1,ZIINST1,ZIINST1,ZIINST1,ZIINST1,ZIINST1 00299500
C ZAINST1,INDT1,SITE,NS151,MS(5),NST 
C ISN 0215 2030 FORMAT(1X,'NSTEP=',I4,' CNP(5,361)=',E12.4,
C QIN(1)=',E12.4,' TIN=',E12.4,' NS=',I4,' MS=',I4, 00299600
C 1E12.4,' ZIINST1=',E12.4,' ZIINST1=',E12.4,' ZIINST1=',E12.4,
C SITE=',E12.4,' NS=',I4,' MS=',I4) 00299700
C ISN 0216 2020 CONTINUE 00299800
C
C ISN 0217 299 ISTEP=2 00300000
C ISN 0218 K=2*NST 00300100
C ISN 0219 COMPUTE VP AND SEP ON COLUMN M [SECOND HALF TIMESTEP] 
C ISN 0220 CALL VPMSHT(INX,WY,C61,CZ1,C41,AT,AG,NS,R1,N1) 00300200
C ISN 0221 CALL UPMSHT(INX+WY,C61+C21+C41,AT,AG,N1,N2) 00300300
C ISN 0222 SUM=0.0 00300400
C ISN 0223 GRID1 = 0.0 00300500
C ISN 0224 SUM=0.0 00300600
C ISN 0225 BAY AREA 00300700
C ISN 0226 NUM=1 00300800
C ISN 0227 IF(NUM.EQ.NIND) GO TO 36 00300900
C ISN 0228 NSrch=NBD(NUM)/100000 00301000
C ISN 0229 MF =NBD(NUM)/100000-NSrch100 00301100
C ISN 0230 L =NBD(NUM)-NSrch100000-N110000-MF100 00301200
C ISN 0231 MN=1 00301300
C ISN 0232 NGRID = L-MF1 00301400
C ISN 0233 GRIDNZ=GRID1 00301500
C ISN 0234 GRIDNZ=GRIDNZ 00301600
C ISN 0235 DO 22 M=MF1 00301700
C ISN 0236 MM=M-1 00301800
C ISN 0237 SUM=0 00301900
C ISN 0238 SUM=SUM+SUMT 00302000
C ISN 0239 143.0 00302100
C ISN 0240 SUM=SUM+SUMT 00302200
ISN 0241 22 CONTINUE
ISN 0242 NUM+NUM=1
ISN 0243 GO TO 17
ISN 0244 36 SUMZIG=SUMZIG+GRIDT3 + SUMZIG
ISN 0245 C CONSTANT SHOULD EQUAL [AL*(2)*0.09+ENS*0.9/3]
ISN 0246 CONSTA=1.00
ISN 0247 SUMZ +CONSTA+SUMZIG = SUMZIG
ISN 0248 IF(MONINST,IPRIND).EQ.0) GO TO 45
ISN 0249 GO TO 41
ISN 0250 IPRNZ=IPRIND
ISN 0251 IF(DTDELTA) GO TO 47
ISN 0252 IPRNZ=IPRIND*10000
ISN 0253 47 ZIOD(I0)=SUMZIG/IPRIND
ISN 0254 ZIOD(I0)=SUMZIG/IPRIND
ISN 0255 SUMZIG=0.0
ISN 0256 SUMZID=0.0
ISN 0257 CONTINUE
ISN 0258 SUM=0.0
ISN 0259 SUML=0.0
ISN 0260 NUM=1
ISN 0261 GRIDT3=0.0
ISN 0262 NTPL(I)= NBDI(I)
ISN 0263 NTP2(I)= NBD2(I)
ISN 0264 NTP3(I)= NBD3(I)
ISN 0265 NTP4(I)= NBD4(I)
ISN 0266 NTP5(I)= NBD5(I)
ISN 0267 NTP6(I)= NBD6(I)
C C POWER PLANT AREA
ISN 0268 300 IPRNZ=NUM.EQ.0.0) GO TO 310
ISN 0270 NRCH=NTPL(NUM)/1.000000
ISN 0271 N=NTPL(NUM)/1.000000-NRCH*100
ISN 0272 MF=NTPL(NUM)/1.000000-M*100
ISN 0273 L=NTPL(NUM)-NRCH*1000000-M*100
ISN 0274 IF(MF.LT.32) MF=32
ISN 0275 IF(LT.GT.42) L=42
ISN 0276 NN=I
ISN 0277 MF=NN+L
ISN 0278 NF=NN+L
ISN 0279 GRIDT3+GRIDT4+GRIDT5
ISN 0280 N=330+MF
ISN 0281 MM=I
ISN 0282 SUM=CNPL(N,M)+25*(HSN,N)+MM+NM+NM+NM+NM
ISN 0283 I=CNPL(N,M)+25*(HSN,N)+MM+NM+NM+NM+NM
ISN 0284 SUMTPT =CNPL(N,M)+25*(HSN,N)+MM+NM+NM+NM+NM+NM+NM+MM+SEP(N,M)
ISN 0285 I=SUM=SUM+SUMTPT
ISN 0286 330 SUM=SUM+SUMTPT
ISN 0287 SUMZIF=CONSTASUMZIM
ISN 0288 SUMZIG=SUMZIG+SUMZIF
ISN 0289 IP(NONINST,IPRIND).EQ.0) GO TO 65
ISN 0290 GO TO 70
ISN 0291 65 IPRNZ=IPRIND
ISN 0292 IP(DTDELTA) GO TO 67
ISN 0293 IPRNZ=IPRIND*10000
ISN 0294 67 ZIOD(I0)=SUMZIF/IPRIND
ISN 0295 ZIOD(I0)=SUMZIF/IPRIND
ISN 0296 SUMZIF=0.0
ISN 0297 SUMZIF=0.0
ISN 0298 SUMZIF=0.0
ISN 0299 SUMZIF=0.0
SUM1 = 0.0
70 CONTINUE
SUM = SUM + 1
GO TO 310
C
C VELCITY COMPONENTS IN OUTFALL AREA
C
SUM = 0.0
SUM1 = 0.0
NZ = 1
INS = INS + 1
NS = NS + 1
C
C CHANGE 5 TO NS(2) AND 36 TO NS(1) WHEN YOU RUN POWER PLANT
C
SUM = SUM + SUM1
SUM1 = SUM + SUM1
C
C SUM = 0.0, SUM = NS + NS1
C
NZ = NS
C
C SUM = SUM / ANZ
C
SUM1 = SUM1 / ANZ
C
SUMAA = SUMAA + SUMAA
C
C SUM = SUM + SUMAA
C
SU = SUM / ANZ
C
C CAND 5 TO NS(1) AND 36 TO MS(1) WHEN YOU RUN POWER PLANT
C
SUMAA = SUMAA + SUMAA
SUMA = SUMAA + SUMAA
SUMAB = SUMAA + SUMAA
C
C IF MOD(INST, IPRIND) EQ 0 GO TO 75
C
GO TO 80
C
C VELCITY IN WEST PASSAGE
C
SUM = SUM + SUMAA
SUM1 = SUM1 + SUMAA
C
C IF MOD(INST, IPRIND) EQ 0 GO TO 75
C
GO TO 80
C
C END OF MAIN COMPUTATIONAL SCHEME
C
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