LARSA

# IMPACT OF AN OFFSHORE HATCHERY DISCHARGE ON PHOSPHORUS CONCENTRATIONS IN AND AROUND HAWKINS BAY, LAKE CHAMPLAIN

1986 MAR 20 A 8:20
EC-WR & EE

FOR THE

STATE OF VERMONT

Department of Fish and Wildlife

William W. Walker, Ph.D

Jeffrey P. Laible, Ph.D

Emmet M. Owens, P.E.

and

Steven W. Effler, Ph.D

March 13, 1986

5

TABLE OF CONTENTS


| CHAPTER | | PAGE |
|---|---|---|
| | SUMMARY | i |
| I | INTRODUCTION | 1 |
| II | DIFFUSER DESIGN AND PERFORMANCE | 5 |
| III | MODELING OF CIRCULATION IN AND AROUND HAWKINS BAY | 15 |
| IV | MODEL PROJECTIONS OF THE IMPACT OF THE HATCHERY ON PHOSPHORUS CONCENTRATIONS IN HAWKINS BAY | 32 |
| V | PHOSPHORUS LOADING TO LAKE CHAMPLAIN | 73 |
| | APPENDICES | |

## SUMMARY

This report analyzes the impacts of the proposed Lake Champlain Fish Hatchery on phosphorus concentrations in Hawkins Bay and adjacent areas of the lake. A previous report prepared by the Vermont Department of Water Resources focused on evaluation of a shoreline discharge, but gave preliminary indications that an offshore discharge would provide greater initial dilution for the effluent and thereby reduce localized impacts on phosphorus levels and algal growth. This report expands upon the evaluation of the offshore discharge alternative using a refined model which directly considers the effects of wind-induced currents. The sensitivities of hatchery impacts to discharge concentration, location, climatologic variations, and key model parameters are evaluated.

The Vermont Department of Water Resources has suggested that the impacts of the hatchery be limited to a 5 ppb increase in ambient phosphorus concentration during the critical August and September period, when mixing rates in Hawkins Bay are relatively low and when climatologic conditions are conducive to algal growth. It has been projected by the Vermont Department of Fish and Wildlife that, under conditions of full fish production, the hatchery effluent will contain 182 ppb of phosphorus at a flow rate of 11.5 million gallons/day during August and September. Modeling results indicate that an offshore discharge of this magnitude would cause less than 5ppb increase in the mean phosphorus concentration of the immediate discharge zone (scale of 40 acres) and less than a 3 ppb increase in the mean

concentration of Hawkins Bay (scale of 1850 acres east of Thompson's Point) under average flow and wind conditions for August and September.

Because of flushing rate considerations, it is unlikely that phosphorus increases in the immediate discharge zone (40 acres) would be fully expressed in terms of proportionate increases in algal densities and proportionate decreases in transparency. Increases in aglal densities and reductions in transparency would be more directly related to changes in bay-mean phosphorus concentrations. The associated reductions in mean transparency will be difficult to detect in the context of normal seasonal variability observed in this region of Lake Champlain (2 to 8 meters).

Hydrodynamic model simulations indicate it may be feasible to shorten the previously proposed 3000 ft outfall while, at the same time, reducing impacts on phosphorus concentrations within the immediate discharge zone. However, additional field data (current measurements) and analysis would be required to support this decision. The outfall design should include a multi-port diffuser to maximize dilution rates in the immediate discharge zone and thereby prevent the relatively cold, dense discharge from sinking into the bottom waters of the lake.

# I. INTRODUCTION

The proposed Lake Champlain Fish Hatchery would discharge treated wastewater, associated with the production of fish, to Lake Champlain. Phosphorus has been identified as the constituent of greatest concern with regards to the water quality of the lake (Smeltzer, 1985). "Preliminary water quality modeling work (Smeltzer, 1984) indicated that the possibility existed for the hatchery discharge to cause a eutrophication problem in the lake, depending on the phosphorus concentration in the discharge and the turbulent diffusion characteristics of the lake" (Smeltzer, 1985, p. 1). The focus of the analysis of the potential impact of this operation has been on the region of the lake proximate to the discharge (Figure I-1). The studies to date have shown "that the threshold level for significant impact on the bay (Hawkins Bay) is an increase of 5 ppb in the ambient levels of phosphorus in the bay" (Nov, 1985). Such an increase is expected to lead to a reduction in clarity (e.g. Secchi disc) of approximately 0.5m (Nov, 1985). The increase of 5 ppb in total phosphorus has been accepted here as a criterion for the hatchery discharge.

Smeltzer (1985) utilized a transport model (S2D; Walker, 1985) to evaluate the potential environmental impact of various phosphous levels in the hatchery effluent on the nearby region of the lake (e.g. Figure I-1). The mathematical model (Walker, 1985) is designed to simulate the transport and decay of water quality components in a two-dimensional grid. Both advective and diffusive transport can be accommodated by the model. However, transport was described soley by diffusion in Smeltzer's (1985)

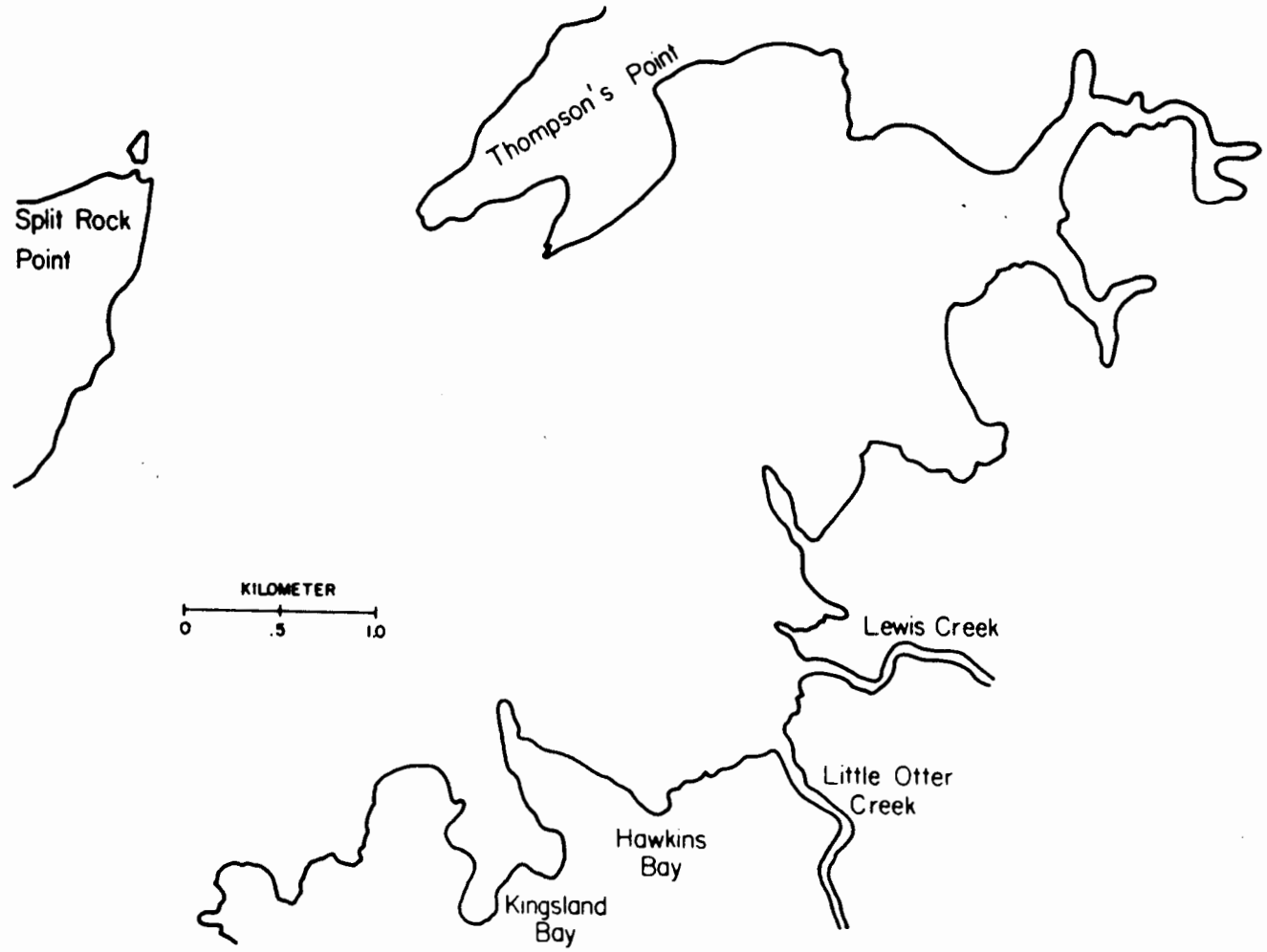



Figure I-1. Study Area

effort, as "it was anticipated that diffusive transport would dominate over advection for the large spatial scale studied" (p.44). Smeltzer's (1985) analysis focused on evaluation of a shoreline discharge, but gave preliminary indications that an offshore discharge would provide greater inital dilution for the effluent and thereby reduced localized impacts on phosphorus levels and algal growth. A subsequent report (UFI, 1985) documented some benefits of a multi-port diffuser configuration in enhancing dilution in the "near field" of the hatchery discharge.

The analysis presented herein expands upon the evaluation of the offshore discharge alternative. The primary objectives are to identify offshore discharge locations that will minimize impact, and to determine the effluent phosphorus concentration which is consistent with a maximum increase of 5 ppb in average phosphorus concentration during the critical (Smeltzer, 1985) August - September period. The analysis employs the same model (Walker, 1985), spatial grid, and data bases employed by Smeltzer (1985). The modeling approach utilized here differs in that independent estimates of advective transport in and around Hawkins Bay, as driven by wind and through-flow from south to north, are derived from a separate hydrodynamic modeling effort and used in the calibration of, and subsequent simulations with, the two-dimensional transport model. Also presented in this report are: 1) the estimated yearly loading of phosphorus anticipated from the hatchery from the perspective of the total load presently received by the entire lake, and 2) additional

aspects of diffuser design and performance as it relates to the impact of the hatchery. The order of the presentaton will progress from the near field (diffuser considerations) to Hawkins Bay and adjoining areas (advection and two-dimensional transport modeling), and finally to lake-wide considerations (phosphorus budget).

## II. DIFFUSER DESIGN AND PERFORMANCE

An earlier effort (UFI, 1985) described the basic principles and types of multiport diffusers, and presented preliminary staged diffuser designs capable of meeting the 5 ppb criterion in the near-field of the discharge with adequate ambient mixing. The following material expands that analysis, and addresses selected aspects of diffuser performance related to the impact of the hatchery discharge.

### A. "Tee" (Unidirectional) Diffuser Designs

Four different "tee" diffuser designs are presented in Table II-1, which represent alternatives to the previously presented (UFI, 1985) staged diffuser designs. These are presented to increase the existing range of design configurations considered adequate to meet the mixing needs of the hatchery effluent in the immediate area of the discharge (near-field). The designs are estimated to be capable of achieving the desired near-field dilution for a discharge concentration of 182 ppb. A wide range of conservatism is incorporated in the designs. The "tee" diffuser designs of Table II-1 give approximately the same dilutions as the four alternate staged diffuser designs presented previously (UFI, 1985; Table 1).

### B. Temperature and Bouyancy of Hatchery Discharge

Temperature (ie. density) differences will exist between the hatchery discharge and the epilimnion of the lake (Figure II-1 (UFI, 1985)); in particular, the hatchery discharge will be substantially colder (ie. more dense) than the receiving water during the months of July, August, and September. Thus, during the later summer months there will be a tendency for the

TABLE II-1 : PRELIMINARY UNIDIRECTIONAL OR "TEE" DIFFUSER DESIGNS

| | A | B | C | D |
|---|---|---|---|---|
| Total Pipe Length, ft. | 2320 | 1040 | 660 | 520 |
| Outfall Pipe Dia., in. | 24 | 24 | 24 | 24 |
| Manifold Length, (Lo), ft. | 520 | 240 | 160 | 120 |
| Water Depth (H), ft. | 26 | 12 | 8 | 6 |
| No. of Ports (N) | 13 | 12 | 8 | 6 |
| Port Diameter, in. | 3 | 3 | 3 | 3 |
| Bottom Slope (θ), ft./ft. | .02 | .01 | .01 | .01 |
| Near-Field Dilution (S) | 103 | 50 | 40 | 35 |

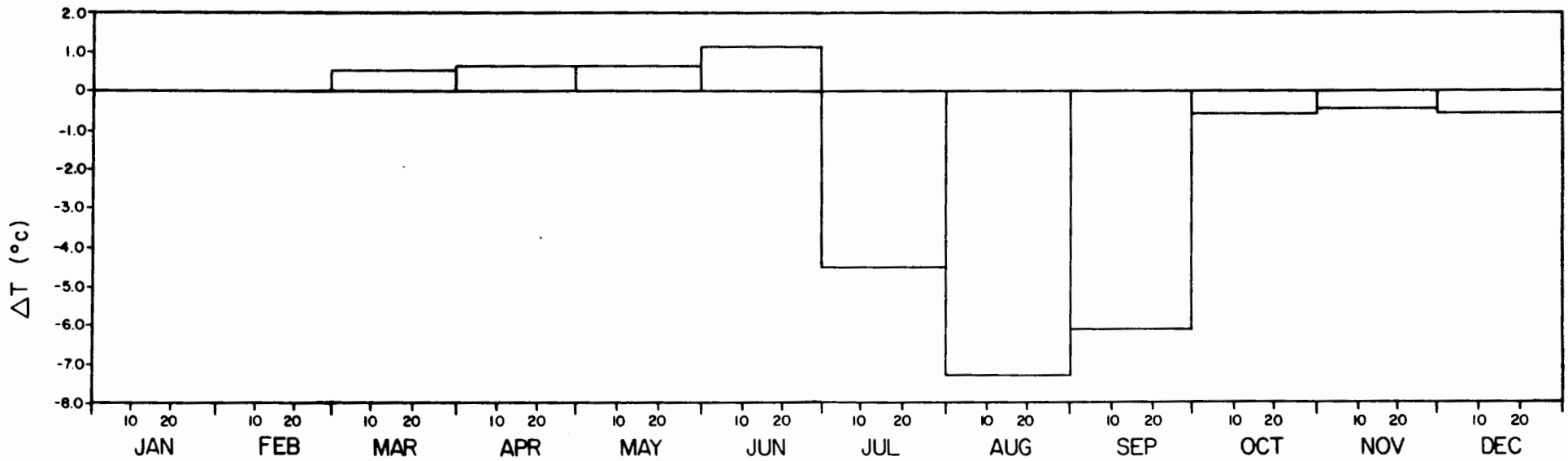



Figure II-1. Expected temperature differences between the hatchery discharge and Hawkins Bay (ΔT = hatchery temp. - Hawkins Bay temp.; Richardson, 1985).

discharge to plunge (ie. underflow), if it is not rapidly diluted.

The tendency to create stratified flow conditions in the immediate vicinity of the discharge, for the "no-diffuser" case, can be evaluated using the densimetric Froude number Fd, which describes the relative importance of inertial and bouyant forces. Fd is defined as

$$F_d = \frac{\frac{\Delta\rho}{\rho} gh}{u} \qquad \text{(II-1)}$$

where: $\Delta\rho$ = density difference between the discharge and receiving water,

$\rho$ = reference (receiving water) density,

g = acceleration due to gravity,

h = length of scale, and

u = velocity scale.

Generally, if Fd>1 then buoyant forces predominate over inertial (flow) forces, and stratified flow conditions may occur. For a 30 inch outfall pipe discharging at 17.8 cfs (ie. u = 3.63 ft $s^{-1}$, h = 2.5 ft), and $\frac{\Delta\rho}{\rho} = 1.4X10^{-3}$ (for the worst case (August, see Figure II-1), 7.3 °C temperature difference), Fd would equal approximately 0.1. Thus it is unlikely that stratified flow (eg. plunging) would occur in the immediate vicinity of the discharge at this flow rate. Some mixing with ambient waters would therefore occur even without a diffuser. However, plunging would probably occur downstream of the discharge, as the velocity would likely be reduced more quickly than $\rho$ (see equation II-1).

The tendency to create stratified conditons (ie. plunging) in a diffuser plume can be evaluated by an expression developed

by Jirka (1982). A diffuser plume will remain unstratified (ie. no plunging) if

$$\frac{M_o}{p_o^{2/3} \cdot H} > 0.52 \qquad \text{(II-2)}$$

where: $M = u^2 B$

$u$ = diffuser discharge velocity

$B = \frac{\pi}{4} \frac{D^2}{\ell}$

$D$ = port diameter

$l$ = port spacing

$p = u\ Bg'$

$g' = \frac{\Delta\rho}{\rho} g$

$H$ = depth of water, ft.

Use of alternative D of the preliminary staged diffuser designs (UFI, 1985; Table 1; ie. $u = 7.18$ ft $s^{-1}$, $D = 0.25$ ft., $l = 20$ ft., $\frac{\Delta\rho}{\rho} = 1.4 \times 10^{-2}$, $B = 0.98$ ft., $H = 20$ ft., $Mo = 50.5$ ft $s^{-1}$, $p = 1.41 \times 10^{-2}$ ft s ) would assure that plunging would not occur, as $\frac{M_o}{p_o^{2/3} H} = 43.3 > 0.52$.

The dramatic reduction in temperature differences between the discharge and the receiving (epilimnetic) waters that would be achieved in the near field for design D of the staged diffuser, particularly during the late summer months, is shown in Figure II-2. The maximum temperature difference would be 0.24 C, during the month of August. Other benefits of a diffuser configuration on the hatchery discharge, besides the elimination of the tendency for the effluent to plunge, include : 1) dilution of the discharge in a small area, 2) momentum away from shore and

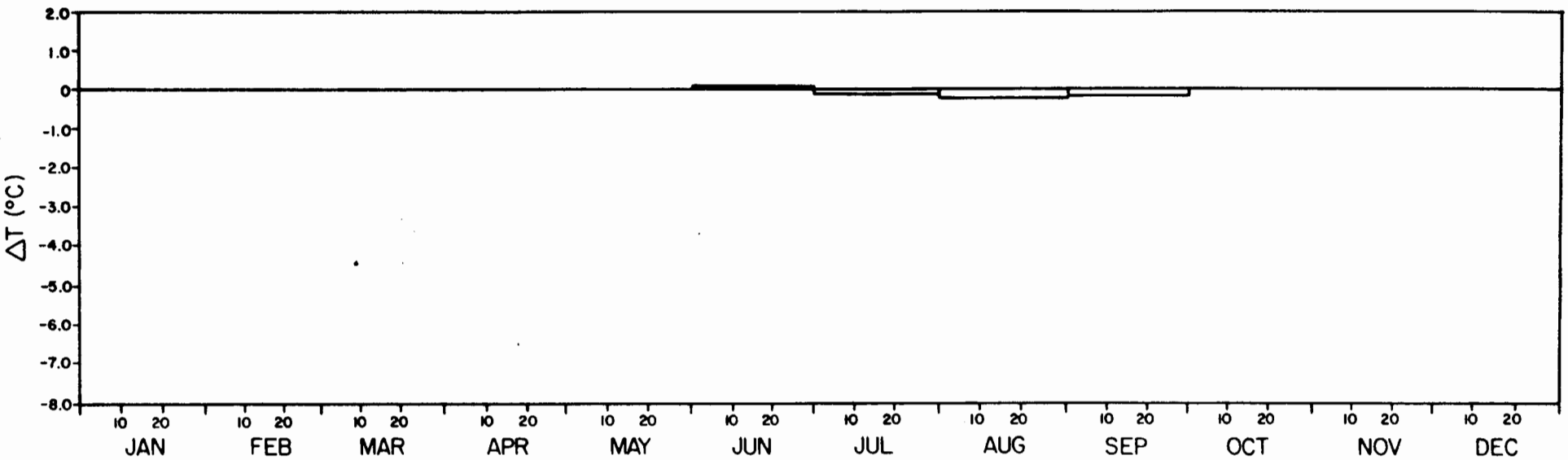



Figure II-2. Expected temperature differences between the hatchery discharge and Hawkins Bay (ΔT = harchery temp. - Hawkins Bay temp.; Richardson, 1985) with stage diffuser.

toward the main lake , and 3) minimization of areas of high concentration (i.e. size of mixing zone) of discharged materials.

C. Contours of Phosphorus for Staged Diffuser Performance

Predictions of the phosphorus concentration field around a staged diffuser (alternate D; UFI,1985),for the idealized condition of quiescence, were made using theory presented by Jirka (1982). Discharge conditions of 17.8 cfs and a phosphorus concentration of 175 ppb were used. Ambient water (i.e. background phosphorus concentration) was assumed to be available for dilution. The predicted phosphorus concentration field is presented as increases above the ambient, in Figure II-3. The maximum predicted increase in concentration is 8.5 ppb, located at a point approximately 100 ft. out from the end of the diffuser. The areas over which selected integer increases in the concentration of total phosphorus would be exceeded for this case (as per Figure II-3) are presented in Table II-2. Under these ideal conditions a rather limited portion of the bay would be expected to experience increases of more than 4 ppb under these conditons.

Under turbulent ambient mixing conditions the impact of the diffuser in modifying the flow field of the bay will be limited to the near field (within approximately 100 ft of the staged diffuser manifold). The frequency of occurrence of quiescent conditions (i.e. greater impact on the flow field of the bay) cannot be determined without additonal field data. A diffuser will provide substantial initial dilution. However, natural transport processes must be relied upon to disperse and further dilute the hatchery wastewater in the bay and adjoining lake.

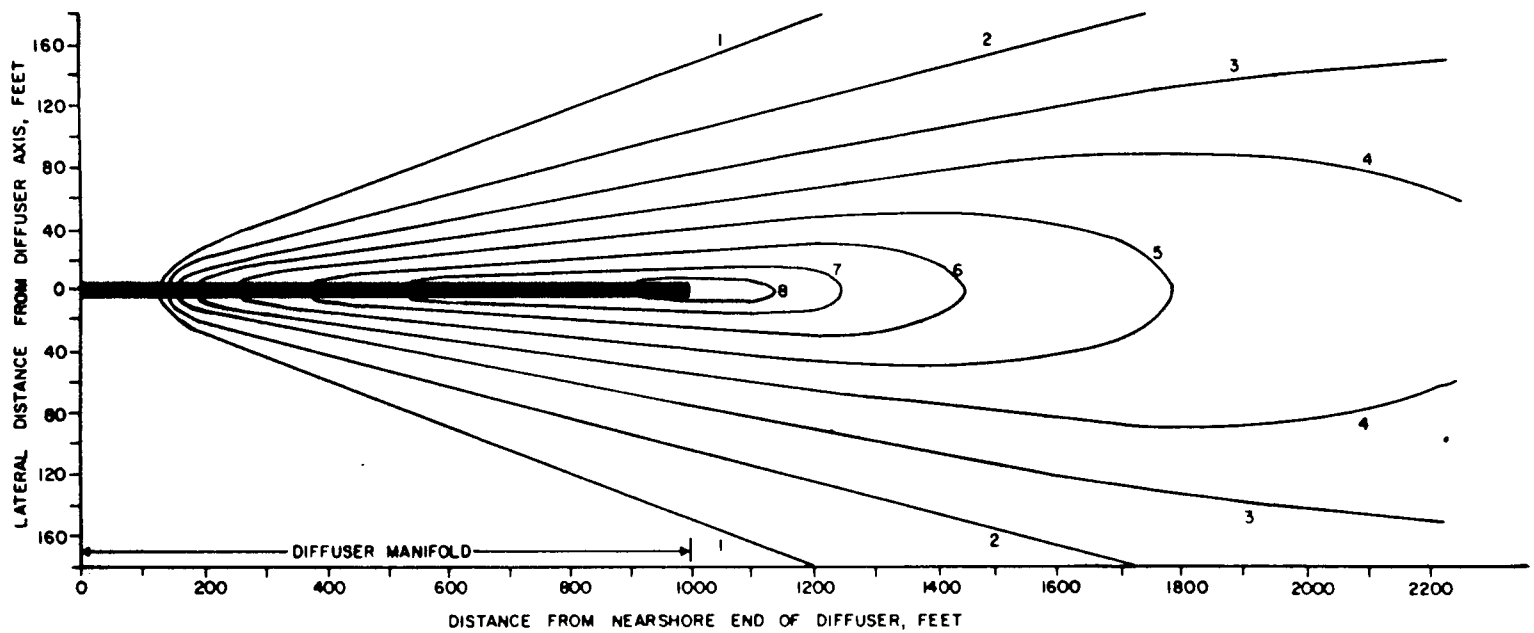



Figure II-3. Concentrations (ppb) above ambient for staged diffuser alternate D (UFI, 1985; Table 1) for quiescent ambient. Discharge rate = 17.8 cfs, concentration = 182 mg/ℓ. Ambient concentration = 12 mg/ℓ.

TABLE II-2: Regionalization of Phosphorus Concentrations Around Hatchery Discharge, Under Quiescent Conditions, Staged Diffuser Alternate D (UFI, 1985).

| Concentration Increase Above Ambient | Area Over Which Concentration Would Be Exceeded (acres) |
|---|---|
| 8 | 0.1 |
| 7 | 0.4 |
| 6 | 1.0 |
| 5 | 1.9 |
| 4 | 6.0 |

Subsequent chapters address the extent to which adequate ambient mixing exists in the Hawkins Bay area to achieve specified dilution goals.

## III. MODELING OF CIRCULATION IN AND AROUND HAWKINS BAY

### A. Background

There are generally two components of pollutant transport in a natural water body, namely advective and diffusive transport. Advective transport may be defined as that due to the average, large-scale motion of the water body, while diffusive transport is brought about by small-scale turbulent fluctuations from the average conditions. The previous transport modeling efforts for the hatchery discharge essentially "lumped" the cumulative effects of advective and diffusive transport into a diffusive type process. In the present work, the individual effects of diffusion and advection are assessed. The time averaged, large-scale motion of water in Hawkins Bay due to wind and south-to-north lake through-flow were assessed using a mathematical model. The flow fields produced by the model were then used in the transport model, allowing a more realistic description of the individual effects of advection and diffusion.

The following sections provide a brief overview of the theory upon which the circulation model is based, its application to the Hawkins Bay area, and some of the salient results. A more detailed review of the circulation model and its application in this study is given in the Appendices.

### B. Overview of Model Theory

As in many mathematical models of fluid flow, the analysis of currents in Hawkins Bay and adjacent areas of Lake Champlain is based on the equations for conservation of mass and momentum. In arriving at the specific equations used, two major simplifying assumptions were made. First, it was assumed that the wind

conditions during the critical summer months could be represented by an average wind speed, wind direction, and lake through-flow. Thus, a steady-state formulation was used. Second, it was assumed (and supported by field data) that Lake Champlain is thermally stratified during the portions of the year of interest in the transport analysis. Thus, the major wind-driven currents will be restricted to a relatively shallow surface layer, and the vertical component of lake currents will be relatively small. With these simplifications, the governing equations are in a form in which they can be solved by a variety of methods. Because the equations must be solved over the irregularly shaped geometry of the bay and lake, the equations are particularly well suited to solution by the finite-element method.

C. Methodology

The area of the lake to be modeled (Figure III-1) was broken up into a number of polygons, in this case triangles (Figure III-2). The triangles themselves are the finite elements, and the points at which the sides of the triangles intersect are termed nodes. The finite element mesh (Figure III-2) consisted of 197 nodes and 328 elements. The finer mesh in the Hawkins Bay region is necessary due to the sharper velocity gradients in this region. The water depth at each node must be specified; in the present case a maximum water depth equal to the depth of the thermocline (10 m) was used. If the water depth at a node is less than the maximum, the actual depth was used. The finite element model (FEM) computes the current speed and direction at each node. These properties vary continuously over

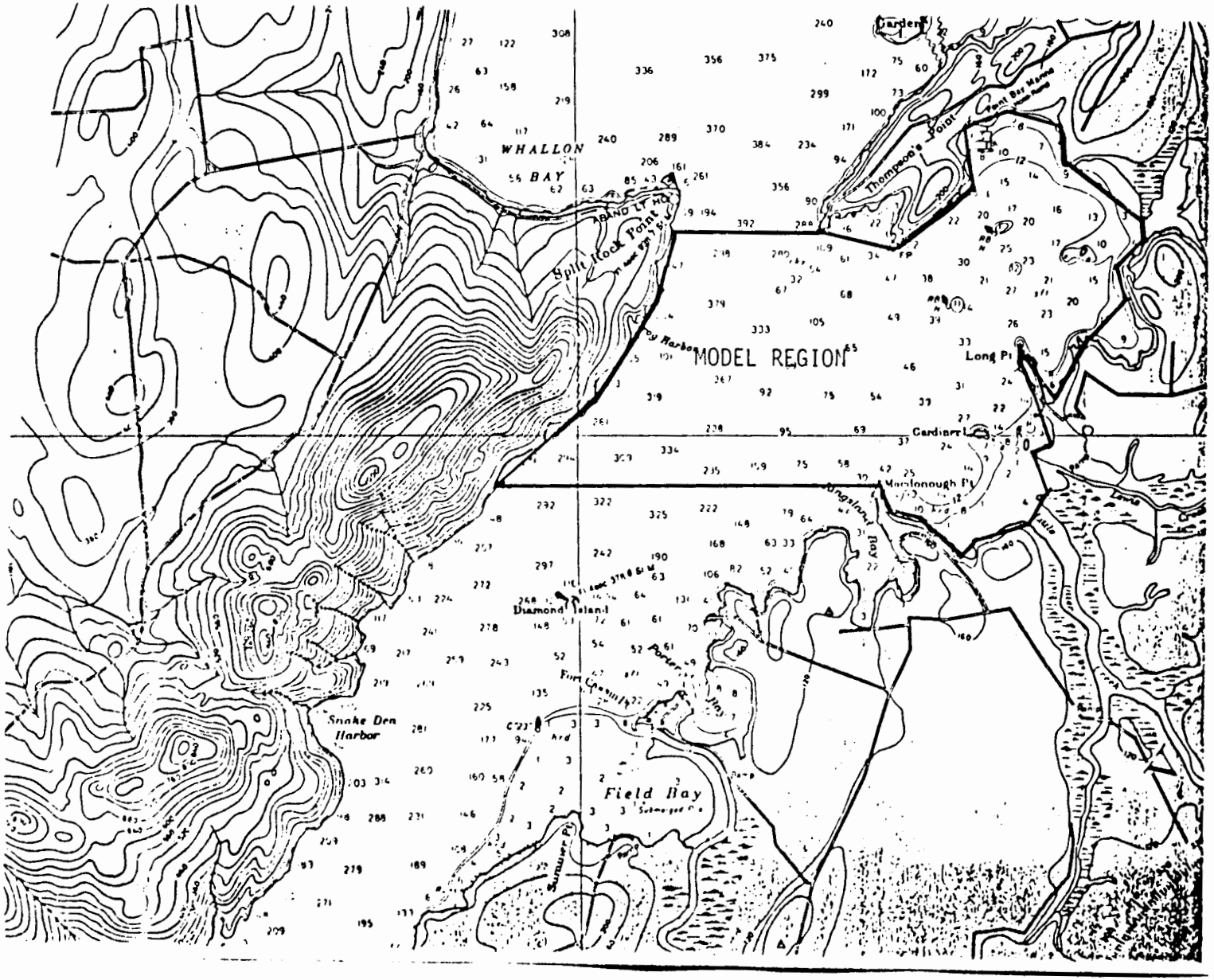



Figure III-1. *Lake Champlain - Hawkins Bay Region : Model Region.*

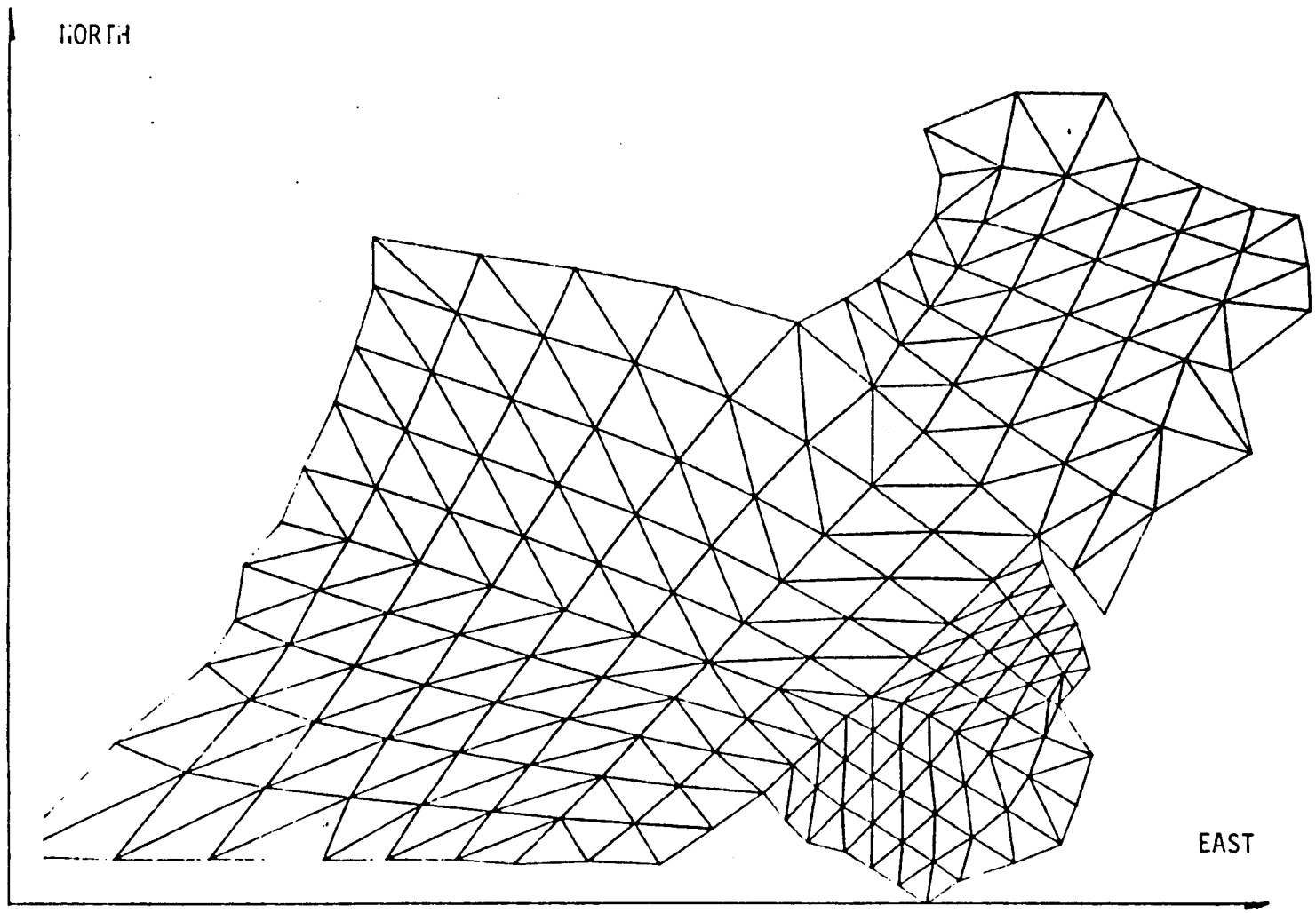



**Figure III-2.** *Finite Element Mesh : 197 Nodes , 328 Elements.*

depth from the water surface to the lake bottom or thermocline. Of greatest importance for use in the transport model is the depth-averaged current speed and direction at each node.

A number of boundary conditions must be specified as a part of the solution. First, the currents at the lake bottom or at the thermocline are set equal to zero. This condition is applied through the specification of the shear stress imparted by the moving water on the lake bottom or thermocline. The shear stress imparted by the wind, at the water surface, is a function of its speed and direction; this, of course, is the driving force for wind-driven circulation. At the outer boundary of the lake area encompassed by the elements, the flow conditions must be specified. For those portions of this boundary coinciding with the lakeshore (see Figure III-2), is is assumed there is no flow crossing the boundary. The effects of tributaries flowing into the lake on its currents are thus neglected; a good assumption except during high runoff events. The flow corresponding to the average south-to-north hydrologic through-flow of was specified at the portions of the boundary crossing the open lake.

Ten different combinations of conditions were investigated using the circulation model. These cases are listed in Table III-1. Cases 1 through 6 represent conditions with no lake-through-flow, the same wind speed of 1 meter per second, and various wind directions. These conditions were analyzed to investigate the effect of various wind directions (only) on predicted currents. The wind conditions in Cases 7 and 9 are the average wind conditions that existed during the August- September

TABLE III-1

Conditions Analyzed with Circulation

| Case | Wind Direction degrees | Wind Speed m/s | Lake Through-Flow m3/s |
|---|---|---|---|
| 1 | 122 | 1.0 | 0 |
| 2 | 75 | 1.0 | 0 |
| 3 | 15 | 1.0 | 0 |
| 4 | 330 | 1.0 | 0 |
| 5 | 285 | 1.0 | 0 |
| 6 | 105 | 1.0 | 0 |
| 7 | 122 | 1.78 | 0 |
| 8 | 75 | 2.0 | 0 |
| 9 | 122 | 1.78 | 37 |
| 10 | 75 | 2.0 | 45 |

Wind from: West: direction = 0
North: direction = 270
East: direction = 180
South: direction = 90

1984 period of water quality monitoring on Hawkins Bay. These wind conditions were obtained by examining the Burlington Airport data for that period. Case 7 neglected lake through-flow while Case 9 included the estimated average through-flow for this two-month period. Cases 8 and 10 utilize the "prevailing wind" as determined from measurements at St. Albans Bay on Lake Champlain. Case 8 considered no lake through-flow while Case 10 included the estimated long-term average through-flow during August and September. Case 9 was designed to generate a flow field to be used in the transport model during its calibration for the August- September 1984 period. The flow fields for Case 10 were used in the transport model when projections of the concentration field resulting from the hatchery discharge were made.

The through-flow was computed using data from the U.S. Geological Survey Water-Data Reports. To obtain the estimates of the through-flow the Otter Creek gage at Middlebury was used. The drainage area above the Middlebury gage is 1626 $km^2$. The total drainage area into Lake Champlain below Thompson's point is 6257 $km^2$. Assuming a uniform drainage for all areas, the flows at the Middlebury gage are multiplied by (6257/1626) to approximate the anticipated through-flow. Flows for Little Otter Creek and Lewis Creek are orders of magnitude lower than the computed through-flow and can be neglected. Average monthly flows for June, July, August, and September for the years 1964 to 1984 were evaluated. For the 1984 field study period of August-September the average flow was approximately 37 $m^3/s$. For the prevailing wind load case the mean value of the flows for the August-September interval for the years 1964-1984 were used. If

all years are used the mean flow is 52 $m^3/s$. Since through-flow during this period is benificial to the transport of phosphorus out of Hawkins Bay, a more conservative estimate of the flow can be computed by excluding the unusually high run-off events of August-September 1976. Excluding 1976 data, the through-flow for the period August - September is computed to be 45 $m^3/s$. This flow was used with the prevailing wind load.

The current velocities obtained from the finite element analysis provide a point wise description of the flow field. The transport model used for this discharge study however was based on a cell model. The cell model required the specification of the flow on each face of a rectangular cell. The velocities obtained from the finite element analysis were integrated along cell boundaries to obtain the net inflow and outflow along each face. Figure III-3 illustrates the orientation of the rectangular grid mesh over the finite element mesh. Six regions were defined with cells numbered as shown in Figure III-3. Figure III-4 shows the region 1 circulation pattern and the vertically integrated flows on the cell faces from an example model run. These flows were then integrated along each cell face to obtain the net inflow and outflow in units of $m^3/sec$.

The inflow and outflow values for all cells is contained in the Appendices. The cases included are:

1) FLOWSWN Prevailing wind without through-flow
2) FLOWSEN Aug.-Sept. 1984 wind without through-flow
3) FLOWSWNF Prevailing wind with through-flow
4) FLOWSENF Aug.-Sept. 1984 wind with through-flow

A balance of flows was generally well achieved, but some imbalance exists in the cells near the shoreline. This can be

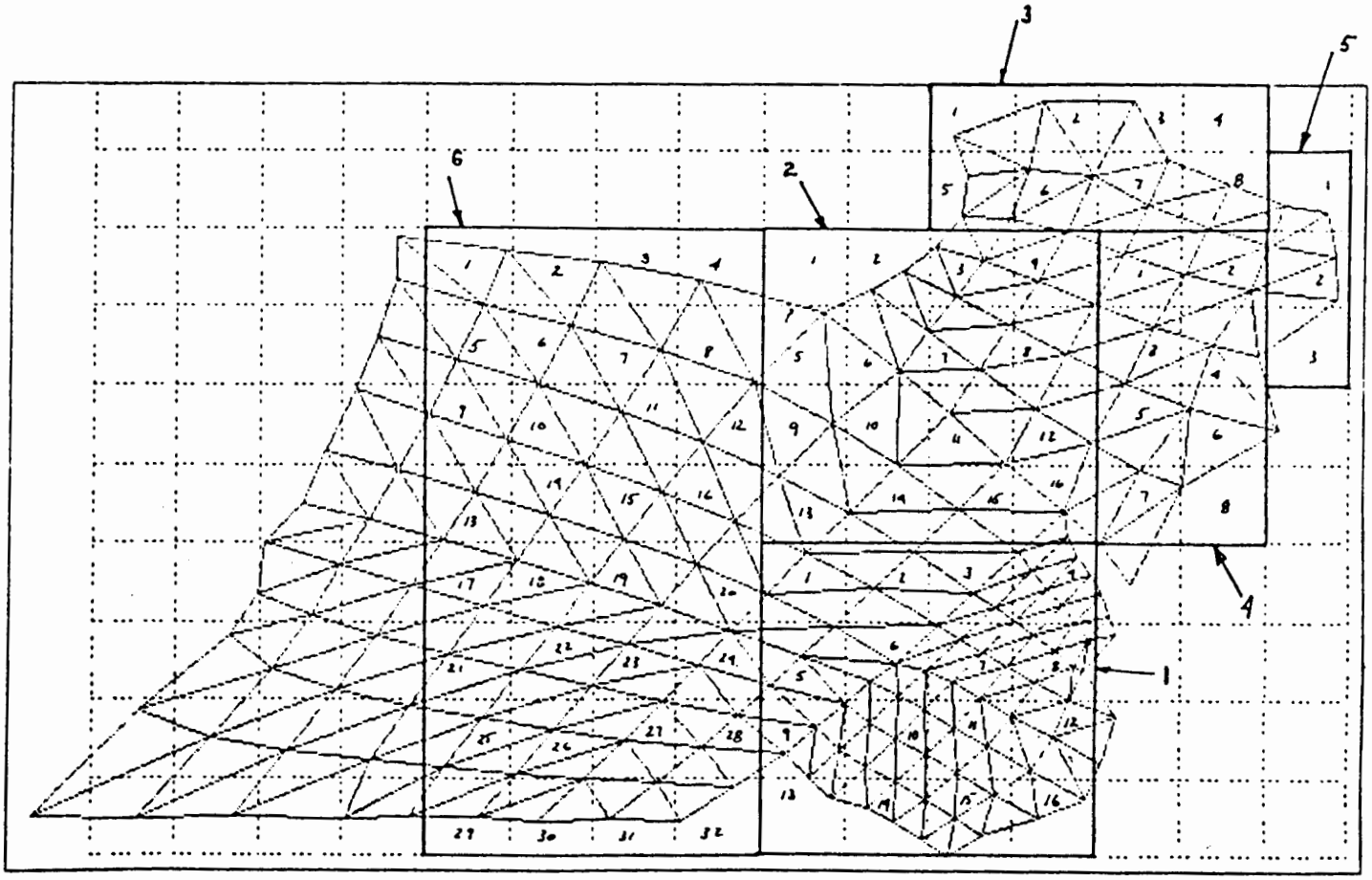



Figure III-3. *Finite Element Mesh and Transport Cell Regions .*

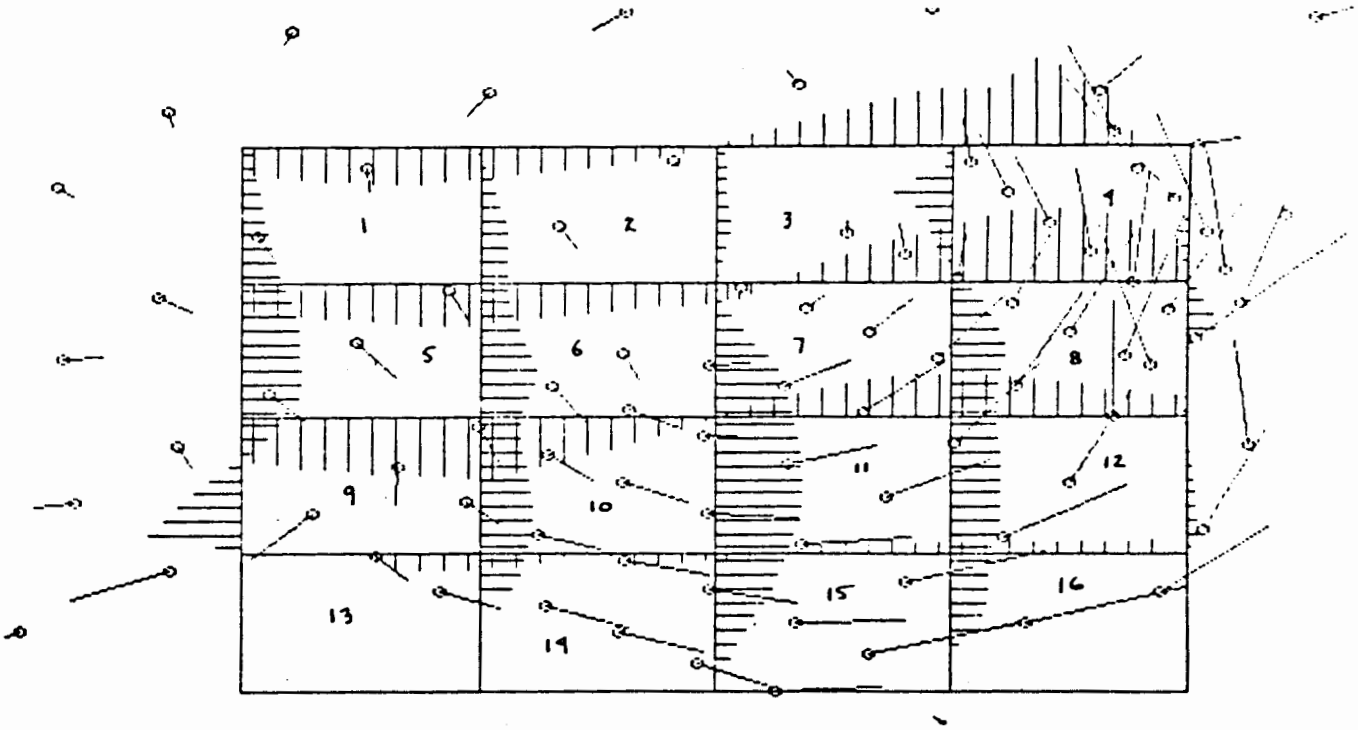



**Figure III-4.** *Nodal Velocities (F.E. Analysis) and Integrated flow for each cell face.*

attributed to numerical modeling approximations. The fact that continuity is satisfied exactly on a point wise basis does not enforce a satisfaction of continuity on a cell wise basis. These flows were balanced and then used in the transport cell model.

D. General Results

The general structures of the wind-induced (vertically averaged) currents generated by the six different wind directions (unit stress load) are presented in Figures III-5 through III-10. Current velocities for specified wind conditions (including speed) can be estimated from the unit load simulations. Two important features of current patterns in and around Hawkins Bay emerge from these analyses that apparently are prevalent, as they were observed over the range of wind directions analyzed. A gyre is predicted to occurr in Hawkins Bay, ie. an area of low current surrounded by a region of higher, rotating velocies. Greater dilution of the hatchery discharge can be achieved by positioning it in a region of higher velocity and away from the center of such gyres (eg. larger arrows in Figures III-5 through Figure III-10). The second important feature is the prediction of outflow from the bay area, northeast of the gyre. Even for the north wind the flows are tangent to the Hawkins Bay boundary, and gradually sweep out into the main lake.

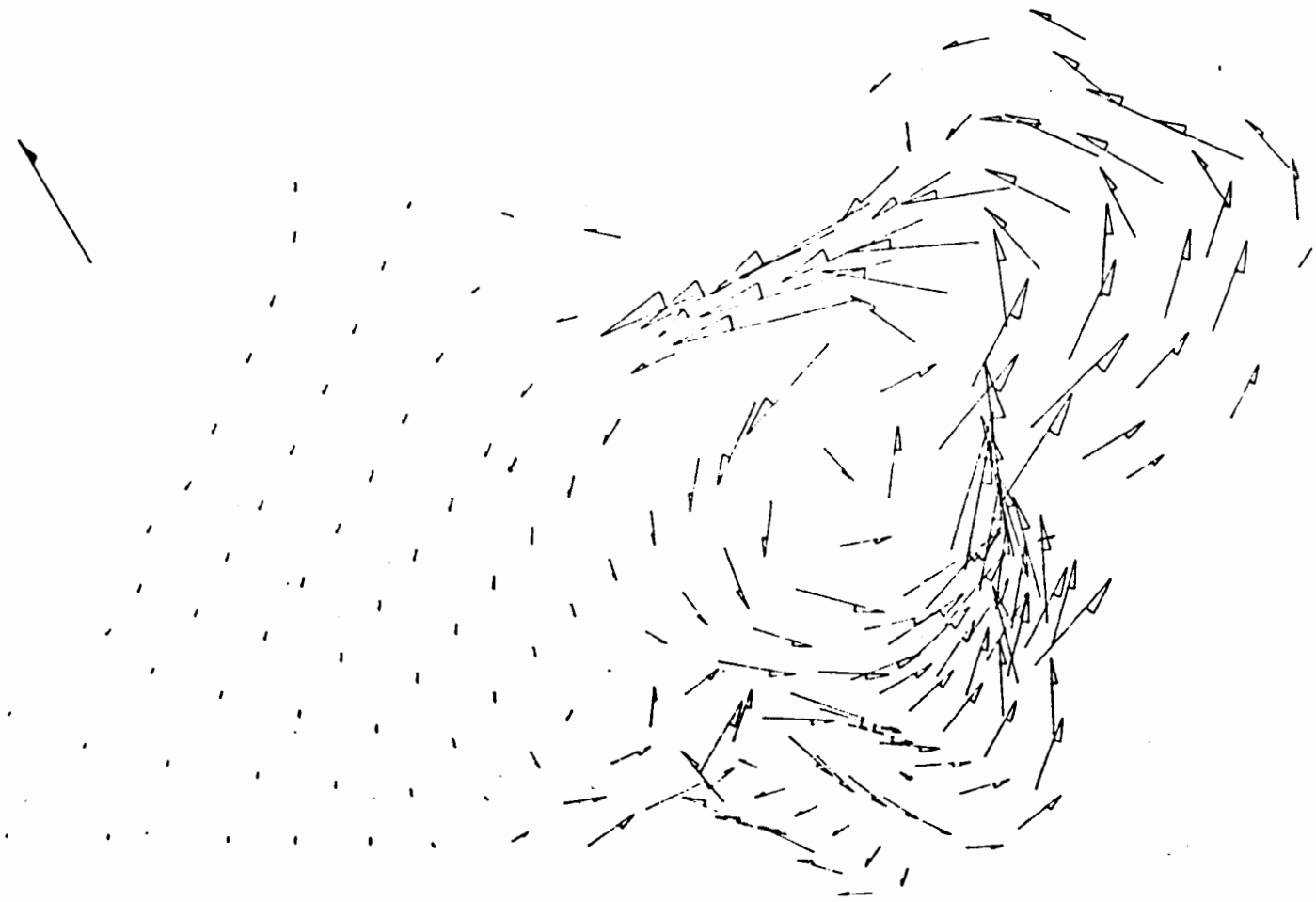


**Figure III-5.** *Circulation Pattern for Wind Load Case 1. SE Bearing.*

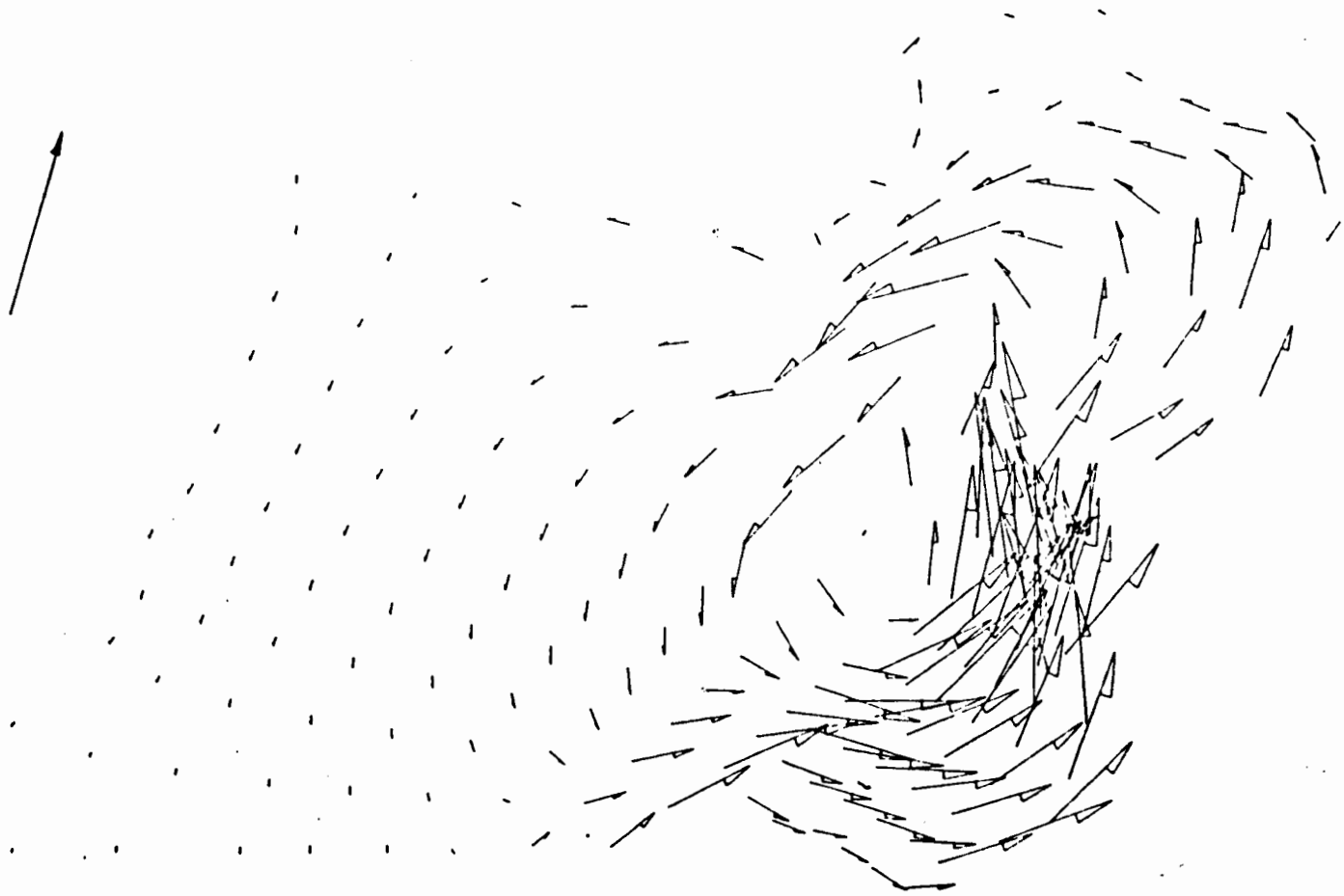


Figure III-6. *Circulation Pattern for Wind Load Case 2. SSW Bearing.*

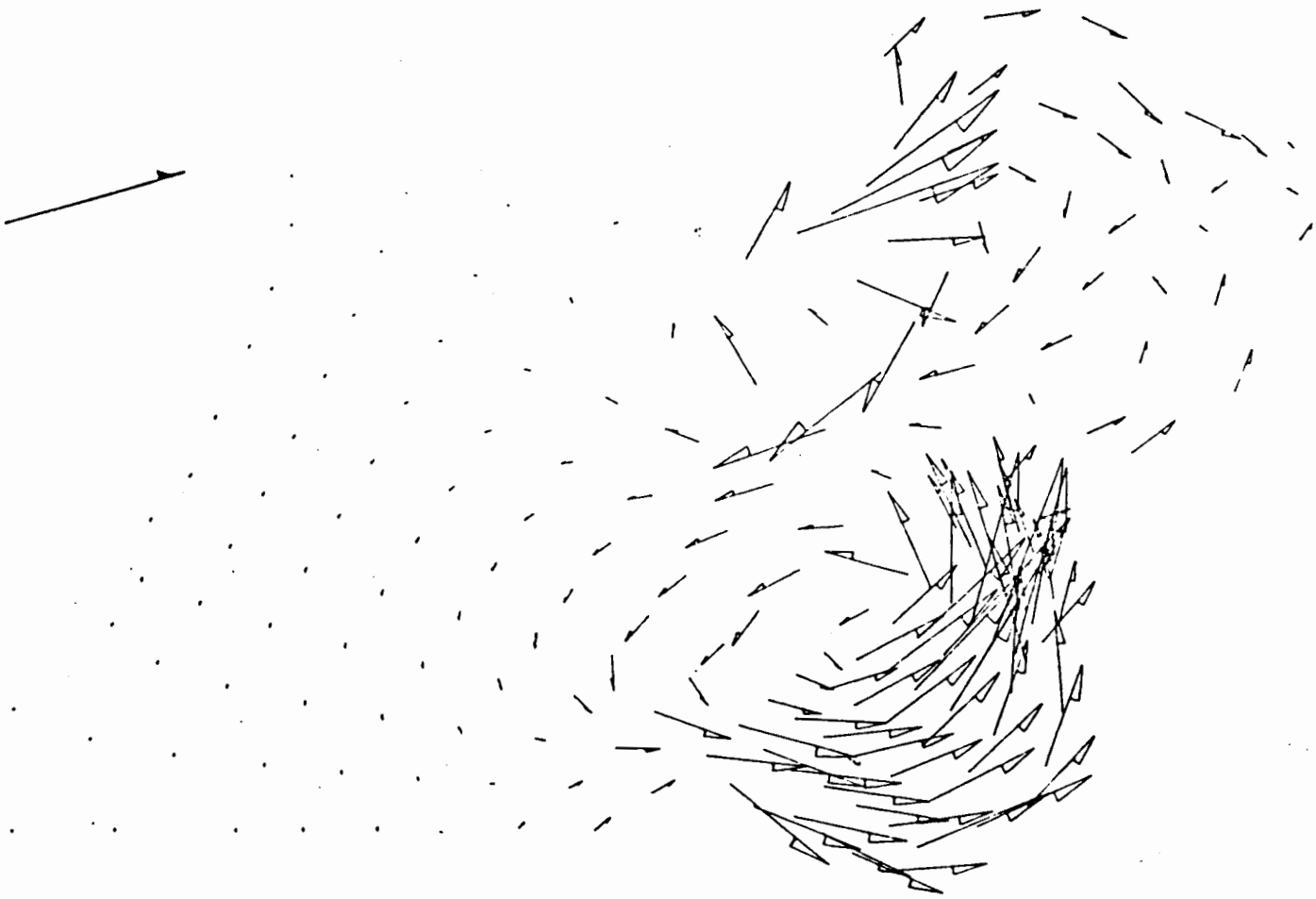


**Figure III-7.** *Circulation Pattern for Wind Load Case 3. W Bearing.*

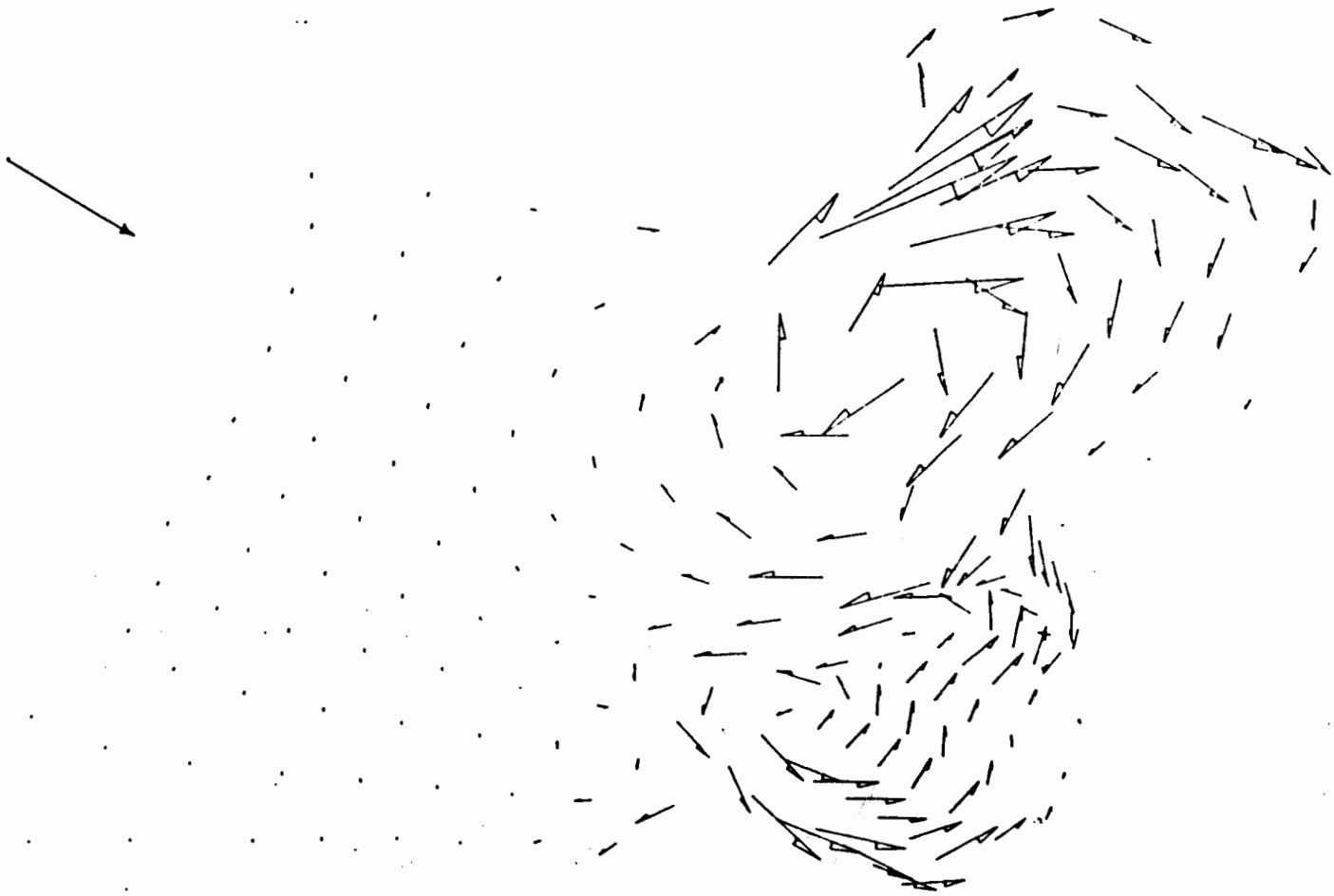


Figure III-8. *Circulation Pattern for Wind Load Case 4 . NW Bearing.*

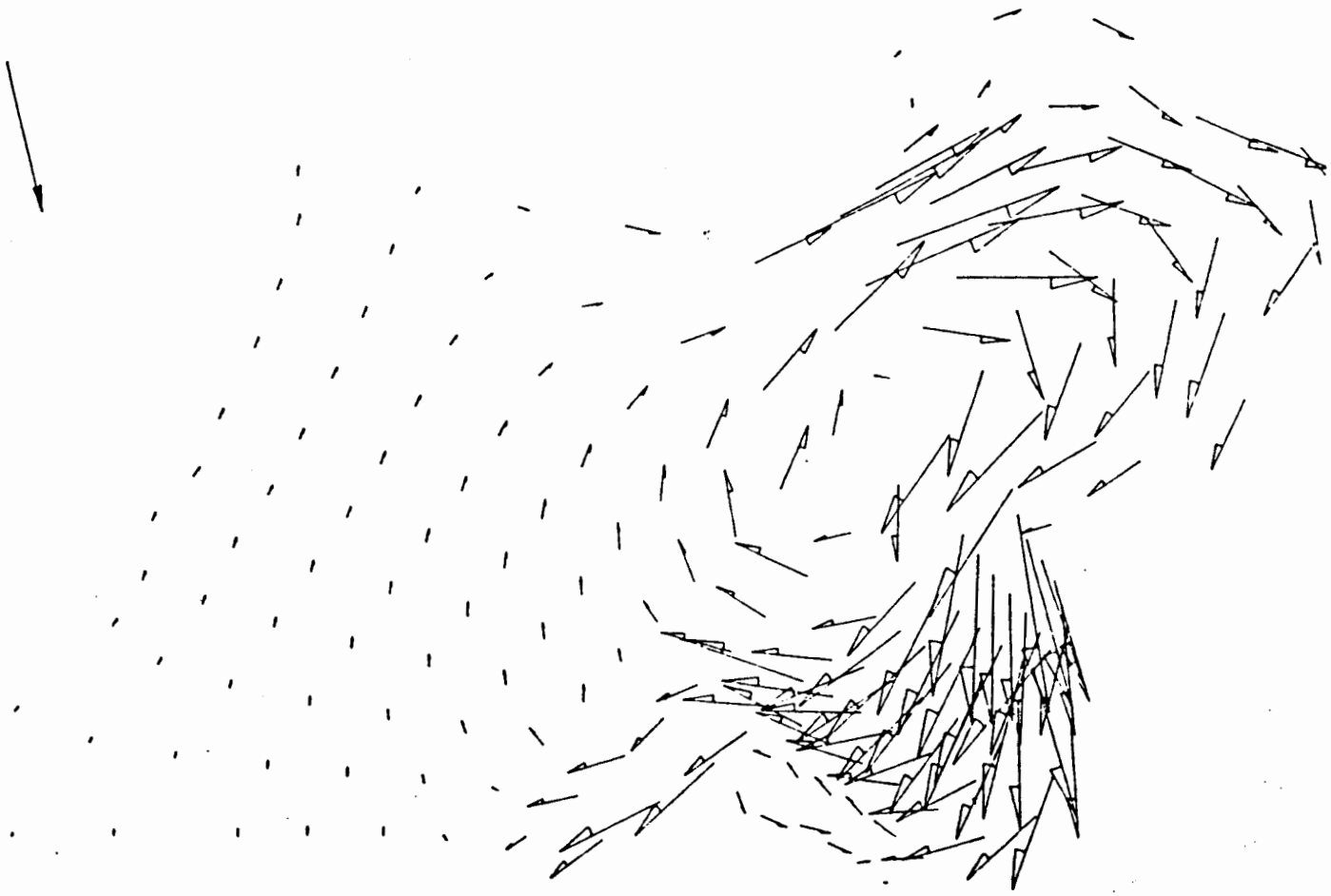


**Figure III-9.** *Circulation Pattern for Wind Load Case 5 . N Bearing.*

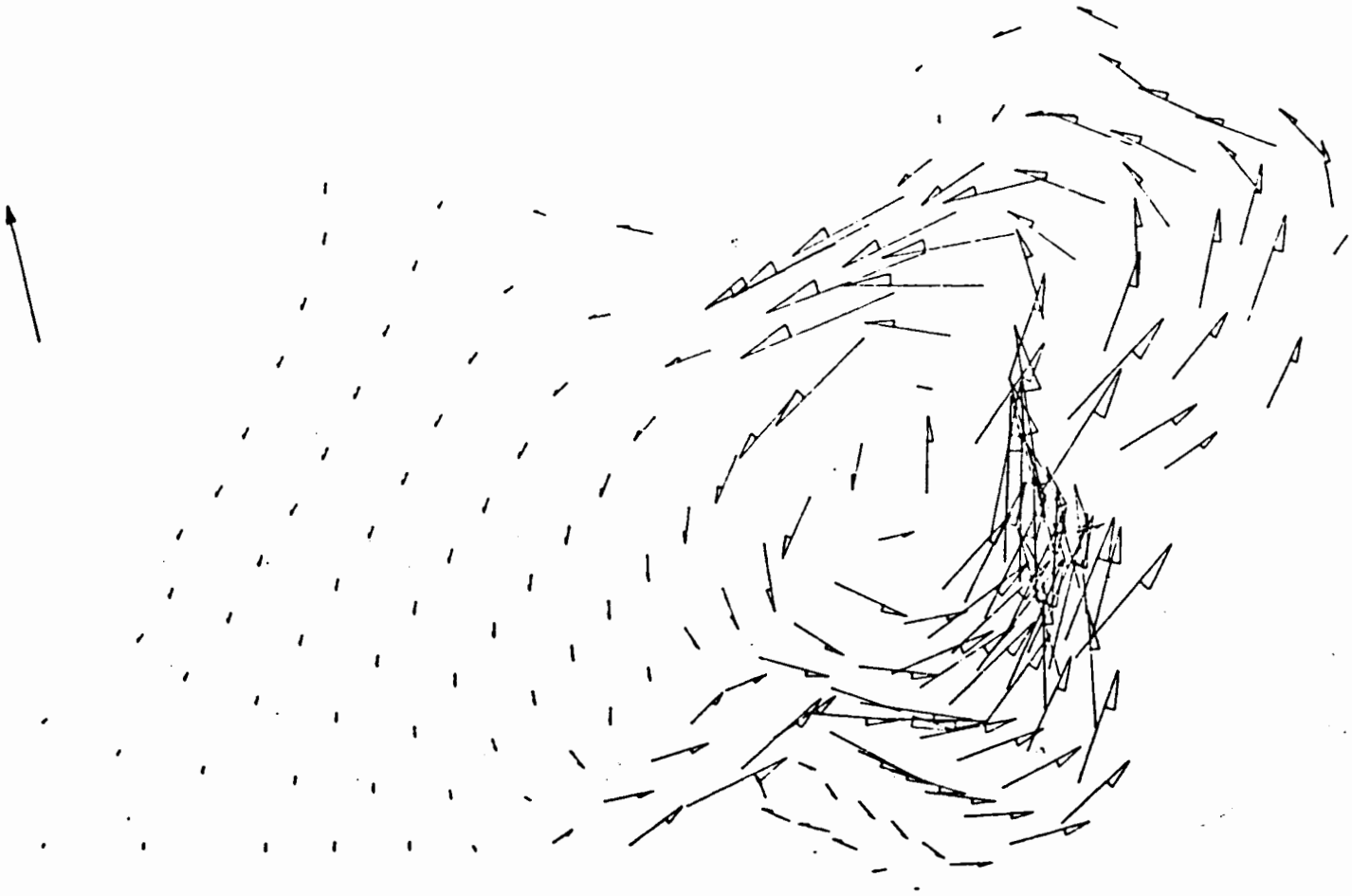


Figure III-10. *Circulation Pattern for Wind Load Case 6. S Bearing.*

## IV. MODEL PROJECTIONS OF THE IMPACT OF THE HATCHERY ON CONCENTRATIONS IN HAWKINS BAY

### A. Introduction

This report analyzes the impacts of the proposed Lake Champlain Fish Hatchery on phosphorus concentrations in Hawkins Bay and adjacent areas of the lake. A previous report (Smeltzer,1985) focused on evaluation of a shoreline discharge, but gave preliminary indications that an offshore discharge would provide greater initial dilution for the effluent and thereby reduce localized impacts on phosphorus levels and algal growth. The following analysis expands upon the evaluation of the offshore discharge alternative. The objective is to assess the sensitivity of hatchery impacts to discharge concentration and location and thus to provide bases for management decisions regarding effluent limitations and outfall design.

### B. Methodology

The analysis employs the same basic methodology, spatial grid, and data bases employed by Smelter (1985). Calculations are performed using S2D, a mathematical model designed for simulating the transport and decay of water quality components in a two-dimensional grid (Walker,1985). The model is refined by developing estimates of horizontal dispersion (mixing) rates which are appropriate for describing the region where the proposed offshore hatchery discharge will be located. Estimates of advective transport in and around Hawkins Bay, as driven primarily by wind, are derived from an independent hydrodynamic modeling effort (Laible,1986) and used in the calibration procedure. Advective transport attributed to the net south-to-

north flow of Lake Champlain is also considered.

As described in detail below, the analysis involves the following steps:

(1) define grid;

(2) calculate average measured phosphorus concentration in each grid cell using August-September 1984 field data;

(3) determine boundary conditions (tributary flows and loadings) appropriate for August-September 1984 period;

(4) based upon hydrodynamic model simulations, estimate advective transport terms;

(5) calibrate the model by adjusting the dispersion coefficient to maximize agreement between observed and predicted phosphorus concentrations in each grid cell;

(6) using the calibrated value of the dispersion coefficient, run the model for alternative hatchery effluent concentrations and discharge locations to quantify impacts under average and critical (low mixing rate) conditions.

Application of the hydrodynamic model to estimate advective transport rates in Hawkins Bay is limited by the lack of site-specific current measurements. The model has been developed, tested, and applied extensively in other regions of Lake Champlain (Laible, 1986). Previous applications provide a reasonable a-priori basis for estimating the required coefficients. The validity of the generated current patterns is supported by the fact that they yield reasonable predictions of the phosphorus distribution in Hawkins Bay when used in the subsequent modeling step (S2D). To reflect limitations in field hydrodynamic data and to evaluate sensitivity to modeling

assumptions, the impact analysis (specifically, Steps (3) to (6) above) is repeated for two cases which employ different methods for estimating horizontal transport:

Case 1: uniform dispersion coefficient without advection

Case 2: uniform dispersion coefficient with advective terms estimated from independent hydrodynamic model.

Both cases consider the net south-to-north flows in Lake Champlain, as driven by the lake's southern watershed. Case 1 represents a more empirical approach which requires less data to implement but which is less complete because it does not represent important mechanisms directly (e.g., wind-induced currents) and assumes that transport rates are uniform in all directions. Case 2 is a more mechanistic representation of bay hydrodynamics which requires more data and judgment to implement. Based upon its theoretical appeal and upon comparisons of observed and predicted phosphorus and dye distributions for consistent sets of coefficients (see below), Case 2 is considered to be a better technical basis for evaluating hatchery impacts.

C. Input Conditions

The grid employed by Smeltzer (1985) is reproduced in Figure IV-1. Figure IV-2 illustrates the same area using the S2D model output format, which is also used to present modeling results below. Each cell is 400 meters on a side and has an area of 16 hectares or 40 acres. Based upon review of temperature profile data a mean mixed-layer depth of 10 meters is representative of August-September conditions. Accordingly, a maximum cell depth

Figure IV-1
Vicinity Map and Cell Grid
(Smeltzer,1985)

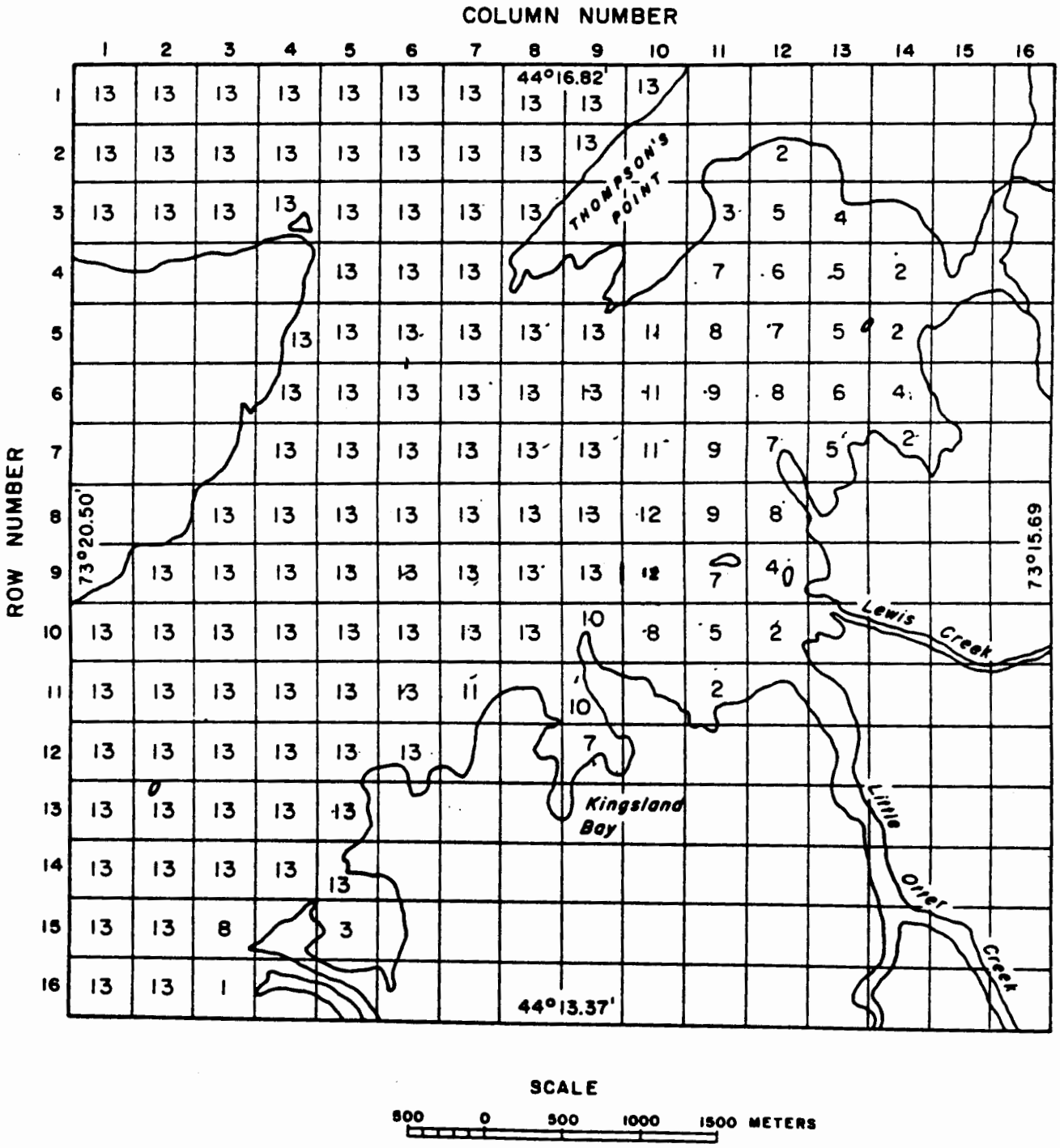
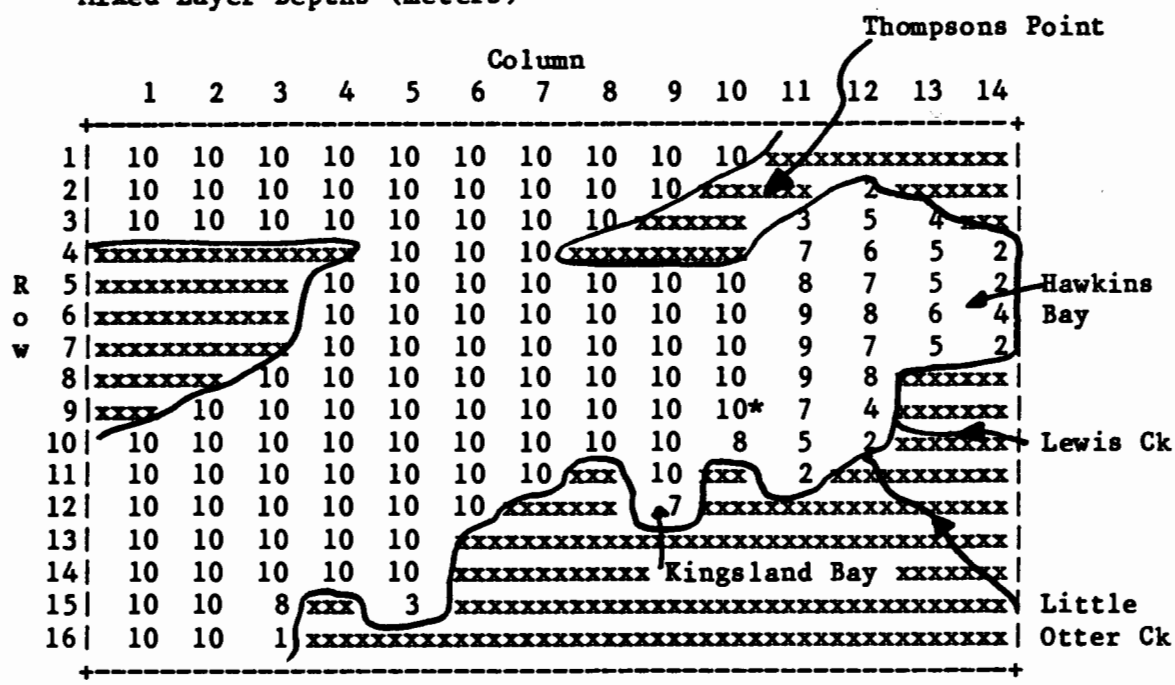


Figure IV-2
Cell Grid in S2D Model Output Format

Mixed Layer Depths (meters)




* Proposed Offshore Hatchery Discharge

Latitude Range : 44°13.37′ to 44°16.82′
Longitude Range: 73°15.69′ to 73°20.50′

North

Scale: 1 Cell = 400 meters square

of 10 meters is used for simulation purposes. This differs from the 13-meter depth assumed by Smeltzer (1985).

The model is calibrated below to predict average phosphorus concentrations measured during August and September of 1984, as reported by Smeltzer (1985). Cell-mean concentrations based upon 765 measurements taken on 7 dates are displayed in Figure IV-3. The spatial profile indicates phosphorus concentrations in the range of 20-40 ppb near the mouths of Little Otter and Lewis Creeks, 13-16 ppb in the open waters of Hawkins Bay, and 10-13 ppb in the open lake. The gradient from the creek mouths to open lake waters reflects the transport and decay of phosphorus loadings from the creeks during the study period.

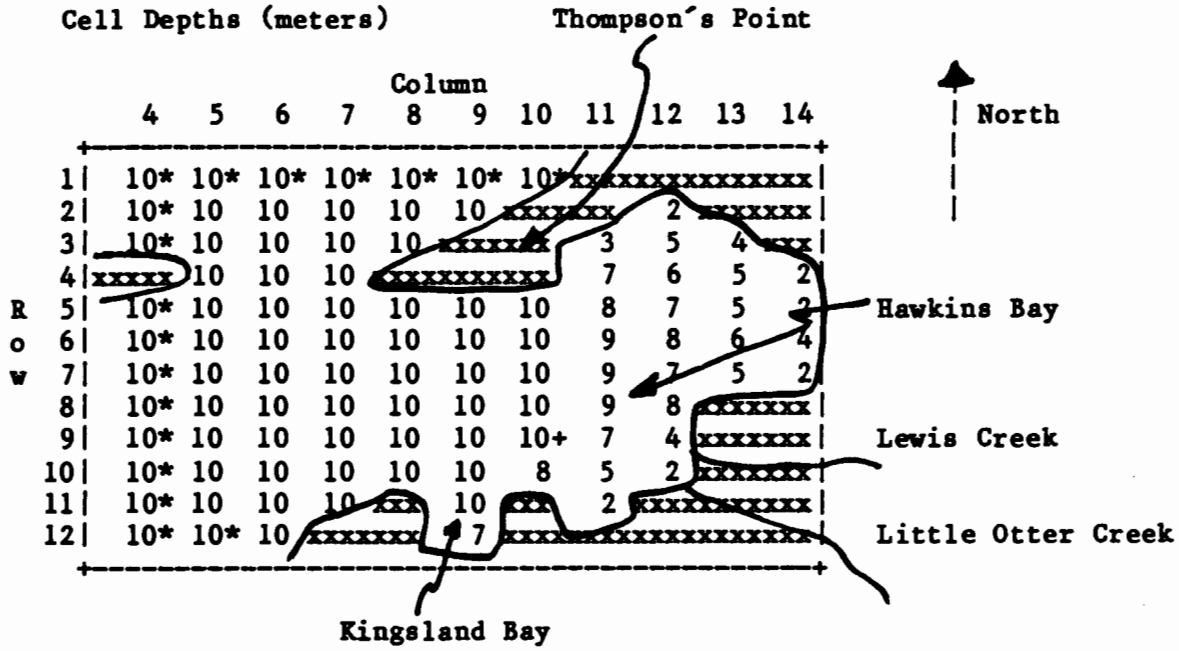
Elevated concentrations (50-60 ppb) in the southwestern portion of the grid reflect loadings from Otter Creek. The lack of adequate data for estimating flows and phosphorus loadings from Otter Creek precludes consideration of the southwestern portion of the grid in the hatchery impact analysis. This region is sufficiently remote (approximately 4 kilometers) from the hatchery discharge location that its exclusion is unlikely to influence the impact simulations. The following analysis considers only the area to the east of column 4 and to the north of row 12, as shown in Figure IV-4. Average measured concentrations in column 4 and row 1 are used to define boundary conditions (fixed concentration) for the simulations. The model area includes a total of 97 cells (1,552 hectares or 3,880 acres), as compared with 47 cells (752 hectares or 1,880 acres) east of column 8 considered by Smeltzer (1985) in simulating the

Figure IV-3
Cell-Mean Phosphorus Concentrations - August-September 1984

| Row \ Column | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 10 | | 12 | 12 | | 12 | | 12 | xxxxxxxxxxxxxxx | | | | |
| 2 | | | | | 10 | 12 | 12 | 11 | 12 | xxxxxxx | | 15 | xxxxxxx | |
| 3 | | 8 | | 9 | 10 | 13 | 13 | 11 | xxxxxxx | | 13 | 14 | 13 | xxx |
| 4 | xxxxxxxxxxxxxxx | | | | 10 | 12 | 13 | xxxxxxxxxxx | | | 13 | 14 | 14 | 15 |
| 5 | xxxxxxxxxxxx | | | | 11 | 13 | 12 | 14 | 16 | 14 | 15 | 16 | 14 | 15 |
| 6 | xxxxxxxxxxxx | | | 11 | 11 | 12 | 13 | 14 | 15 | 15 | 16 | 15 | 14 | 15 |
| 7 | xxxxxxxxxxxx | | | 11 | 12 | 12 | 14 | 14 | 15 | 15 | 14 | 15 | 15 | |
| 8 | xxxxxxxx | | | 13 | 12 | 13 | 13 | 15 | 15 | 14 | 13 | 15 | xxxxxxx | |
| 9 | xxxx | 13 | | 11 | 12 | 13 | 14 | 14 | 15 | 15 | 15 | 19 | xxxxxxx | |
| 10 | | | | 12 | 12 | 14 | 15 | 14 | 14 | 17 | 15 | 34 | xxxxxxx | |
| 11 | 12 | 11 | 9 | 12 | 14 | 13 | 13 | xxx | 14 | xxx | 24 | xxxxxxxxxxx | | |
| 12 | | 11 | 12 | 13 | 16 | 14 | xxxxxxx | | 14 | xxxxxxxxxxxxxxxxxxx | | | | |
| 13 | | 13 | 12 | 13 | 15 | xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx | | | | | | | | |
| 14 | | 11 | | 16 | | xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx | | | | | | | | |
| 15 | | 15 | 58 | xxx | | xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx | | | | | | | | |
| 16 | | 20 | 52 | xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx | | | | | | | | | | |

Mean Phosphorus Concentration (ppb)

**Figure IV-4**
**Reduced Grid Used in Impact Simulations**




* Grid Boundary Cell (Fixed Concentration)
\+ Location of Proposed Offshore Hatchery Discharge
xxx Land Area

impacts of a shoreline hatchery discharge.

Estimates of average circulation patterns under two wind conditions have been developed by Laible (1986) using a finite-element simulation model (FEM). These indicate that counter-clockwise circulation patterns are established within Hawkins Bay under southeast and southwest winds. With some manipulation, output from the FEM can provide estimates of net advective transport rates for use in the hatchery discharge simulations. The FEM velocity fields have been numerically integrated to develop net flux estimates across each cell interface. Minor adjustments in these estimates have been made in order to preserve a water balance in each cell. The adjustment procedure involves marching from the northeastern to the southwestern corner of the grid while partitioning the water-balance error equally between the western and southern boundaries of each cell. The water balance on the northern edge of the FEM simulation area between Thompson's Point and Split Rock Point (Row 4, Columns 5 to 7) is preserved by passing flows northward, to represent the net south-to-north flow determined by the water balance of Lake Champlain. Since the FEM simulation area does not consider the open lake north of Row 4, flows leaving Row 4 are routed to boundary cells in Row 1. These are balanced by inflows entering the southwestern corner of the grid. Because of imperfections in the overlaying of the FEM mesh and S2D grid and inaccuracies in numerical integration of the FEM output, the south-to-north through-flows calculated using the above procedure amount to 61% and 67% of those specified for the FEM simulations (37 m3/sec for

August-September 1984 and 45 m3/sec for mean August-September conditions, respectively). These represent conservative estimates of dilution capacity which are desirable for simulating hatchery impacts.

Results of the advective transport mapping are summarized in Tables IV-1 and IV-2 for southeast and southwest wind regimes, respectively. For each wind condition, transport is expressed in terms of a "Northflow Matrix" and an "Eastflow Matrix". The Northflow Matrix contains flows from each cell to its northern neighbor (row i to row i-1); negative values indicate reversed flows (from row i-1 to row i). The Eastflow Matrix contains flows from each cell to its eastern neighbor (column j to column j+1); negative values indicate reversed flow (from column j+1 to column j). The flow matrices contain advective circulation patterns which reflect FEM output and which satisfy water-balance constraints.

As discussed by Laible (1986), the circulation patterns for a southeast wind (Table IV-1) reflect average wind and flow conditions during the August-September 1984 monitoring period. Circulation patterns for the southwest wind (Table IV-2) reflect prevailing winds and mean flows for the same season, based upon analysis of historical wind velocity records at St. Albans Bay and regional streamflow data. Values from Table IV-1 are used in calibrating the S2D model to predict measured phosphorus concentrations in Hawkins Bay (Figure IV-3). Values from Table IV-2 (prevailing wind) are used to simulate hatchery effluent impacts under average, August-September conditions. The FEM circulation patterns reflect net flows only and do not reflect

Table IV-1
Advective Flows - Southeast Wind

Northflow Matrix

| Row | Column 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | | | | | | | | | | | |
| 4 | | 839 | 852 | 280 | | | | -556 | -220 | 775 | |
| 5 | | 696 | 693 | 582 | | | | -2952 | 751 | 1400 | 801 |
| 6 | | 496 | 324 | 83 | -322 | -1139 | -2164 | -76 | 2325 | 1786 | 675 |
| 7 | | 353 | 141 | -118 | -579 | -1379 | -862 | 1114 | 2398 | 865 | 32 |
| 8 | | 320 | 85 | -178 | -558 | -1494 | -302 | 1944 | 2113 | | |
| 9 | | 349 | 80 | -34 | -214 | -491 | 48* | 1164 | 926 | | |
| 10 | | 437 | 95 | -38 | 652 | 597 | -580 | 156 | 353 | | |
| 11 | | 657 | 351 | 394 | | | | | | | |
| 12 | | 614 | 173 | | | | | | | | |

Eastflow Matrix

| Row | Column 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | | | | | | | | -556 | -775 | | |
| 4 | | -143 | -303 | | | | | -2396 | -1426 | -801 | |
| 5 | | -216 | -585 | -1084 | -1406 | -2546 | -4710 | -1834 | -260 | 127 | |
| 6 | 5 | -122 | -305 | -505 | -762 | -1002 | 300 | 1491 | 1563 | 643 | |
| 7 | 36 | 3 | -53 | -113 | -93 | -208 | 352 | 1182 | 898 | 32 | |
| 8 | 101 | 130 | 124 | 268 | 613 | 1616 | 1967 | 1187 | | | |
| 9 | 156 | 245 | 260 | 256 | 1121 | 2209 | 1582* | 573 | | | |
| 10 | 271 | 491 | 746 | 1178 | 526 | -71 | 509 | 353 | | | |
| 11 | 614 | 572 | 394 | | | | | | | | |
| 12 | | 173 | | | | | | | | | |

Flows in 1000 $m^3$/day  * Hatchery Discharge

Table IV-2
Advective Flows - Southwest Wind

**Northflow Matrix**

| Row | Column 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | | | | | | | | | | | |
| 4 | | 1005 | 1056 | 535 | | | | -18 | -244 | 262 | |
| 5 | | 885 | 901 | 810 | | | | -1197 | -206 | 710 | 693 |
| 6 | | 664 | 485 | 274 | -51 | 36 | -912 | -1112 | 1256 | 1225 | 755 |
| 7 | | 479 | 191 | -43 | -360 | -596 | -994 | 705 | 2235 | 933 | 115 |
| 8 | | 374 | 44 | -230 | -594 | -1229 | -360 | 2201 | 2483 | | |
| 9 | | 313 | -21 | -248 | -587 | -867 | -555* | 1846 | 2701 | | |
| 10 | | 462 | 53 | -208 | 71 | -2 | -270 | 1238 | 1112 | | |
| 11 | | 814 | 547 | 752 | | | | | | | |
| 12 | | 850 | 412 | | | | | | | | |

**Eastflow Matrix**

| Row | Column 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | | | | | | | | -18 | -262 | | |
| 4 | | -120 | -276 | | | | | -1180 | -1141 | -693 | |
| 5 | | -245 | -661 | -1197 | -1248 | -1212 | -2124 | -2039 | -577 | -62 | |
| 6 | | -231 | -524 | -842 | -1151 | -1783 | -1865 | -48 | 932 | 640 | |
| 7 | | -129 | -276 | -462 | -696 | -1330 | -696 | 801 | 1048 | 115 | |
| 8 | 12 | 46 | -20 | -38 | -31 | 332 | 137 | -218 | | | |
| 9 | 127 | 276 | 350 | 390 | 1047 | 1912 | 2197* | 1589 | | | |
| 10 | 343 | 695 | 1189 | 2149 | 2078 | 2081 | 2350 | 1112 | | | |
| 11 | 850 | 886 | 752 | | | | | | | | |
| 12 | | 412 | | | | | | | | | |

Flows in 1000 $m^3$/day

* Hatchery Discharge Cell

bidirectional exchanges between cells, which are treated as diffusion processes by the S2D model.

Input conditions and calibration results for each case are summarized in Table IV-3. Tributary flows, tributary concentrations, and phosphorus decay rates are identical to those assumed by Smeltzer (1985). An atmospheric phosphorus loading rate of .055 mg/m2-day (20 mg/m2-year) has been assumed for all cases. When this value is applied to the total area of Hawkins Bay, the total atmospheric loading amounts to 13% of the loading contributed by local tributaries (Little Otter, Lewis, Thorp, and Kimball). Thus, results are insensitive to the assumed atmospheric loading rate.

Calibration of the model involves adjustment of the dispersion coefficient to maximize agreement between the observed and simulated spatial distribution of phosphorus for each case. Cells within the bay east of Thompson's Point (east of and including Column 8) have been used for calibration purposes. Shallow areas in the southeastern corner of the bay typically contain aquatic weeds during August and September (Smeltzer,1985). Because these areas are expected to have lower mixing rates and are irrelevant for evaluating offshore hatchery discharge locations, they have been excluded from the calibration process. While both the hydrodynamic model and mass-balance model could be approximately adjusted to account for the weed beds, such adjustments are not warranted, considering the objectives of the analysis.

For each case, the model has been run using several

Table IV-3
Input Conditions and Parameter Estimates

Simulation Grid: As shown in Figure 4

Boundary Cells: Column 4, Rows 2 to 12
Row 1, Columns 2 to 10
Row 12, Column 5
Fixed at Mean Measured Concentrations in Figure 3

Tributary Loadings for August-September 1984 (Smeltzer,1985):
Lewis and Litter Otter Creeks (entering Column 12, Row 10)
Flow = 49,000 $m^3$/day, P Conc. = 61 ppb
Thorp and Kimball (entering Column 14, Row 4)
Flow = 2,000 $m^3$/day, P Conc. = 61 ppb

Atmospheric P Loading = .055 mg/$m^2$-day = 20 mg/$m^2$-yr

Phosphorus Decay Rate = .001 $day^{-1}$
Dye Effective Settling Velocity = .091 m/day
Dye Loading Rate = 87 grams/day in Column 11, Row 11

Case 1: Uniform Dispersion Field
South to North Advective Flow in Main Lake (Col 6):
Calibration - 37 $m^3$/sec (August-Sept 1984)
Hatchery Simulations - 45 $m^3$/sec (August-Sept Mean)
- 22 $m^3$/sec (August-Sept Low-Flow)

Case 2: Uniform Dispersion Field
Advective Transport Based Upon Hydrodynamic Model Simulations
Calibration - Table 1 (August-Sept 1984)
Hatchery Simulations - Table 2 (August-Sept Mean)
- Table 2 x .48 (August-Sept Low-Flow)

Calibration Results:

| | Dispersion Coef. ($m^2$/day) | Mean-Squared-Error ($ppb^2$)* Phosphorus | Dye |
|---|---|---|---|
| Case 1 - Minimum Error for P | 80,000 | .77 | .00117 |
| Case 1 - Used in Simulations | 70,000 | .79 | .00137 |
| Case 2 - Minimum Error for P | 40,000 | .72 | .00070 |
| Case 2 - Used in Simulations | 20,000 | .80 | .00072 |

* Mean (Predicted Conc - Observed Conc)$^2$
Calculated for Cells in Hawkins/Town Farm Bay (East of Column 7), Excluding Shallow Weedy Areas in Southeast Corner of Grid (Col/Row = 12/09,12/10, 11/11), n = 47

values of the dispersion coefficient (ranging from 1,000 to 1,000,000 m2/day) and output has been compared with measured concentrations for August- September 1984. The degree of fit is measured by the mean squared error for 47 grid cells (Predicted P - Observed P2). Lower values for this statistic indicate better agreement between observed and predicted concentrations. Mean squared error is plotted against the dispersion coefficient for each case in Figure IV-5. For Case 1, a clearly defined error minimum is apparent for dispersion coefficients in the range of 70,000 to 80,000 m2/day. The lower end of this range has been selected for use in hatchery simulations. Because wind-induced mixing apparently accounts for a major portion of the circulation within Hawkins Bay, the mean squared error for Case 2 is generally less sensitive to the dispersion coefficient. While the minimum error occurs at a dispersion coefficient of 40,000 m2/day, a conservative value of 20,000 m2/day has been selected for use in hatchery simulations.

The spatial distributions of simulated phosphorus concentrations, measured concentrations, and errors are illustrated for Cases 1 and 2 in Figures IV-6 and, IV-7, respectively, using the calibrated dispersion coefficients discussed above. Plotted values are truncated integers (i.e., a plot symbol of "1" means that the corresponding value is greater than or equal to 1.0 ppb and less than 2.0 ppb). In both cases, the model under-predicts phosphorus concentrations in the southeastern portions of the bay, where weed beds inhibit lakeward transport of phosphorus entering from tributary creeks and where eddy scales arelikely to be smaller. Agreement between

Figure IV-5
Mean Squared Error vs. Dispersion Coefficient

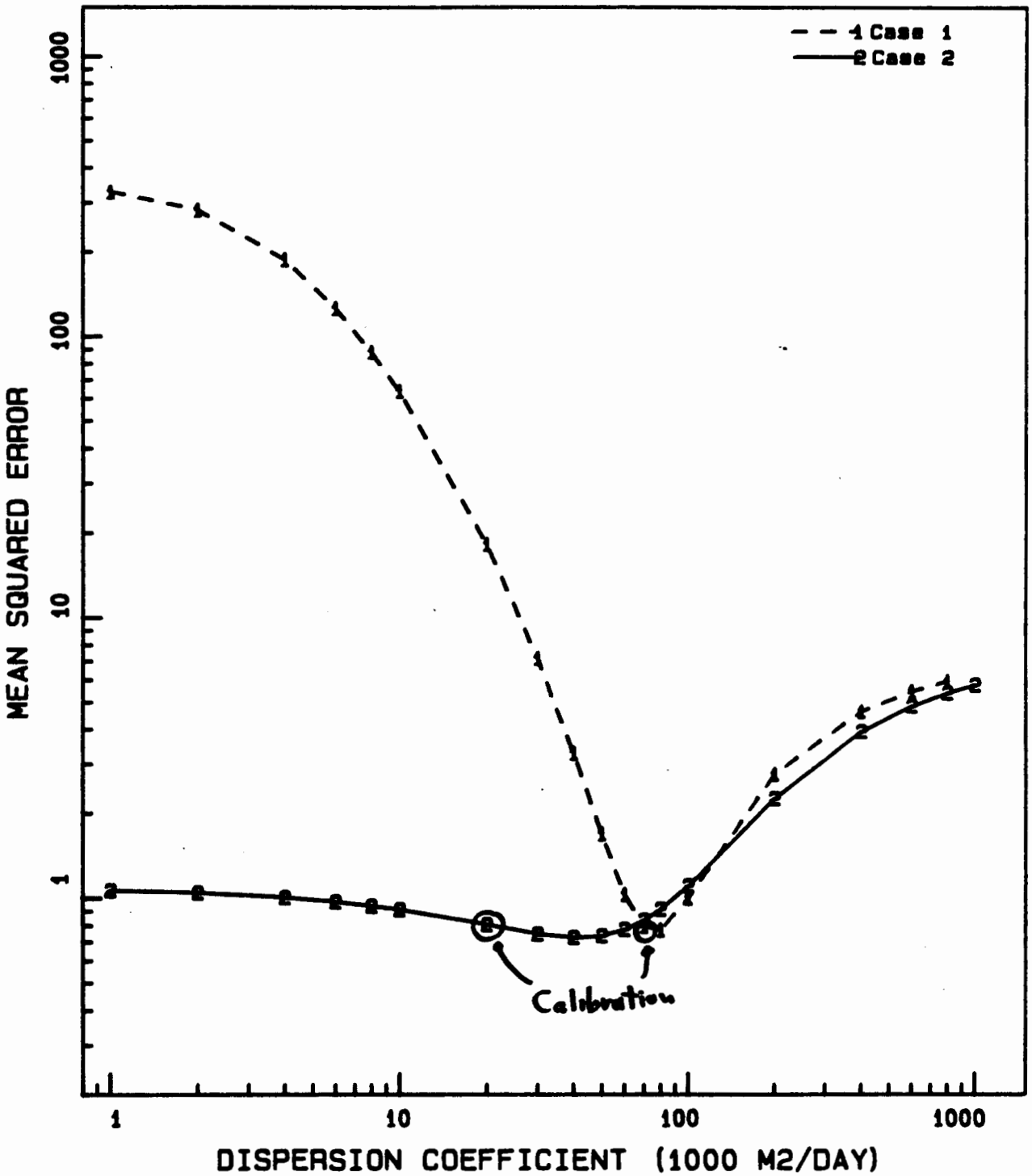


Figure IV-6
Measured and Predicted Phosphorus Concentrations for Case 1
Dispersion Coefficient = 70,000 $m^2$/day

Measured P (ppb)
August-Sept 1984

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | xxxx | xxxx | xxxx | xxxx |
| 2 | 10 | 10 | 12 | 12 | 11 | 12 | xxxx | xxxx | 15 | xxxx | xxxx |
| 3 | 9 | 10 | 13 | 13 | 11 | xxxx | xxxx | 13 | 14 | 13 | xxxx |
| 4 | xxxx | 10 | 12 | 13 | xxxx | xxxx | xxxx | 13 | 14 | 14 | 15 |
| 5 | 10 | 11 | 13 | 12 | 14 | 16 | 14 | 15 | 16 | 14 | 15 |
| 6 | 11 | 11 | 12 | 13 | 14 | 15 | 15 | 16 | 15 | 14 | 15 |
| 7 | 11 | 12 | 12 | 14 | 14 | 15 | 15 | 14 | 15 | 15 | |
| 8 | 13 | 12 | 13 | 13 | 15 | 15 | 14 | 13 | 15 | xxxx | xxxx |
| 9 | 11 | 12 | 13 | 14 | 14 | 15 | 15 | 15 | 19 | xxxx | xxxx |
| 10 | 12 | 12 | 14 | 15 | 14 | 14 | 17 | 15 | 34 | xxxx | xxxx |
| 11 | 12 | 14 | 13 | 13 | xxxx | 14 | xxxx | 24 | xxxx | xxxx | xxxx |
| 12 | 13 | 16 | 14 | xxxx | xxxx | 14 | xxxx | xxxx | xxxx | xxxx | xxxx |

Predicted P (ppb)

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | xxxx | xxxx | xxxx | xxxx |
| 2 | 10 | 11 | 11 | 12 | 12 | 12 | xxxx | xxxx | 15 | xxxx | xxxx |
| 3 | 9 | 10 | 12 | 12 | 12 | xxxx | xxxx | 15 | 15 | 15 | xxxx |
| 4 | xxxx | 11 | 12 | 12 | xxxx | xxxx | xxxx | 15 | 15 | 15 | 15 |
| 5 | 10 | 11 | 12 | 12 | 13 | 14 | 14 | 14 | 15 | 15 | 15 |
| 6 | 11 | 11 | 12 | 13 | 13 | 14 | 14 | 15 | 15 | 15 | 15 |
| 7 | 11 | 12 | 13 | 13 | 13 | 14 | 14 | 15 | 15 | 15 | 15 |
| 8 | 13 | 12 | 13 | 13 | 14 | 14 | 15 | 15 | 16 | xxxx | xxxx |
| 9 | 11 | 12 | 13 | 13 | 14 | 14 | 15 | 16 | 17 | xxxx | xxxx |
| 10 | 12 | 13 | 13 | 14 | 14 | 15 | 15 | 17 | 21 | xxxx | xxxx |
| 11 | 12 | 13 | 14 | 14 | xxxx | 15 | xxxx | 17 | xxxx | xxxx | xxxx |
| 12 | 13 | 16 | 15 | xxxx | xxxx | 14 | xxxx | xxxx | xxxx | xxxx | xxxx |

Predicted-Measured

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx | xxxx | xxxx |
| 2 | 0 | 0 | -0 | -0 | 0 | -0 | xxxx | xxxx | 0 | xxxx | xxxx |
| 3 | 0 | 0 | -0 | -1 | 0 | xxxx | xxxx | 1 | 0 | 1 | xxxx |
| 4 | xxxx | 0 | -0 | -0 | xxxx | xxxx | xxxx | 1 | 0 | 0 | -0 |
| 5 | 0 | -0 | -1 | 0 | -0 | -2 | -0 | -0 | -1 | 0 | 0 |
| 6 | 0 | 0 | 0 | -0 | -0 | -1 | -0 | -1 | -0 | 0 | -0 |
| 7 | 0 | -0 | 0 | -0 | -0 | -0 | -0 | 0 | 0 | 0 | |
| 8 | 0 | -0 | -0 | 0 | -0 | -0 | 0 | 1 | 1 | xxxx | xxxx |
| 9 | 0 | -0 | 0 | -0 | -0 | -0 | 0 | 1 | -2 | xxxx | xxxx |
| 10 | 0 | 0 | -0 | -0 | 0 | 0 | -1 | 2 | -1 | xxxx | xxxx |
| 11 | 0 | -0 | 1 | 1 | xxxx | 0 | xxxx | -7 | xxxx | xxxx | xxxx |
| 12 | 0 | 0 | 1 | xxxx | xxxx | 0 | xxxx | xxxx | xxxx | xxxx | xxxx |

Figure IV-7
Measured and Predicted Phosphorus Concentrations for Case 2
Dispersion Coefficient = 20,000 $m^2$/day

Measured P (ppb)
August-Sept 1984

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | | | | |
| 2 | 10 | 10 | 12 | 12 | 11 | 12 | | | 15 | | |
| 3 | 9 | 10 | 13 | 13 | 11 | | | 13 | 14 | 13 | |
| 4 | | 10 | 12 | 13 | | | | 13 | 14 | 14 | 15 |
| 5 | 10 | 11 | 13 | 12 | 14 | 16 | 14 | 15 | 16 | 14 | 15 |
| 6 | 11 | 11 | 12 | 13 | 14 | 15 | 15 | 16 | 15 | 14 | 15 |
| 7 | 11 | 12 | 12 | 14 | 14 | 15 | 15 | 14 | 15 | 15 | |
| 8 | 13 | 12 | 13 | 13 | 15 | 15 | 14 | 13 | 15 | | |
| 9 | 11 | 12 | 13 | 14 | 14 | 15 | 15 | 15 | 19 | | |
| 10 | 12 | 12 | 14 | 15 | 14 | 14 | 17 | 15 | 34 | | |
| 11 | 12 | 14 | 13 | 13 | | 14 | | 24 | | | |
| 12 | 13 | 16 | 14 | | | 14 | | | | | |

Predicted P (ppb)

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | | | | |
| 2 | 10 | 12 | 13 | 13 | 12 | 12 | | | 15 | | |
| 3 | 9 | 12 | 14 | 14 | 13 | | | 15 | 15 | 15 | |
| 4 | | 13 | 14 | 14 | | | | 15 | 15 | 15 | 15 |
| 5 | 10 | 13 | 14 | 14 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| 6 | 11 | 12 | 14 | 14 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| 7 | 11 | 12 | 13 | 14 | 14 | 15 | 15 | 14 | 15 | 15 | 15 |
| 8 | 13 | 13 | 13 | 14 | 14 | 14 | 14 | 14 | 15 | | |
| 9 | 11 | 13 | 13 | 13 | 14 | 14 | 14 | 14 | 16 | | |
| 10 | 12 | 13 | 14 | 14 | 14 | 14 | 14 | 14 | 19 | | |
| 11 | 12 | 14 | 14 | 14 | | 14 | | 14 | | | |
| 12 | 13 | 16 | 15 | | | 14 | | | | | |

Predicted-Measured

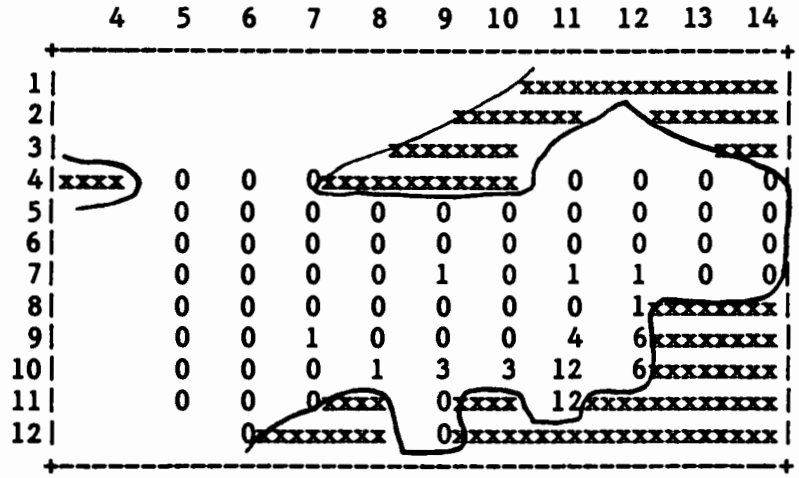
| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 2 | 1 | 0 | 1 | -0 | | | 0 | | |
| 3 | 0 | 2 | 1 | 0 | 1 | | | 1 | 0 | 1 | |
| 4 | | 2 | 1 | 1 | | | | 1 | 0 | 0 | -0 |
| 5 | 0 | 1 | 0 | 2 | 0 | -0 | 0 | 0 | -1 | 0 | 0 |
| 6 | 0 | 1 | 1 | 1 | 0 | -0 | -0 | -1 | -0 | 0 | -0 |
| 7 | 0 | 0 | 0 | 0 | 0 | -0 | -0 | 0 | -0 | 0 | |
| 8 | 0 | 0 | -0 | 0 | -0 | -0 | 0 | 0 | 0 | | |
| 9 | 0 | 0 | 0 | -0 | -0 | -1 | -0 | -0 | -3 | | |
| 10 | 0 | 1 | -0 | -0 | -0 | -0 | -2 | -0 | -14 | | |
| 11 | 0 | 0 | 1 | 1 | | -0 | | -9 | | | |
| 12 | 0 | 0 | 1 | | | -0 | | | | | |

observed and predicted concentrations is generally within 2 ppb for cells in the calibration region east of Thompson's Point. For Case 2, under-estimation of phosphorus concentrations in the northwestern portion of the grid by 1 to 2 ppb reflects that fact that the hydrodynamic model used to estimate advective transport does not extend north of Thompson's Point (Row 4), with the result that mixing rates are under-estimated in this region.

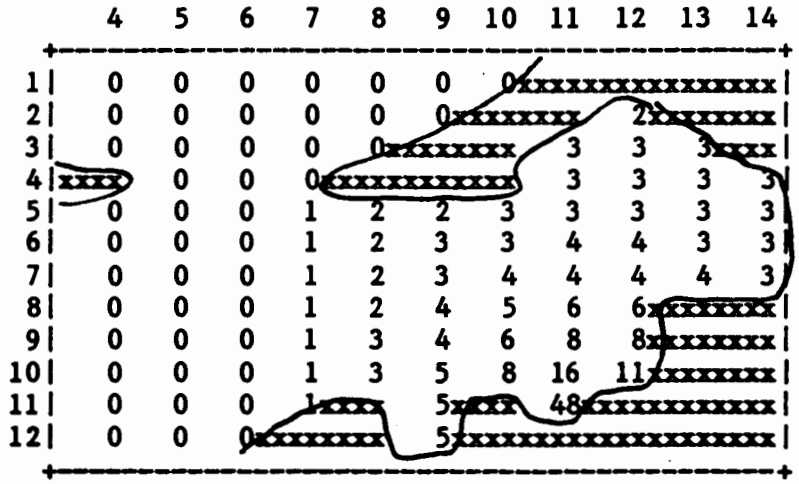
Field studies conducted by the Vermont Department of Water Resources (Smeltzer,1985) included an experimental dye release at the near-shore discharge location (Column 11, Row 11). The intent of the experiment was to provide an independent basis for estimating dispersion rates. Because the dye release rate was apparently too low in relation to the dispersion and/or effective decay rates, the measured concentrations in the bay were too low to provide a primary basis for calibrating the model. The measurements do provide, however, some independent basis for comparing the performances of Cases 1 and 2 using dispersion coefficients calibrated for predicting phosphorus. The decay rate used for die (effective settling velocity of .091 m/day, Table 3) is based upon field incubation experiments (Smeltzer,1985) and primarily reflects a photochemical decay mechanism. This likely represents a lower limit to the effective decay rate because adsorption onto suspended sediments and/or lake bottom sediments is also expected to account for dye removal.

Figures 8 and 9 compare observed and predicted dye distributions for Cases 1 and 2, using the dispersion

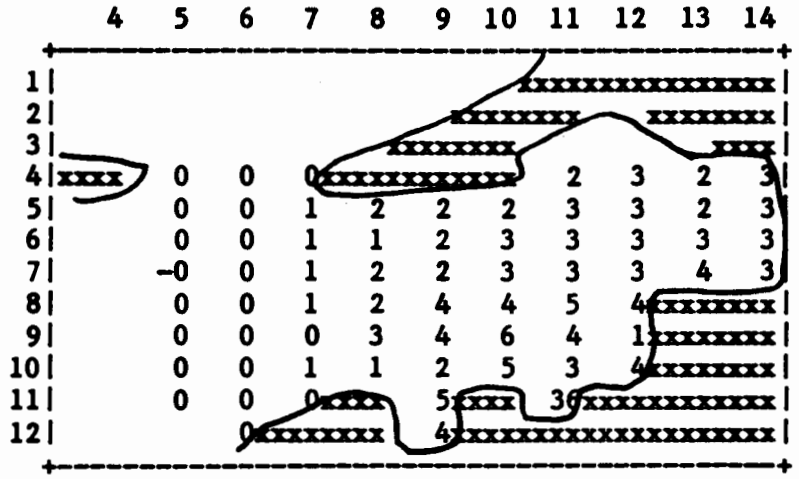
Figure IV-8
Measured and Predicted Dye Concentrations for Case 1
Dispersion Coefficient = 70,000 $m^2$/day




Measured Dye
ppb x 100
August-Sept 1984

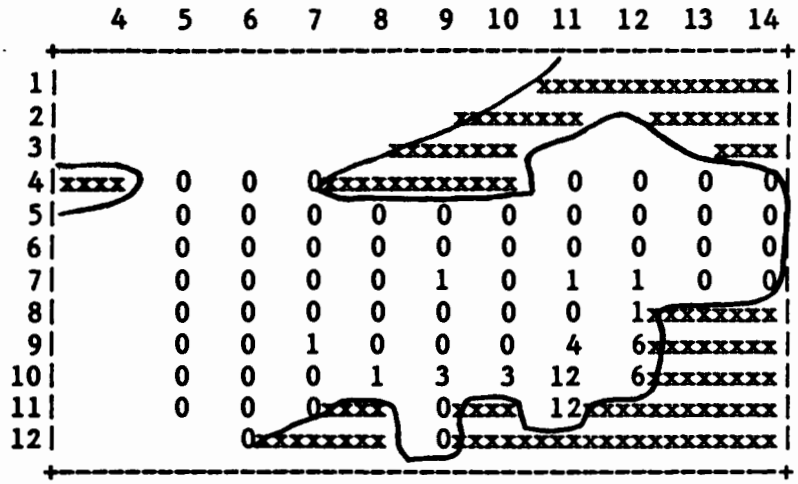



Predicted Dye
(ppb x 100)

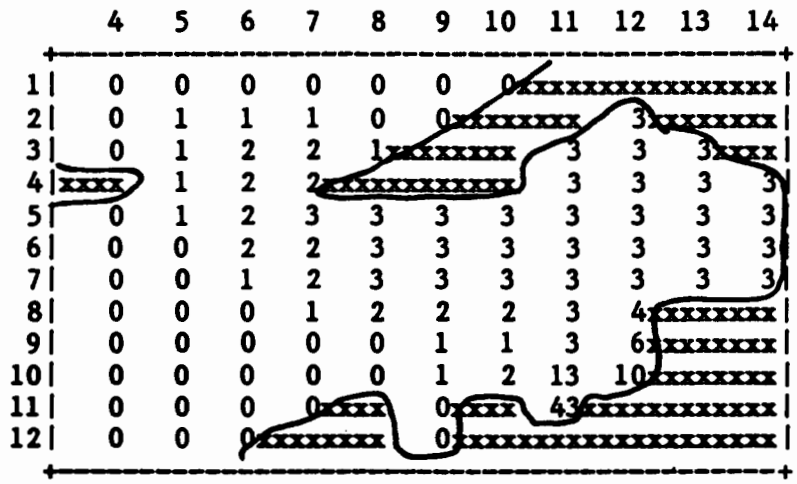



Predicted-Measured

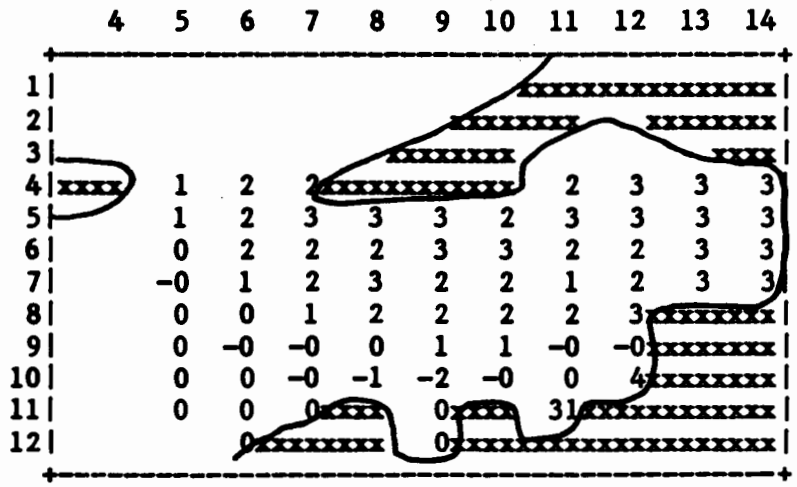
Figure IV-9
Measured and Predicted Dye Concentrations for Case 2
Dispersion Coefficient = 20,000 $m^2$/day




Measured Dye
August-Sept 1984
(ppb x 100)




Predicted Dye
(ppb x 100)




Predicted-Measured

coefficients calibrated for predicting phosphorus. In both cases, dye concentrations in the northern portions of Hawkins Bay are over-predicted by .01 to .03 ppb. This may reflect higher dispersion rates and/or higher decay rates than those assumed in the simulations. The performance of Case 2 in the vicinity of the proposed offshore discharge is considerably better than that of Case 1, however. In the 9 cells surrounding the discharge location (Column 10, Row 9), Case 1 consistently over-predicts dye concentrations by .02 to .06 ppb, whereas Case 2 errors are centered around 0.0 and in a range of -.02 to +.02 ppb. For cells inside Hawkins Bay, mean squared errors are .00137 and

Calibration results and theoretical considerations suggest that Case 2 simulations provide a more reliable basis for evaluating hatchery impacts.

D. Model Applications

The effects of an offshore hatchery discharge have been evaluated by running the model over a range of effluent phosphorus levels using the dispersion coefficient calibrated for each case. The hatchery discharge of 42,000 m3/day (11 mgd) is located in Column 10, Row 9, as shown in Figure IV-4. Impacts have been evaluated under two sets of conditions. "Mean flow" conditions correspond to prevailing winds and mean discharge conditions for Lake Champlain during August and September. "Low flow" conditions reflect average dilution potential and mixing rates which would be exceeded nine years out of ten during August and September. Based upon analysis of historical flow data from the Otter Creek gauge, the 10-year-frequency low flow is 48.3% of

the mean flow for August and September. Twenty years of wind speed data from Burlington Airport indicate that the minimum monthly-mean wind load (based upon the square of the monthly-mean wind speed) is 77% of the mean load for August and 48% of the mean load for September. Advective transport terms under low-flow conditions have been estimated at 48% of their respective values under mean-flow conditions. Since there is no basis for a similar adjustment of dispersive transport terms, they have been held fixed. The resulting simulations are intended to provide approximate indications of "worst case" hatchery impacts which might be experienced one year out of ten under unfavorable wind and flow conditions.

Simulation results for a range of effluent phosphorus levels (50 to 200 ppb) are shown in Figure IV-10 (Case 1) and Figure IV-11 (Case 2). Each figure presents results for mean-flow and low-flow conditions. Since Case 1 simulations are not very sensitive to advective transport terms, mean- and low-flow impacts are similar. Because advective terms dominate for Case 2, impacts are roughly doubled under low-flow as compared with mean-flow conditions. The counter-clockwise circulation pattern within Hawkins Bay predicted by the hydrodynamic model causes the hatchery plume to be skewed towards the northeast for Case 2, whereas the plume spreads roughly equally in all directions for Case 1.

At higher effluent phosphorus concentrations, 1-3 ppb increases in open lake waters north of Thompson's Point are indicated for Case 2. These increases reflect under-estimation of transport rates in this region because the hydrodynamic model

# Figure IV-10
## Impacts of Alternative Discharge Concentrations - Case 1

**Case 1: Mean Flow Conditions**
**Simulated P Concentrations (ppb) without Hatchery**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | | | | |
| 2 | 10 | 11 | 12 | 12 | 12 | 12 | | | 15 | | |
| 3 | 9 | 10 | 12 | 12 | 12 | | | 15 | 15 | 15 | |
| 4 | | 11 | 12 | 12 | | | | 15 | 15 | 15 | 15 |
| 5 | 10 | 11 | 12 | 12 | 13 | 14 | 14 | 14 | 15 | 15 | 15 |
| 6 | 11 | 11 | 12 | 13 | 13 | 14 | 14 | 15 | 15 | 15 | 15 |
| 7 | 11 | 12 | 13 | 13 | 13 | 14 | 14 | 15 | 15 | 15 | 15 |
| 8 | 13 | 12 | 13 | 13 | 14 | 14 | 15 | 15 | 16 | | |
| 9 | 11 | 12 | 13 | 13 | 14 | 14 | 15 | 16 | 17 | | |
| 10 | 12 | 13 | 13 | 14 | 14 | 15 | 15 | 17 | 21 | | |
| 11 | 12 | 13 | 14 | 14 | | 15 | | 17 | | | |
| 12 | 13 | 16 | 15 | | | 15 | | | | | |

**Case 1 : Low Flow Conditions**
**Simulated P Concentrations (ppb) without Hatchery**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | | | | |
| 2 | 10 | 11 | 11 | 11 | 11 | 11 | | | 15 | | |
| 3 | 9 | 10 | 11 | 11 | 12 | | | 15 | 15 | 15 | |
| 4 | | 11 | 12 | 12 | | | | 15 | 15 | 15 | 15 |
| 5 | 10 | 11 | 12 | 12 | 13 | 14 | 14 | 14 | 15 | 15 | 15 |
| 6 | 11 | 11 | 12 | 13 | 13 | 14 | 14 | 15 | 15 | 15 | 15 |
| 7 | 11 | 12 | 13 | 13 | 13 | 14 | 14 | 15 | 15 | 15 | 15 |
| 8 | 13 | 12 | 13 | 13 | 14 | 14 | 15 | 15 | 16 | | |
| 9 | 11 | 12 | 13 | 13 | 14 | 14 | 15 | 16 | 17 | | |
| 10 | 12 | 13 | 13 | 14 | 14 | 15 | 15 | 17 | 21 | | |
| 11 | 12 | 13 | 14 | 14 | | 15 | | 17 | | | |
| 12 | 13 | 16 | 15 | | | 15 | | | | | |

**Increase for Effluent P = 50 ppb**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | | | 1 | | |
| 3 | 0 | 0 | 0 | 0 | 0 | | | 1 | 1 | 1 | |
| 4 | | 0 | 0 | 0 | | | | 1 | 1 | 1 | 1 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| 6 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | | |
| 9 | 0 | 0 | 0 | 0 | 0 | 1 | 2* | 1 | 1 | | |
| 10 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | | |
| 11 | 0 | 0 | 0 | 0 | | 1 | | 1 | | | |
| 12 | 0 | 0 | 0 | | | 1 | | | | | |

**Increase for Effluent P = 50 ppb**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | | | 1 | | |
| 3 | 0 | 0 | 0 | 0 | 0 | | | 1 | 1 | 1 | |
| 4 | | 0 | 0 | 0 | | | | 1 | 1 | 1 | 1 |
| 5 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | | |
| 9 | 0 | 0 | 0 | 0 | 1 | 1 | 2* | 1 | 1 | | |
| 10 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | | |
| 11 | 0 | 0 | 0 | 0 | | 1 | | 1 | | | |
| 12 | 0 | 0 | 0 | | | 1 | | | | | |

**Increase for Effluent P = 100 ppb**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | | | 2 | | |
| 3 | 0 | 0 | 0 | 0 | 0 | | | 2 | 2 | 2 | |
| 4 | | 0 | 0 | 0 | | | | 2 | 2 | 2 | 2 |
| 5 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 |
| 6 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 3 |
| 7 | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 3 |
| 8 | 0 | 0 | 0 | 1 | 2 | 2 | 3 | 3 | 3 | | |
| 9 | 0 | 0 | 0 | 1 | 2 | 3 | 5* | 4 | 3 | | |
| 10 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 3 | 3 | | |
| 11 | 0 | 0 | 0 | 0 | | 3 | | 3 | | | |
| 12 | 0 | 0 | 0 | | | 3 | | | | | |

**Increase for Effluent P = 100 ppb**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | | | 3 | | |
| 3 | 0 | 0 | 0 | 0 | 0 | | | 3 | 3 | 3 | |
| 4 | | 0 | 0 | 0 | | | | 3 | 3 | 3 | 3 |
| 5 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 3 |
| 6 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 |
| 7 | 0 | 0 | 0 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 |
| 8 | 0 | 0 | 0 | 1 | 2 | 3 | 3 | 3 | 3 | | |
| 9 | 0 | 0 | 0 | 1 | 2 | 3 | 5* | 4 | 3 | | |
| 10 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 4 | 3 | | |
| 11 | 0 | 0 | 0 | 0 | | 3 | | 4 | | | |
| 12 | 0 | 0 | 0 | | | 3 | | | | | |

**Increase for Effluent P = 150 ppb**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | | | 4 | | |
| 3 | 0 | 0 | 0 | 0 | 0 | | | 4 | 4 | 4 | |
| 4 | | 0 | 0 | 1 | | | | 4 | 4 | 4 | 4 |
| 5 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 4 | 4 | 4 | 4 |
| 6 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 4 | 4 | 4 | 4 |
| 7 | 0 | 0 | 0 | 1 | 3 | 4 | 4 | 5 | 5 | 4 | 4 |
| 8 | 0 | 0 | 0 | 2 | 3 | 4 | 5 | 5 | 5 | | |
| 9 | 0 | 0 | 0 | 2 | 3 | 5 | 8* | 6 | 5 | | |
| 10 | 0 | 0 | 0 | 1 | 3 | 4 | 6 | 6 | 5 | | |
| 11 | 0 | 0 | 0 | 1 | | 4 | | 6 | | | |
| 12 | 0 | 0 | 0 | | | 4 | | | | | |

**Increase for Effluent P = 150 ppb**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | | | 4 | | |
| 3 | 0 | 0 | 0 | 0 | 0 | | | 4 | 4 | 4 | |
| 4 | | 0 | 1 | 1 | | | | 4 | 4 | 4 | 4 |
| 5 | 0 | 0 | 1 | 1 | 2 | 3 | 4 | 4 | 4 | 4 | 4 |
| 6 | 0 | 0 | 1 | 2 | 3 | 3 | 4 | 4 | 5 | 5 | 5 |
| 7 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 5 | 5 | 5 | 5 |
| 8 | 0 | 0 | 1 | 2 | 3 | 4 | 6 | 6 | 5 | | |
| 9 | 0 | 0 | 1 | 2 | 3 | 5 | 8* | 6 | 6 | | |
| 10 | 0 | 0 | 0 | 2 | 3 | 5 | 6 | 6 | 5 | | |
| 11 | 0 | 0 | 0 | 1 | | 5 | | 6 | | | |
| 12 | 0 | 0 | 0 | | | 5 | | | | | |

**Increase for Effluent P = 200 ppb**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | | | 6 | | |
| 3 | 0 | 0 | 1 | 0 | 0 | | | 6 | 6 | 6 | |
| 4 | | 0 | 1 | 1 | | | | 6 | 6 | 6 | 6 |
| 5 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 6 | 6 | 6 |
| 6 | 0 | 0 | 1 | 2 | 3 | 5 | 5 | 6 | 6 | 6 | 6 |
| 7 | 0 | 0 | 1 | 2 | 4 | 5 | 6 | 6 | 6 | 6 | 6 |
| 8 | 0 | 0 | 1 | 2 | 4 | 6 | 7 | 7 | 7 | | |
| 9 | 0 | 0 | 1 | 2 | 4 | 7 | 10* | 9 | 8 | | |
| 10 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 8 | 7 | | |
| 11 | 0 | 0 | 0 | 1 | | 6 | | 8 | | | |
| 12 | 0 | 0 | 0 | | | 6 | | | | | |

**Increase for Effluent P = 200 ppb**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | | | 6 | | |
| 3 | 0 | 0 | 1 | 1 | 0 | | | 6 | 6 | 6 | |
| 4 | | 0 | 1 | 1 | | | | 6 | 6 | 6 | 6 |
| 5 | 0 | 0 | 1 | 2 | 4 | 5 | 5 | 6 | 6 | 6 | 6 |
| 6 | 0 | 0 | 1 | 2 | 4 | 5 | 6 | 6 | 6 | 6 | 6 |
| 7 | 0 | 0 | 1 | 3 | 4 | 5 | 6 | 7 | 7 | 7 | 7 |
| 8 | 0 | 0 | 1 | 3 | 4 | 6 | 7 | 8 | 8 | | |
| 9 | 0 | 0 | 1 | 3 | 5 | 7 | 11* | 9 | 8 | | |
| 10 | 0 | 0 | 1 | 2 | 5 | 7 | 9 | 8 | 7 | | |
| 11 | 0 | 0 | 0 | 1 | | 7 | | 8 | | | |
| 12 | 0 | 0 | 0 | | | 7 | | | | | |

# Figure IV-11
# Impacts of Alternative Discharge Concentrations - Case 2

**Case 2: Mean Flow Conditions**
**Simulated P Concentrations (ppb) without Hatchery**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | | | | |
| 2 | 10 | 12 | 13 | 13 | 12 | 12 | | | 15 | | |
| 3 | 9 | 12 | 14 | 14 | 13 | | | 15 | 15 | 15 | |
| 4 | | 13 | 14 | 14 | | | | 15 | 15 | 15 | 15 |
| 5 | 10 | 13 | 14 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| 6 | 11 | 13 | 14 | 14 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| 7 | 11 | 13 | 14 | 14 | 14 | 15 | 14 | 14 | 15 | 15 | 15 |
| 8 | 13 | 13 | 13 | 14 | 14 | 14 | 14 | 14 | 15 | | |
| 9 | 11 | 13 | 13 | 14 | 14 | 14 | 14 | 14 | 15 | | |
| 10 | 12 | 13 | 14 | 14 | 14 | 14 | 14 | 14 | 16 | | |
| 11 | 12 | 14 | 14 | 14 | | 14 | | 14 | | | |
| 12 | 13 | 16 | 16 | | | 14 | | | | | |

**Increase for Effluent P = 50 ppb**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | | | 0 | | |
| 3 | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | |
| 4 | | 0 | 0 | 0 | | | | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 1* | 0 | 0 | | |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 11 | 0 | 0 | 0 | | | 0 | | 0 | | | |
| 12 | 0 | 0 | 0 | | | 0 | | | | | |

**Increase for Effluent P = 100 ppb**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | | | 1 | | |
| 3 | 0 | 0 | 1 | 1 | 0 | | | 1 | 1 | 1 | |
| 4 | | 0 | 1 | 1 | | | | 1 | 1 | 1 | 1 |
| 5 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| 9 | 0 | 0 | 0 | 0 | 0 | 1 | 2* | 1 | 1 | | |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 11 | 0 | 0 | 0 | | | 0 | | 0 | | | |
| 12 | 0 | 0 | 0 | | | 0 | | | | | |

**Increase for Effluent P = 150 ppb**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 0 | 1 | 1 | 0 | 0 | | | 2 | | |
| 3 | 0 | 1 | 1 | 1 | 1 | | | 2 | 2 | 2 | |
| 4 | | 1 | 1 | 2 | | | | 2 | 2 | 2 | 2 |
| 5 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 6 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 7 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 8 | 0 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | | |
| 9 | 0 | 0 | 0 | 0 | 1 | 1 | 3* | 2 | 2 | | |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | | |
| 11 | 0 | 0 | 0 | | | 0 | | 1 | | | |
| 12 | 0 | 0 | 0 | | | 0 | | | | | |

**Increase for Effluent P = 200 ppb**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 1 | 1 | 1 | 1 | 0 | | | 3 | | |
| 3 | 0 | 1 | 2 | 2 | 1 | | | 3 | 3 | 3 | |
| 4 | | 1 | 2 | 2 | | | | 3 | 3 | 3 | 3 |
| 5 | 0 | 1 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 6 | 0 | 1 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 7 | 0 | 0 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 8 | 0 | 0 | 1 | 2 | 2 | 3 | 3 | 3 | 2 | | |
| 9 | 0 | 0 | 0 | 1 | 1 | 2 | 5* | 3 | 2 | | |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | | |
| 11 | 0 | 0 | 0 | | | 0 | | 1 | | | |
| 12 | 0 | 0 | 0 | | | 0 | | | | | |

**Case 2: Low Flow Conditions**
**Simulated P Concentrations (ppb) without Hatchery**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | | | | |
| 2 | 10 | 12 | 13 | 13 | 12 | 12 | | | 16 | | |
| 3 | 9 | 12 | 13 | 14 | 13 | | | 15 | 15 | 16 | |
| 4 | | 13 | 14 | 14 | | | | 15 | 15 | 16 | 16 |
| 5 | 10 | 13 | 14 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| 6 | 11 | 13 | 14 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| 7 | 11 | 13 | 14 | 14 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| 8 | 13 | 13 | 13 | 14 | 15 | 15 | 15 | 15 | 16 | | |
| 9 | 11 | 13 | 13 | 14 | 14 | 14 | 14 | 14 | 16 | | |
| 10 | 12 | 13 | 14 | 14 | 14 | 14 | 14 | 14 | 18 | | |
| 11 | 12 | 14 | 14 | 14 | | 14 | | 14 | | | |
| 12 | 13 | 16 | 15 | | | 14 | | | | | |

**Increase for Effluent P = 50 ppb**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | | | 1 | | |
| 3 | 0 | 0 | 0 | 0 | 0 | | | 1 | 1 | 1 | |
| 4 | | 0 | 0 | 0 | | | | 1 | 1 | 1 | 1 |
| 5 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | | |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 1* | 1 | 1 | | |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 11 | 0 | 0 | 0 | | | 0 | | 0 | | | |
| 12 | 0 | 0 | 0 | | | 0 | | | | | |

**Increase for Effluent P = 100 ppb**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 0 | 1 | 1 | 0 | 0 | | | 2 | | |
| 3 | 0 | 1 | 1 | 1 | 1 | | | 2 | 2 | 2 | |
| 4 | | 1 | 1 | 2 | | | | 2 | 2 | 2 | 2 |
| 5 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 6 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 7 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 |
| 8 | 0 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 2 | | |
| 9 | 0 | 0 | 0 | 1 | 1 | 2 | 4* | 3 | 2 | | |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | | |
| 11 | 0 | 0 | 0 | | | 0 | | 1 | | | |
| 12 | 0 | 0 | 0 | | | 0 | | | | | |

**Increase for Effluent P = 150 ppb**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 1 | 2 | 1 | 1 | 0 | | | 4 | | |
| 3 | 0 | 1 | 2 | 2 | 1 | | | 4 | 4 | 4 | |
| 4 | | 2 | 3 | 3 | | | | 4 | 4 | 4 | 4 |
| 5 | 0 | 1 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 6 | 0 | 1 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 7 | 0 | 1 | 2 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 8 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 4 | 4 | | |
| 9 | 0 | 0 | 0 | 1 | 2 | 3 | 6* | 5 | 4 | | |
| 10 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 2 | | |
| 11 | 0 | 0 | 0 | | | 1 | | 2 | | | |
| 12 | 0 | 0 | 0 | | | 1 | | | | | |

**Increase for Effluent P = 200 ppb**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| 2 | 0 | 1 | 2 | 2 | 1 | 0 | | | 5 | | |
| 3 | 0 | 2 | 3 | 3 | | | | 5 | 5 | 5 | |
| 4 | | 2 | 4 | 4 | | | | 5 | 5 | 5 | 5 |
| 5 | 0 | 2 | 4 | 5 | 5 | 6 | 6 | 5 | 6 | 5 | 5 |
| 6 | 0 | 2 | 4 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 5 |
| 7 | 0 | 1 | 3 | 4 | 5 | 6 | 6 | 6 | 6 | 5 | 5 |
| 8 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 6 | 5 | | |
| 9 | 0 | 0 | 1 | 2 | 3 | 4 | 9* | 7 | 5 | | |
| 10 | 0 | 0 | 0 | 0 | 1 | 1 | 3 | 3 | 3 | | |
| 11 | 0 | 0 | 0 | | | 1 | | 3 | | | |
| 12 | 0 | 0 | 0 | | | 1 | | | | | |

does not extend north of Thompson's Point. It is unlikely that such increases would occur. Expansion of the hydrodynamic model region would be required in order to correct this inadequacy in the Case 2 simulations.

Figures IV-12 and IV-13 illustrate sensitivities to discharge location for a fixed effluent concentration of 150 ppb under mean flow conditions. Because the transport models are linear, impacts for other discharge concentrations can be calculated by assuming that they are proportional to the effluent concentration minus the background concentration of 15 ppb (i.e., if the increase in a given cell is 9 ppb at a hatchery effluent concentration of 150 ppb, then the increase for a 100 ppb effluent would be 9 x (100-15)/(150-15) or 5.7 ppb). For both cases, there is a major qualitative difference between offshore locations and the shoreline discharge location (Col 11, Row 11) evaluated by Smeltzer (1985). For both cases, an increase of 30 ppb is indicated for the shoreline discharge, vs. a range of 2 to 10 ppb for other locations. Since both cases under-predict phosphorus concentrations at the shoreline discharge site (Figures IV-6 and IV-7), the differences between the shoreline and offshore dilution potentials are likely to be greater than those indicated by the simulations. The simulations suggest that moving the discharge location offshore vastly reduces impacts on phosphorus concentrations in the discharge cell.

Because of the counter-clockwise circulation patterns in the bay, Case 2 simulations indicate that moving the offshore discharge point (originally set at Column 10, Row 9) further out

## Figure IV-12
## Impacts of Alternative Discharge Locations - Case 1

**Simulated P Concentrations (ppb) without Hatchery**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | xxxx | xxxx | xxxx | xxxx |
| 2 | 10 | 11 | 12 | 12 | 12 | 13 | xxxx | 15 | xxxx | xxxx | xxxx |
| 3 | 9 | 10 | 12 | 12 | 12 | xxxx | 15 | 15 | 15 | xxxx | xxxx |
| 4 | xxxx | 11 | 12 | 12 | xxxx | xxxx | 15 | 15 | 15 | 15 | 15 |
| 5 | 10 | 11 | 12 | 12 | 13 | 14 | 14 | 14 | 15 | 15 | 15 |
| 6 | 11 | 11 | 12 | 13 | 13 | 14 | 14 | 15 | 15 | 15 | 15 |
| 7 | 11 | 12 | 13 | 13 | 13 | 14 | 14 | 15 | 15 | 15 | 15 |
| 8 | 13 | 12 | 13 | 13 | 14 | 14 | 15 | 15 | 16 | xxxx | xxxx |
| 9 | 11 | 12 | 13 | 13 | 14 | 14 | 15 | 16 | 17 | xxxx | xxxx |
| 10 | 12 | 13 | 13 | 14 | 14 | 15 | 15 | 17 | 21 | xxxx | xxxx |
| 11 | 12 | 13 | 14 | 14 | xxxx | 15 | xxxx | 17 | xxxx | xxxx | xxxx |
| 12 | 13 | 16 | 15 | xxxx | xxxx | 15 | xxxx | xxxx | xxxx | xxxx | xxxx |

**Increases for 150 ppb Hatchery Discharge at (*)**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx | xxxx | xxxx |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | 0 | xxxx | xxxx | xxxx |
| 3 | 0 | 0 | 0 | 0 | 0 | xxxx | 6 | 6 | 6 | xxxx | xxxx |
| 4 | xxxx | 0 | 0 | 1 | xxxx | xxxx | 6 | 6 | 6 | 6 | 6 |
| 5 | 0 | 0 | 0 | 1 | 3 | 4 | 5 | 5 | 6 | 6 | 6 |
| 6 | 0 | 0 | 0 | 1 | 3 | 4 | 5 | 6 | 6 | 6 | 6 |
| 7 | 0 | 0 | 0 | 2 | 3 | 4 | 5 | 7 | 7 | 6 | 6 |
| 8 | 0 | 0 | 0 | 1 | 3 | 4 | 6 | 9* | 7 | xxxx | xxxx |
| 9 | 0 | 0 | 0 | 1 | 3 | 4 | 5 | 7 | 7 | xxxx | xxxx |
| 10 | 0 | 0 | 0 | 1 | 2 | 4 | 5 | 6 | 5 | xxxx | xxxx |
| 11 | 0 | 0 | 0 | 0 | xxxx | 4 | xxxx | 6 | xxxx | xxxx | xxxx |
| 12 | 0 | 0 | 0 | xxxx | xxxx | 4 | xxxx | xxxx | xxxx | xxxx | xxxx |

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx | xxxx | xxxx |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | 5 | xxxx | xxxx | xxxx |
| 3 | 0 | 0 | 0 | 0 | 0 | xxxx | 5 | 5 | 5 | xxxx | xxxx |
| 4 | xxxx | 0 | 0 | 1 | xxxx | xxxx | 5 | 5 | 5 | 5 | 5 |
| 5 | 0 | 0 | 0 | 1 | 3 | 4 | 4 | 5 | 5 | 5 | 5 |
| 6 | 0 | 0 | 0 | 1 | 3 | 4 | 4 | 5 | 5 | 5 | 5 |
| 7 | 0 | 0 | 0 | 2 | 3 | 4 | 5 | 5 | 5 | 5 | 5 |
| 8 | 0 | 0 | 0 | 2 | 3 | 5 | 7* | 6 | 5 | xxxx | xxxx |
| 9 | 0 | 0 | 0 | 1 | 3 | 4 | 5 | 5 | 5 | xxxx | xxxx |
| 10 | 0 | 0 | 0 | 1 | 2 | 4 | 5 | 5 | 4 | xxxx | xxxx |
| 11 | 0 | 0 | 0 | 0 | xxxx | 4 | xxxx | 5 | xxxx | xxxx | xxxx |
| 12 | 0 | 0 | 0 | xxxx | xxxx | 4 | xxxx | xxxx | xxxx | xxxx | xxxx |

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx | xxxx | xxxx |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | 5 | xxxx | xxxx | xxxx |
| 3 | 0 | 0 | 0 | 0 | 0 | xxxx | 5 | 5 | 5 | xxxx | xxxx |
| 4 | xxxx | 0 | 0 | 1 | xxxx | xxxx | 5 | 5 | 5 | 5 | 5 |
| 5 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 5 | 5 | 5 |
| 6 | 0 | 0 | 0 | 1 | 3 | 4 | 4 | 5 | 5 | 5 | 5 |
| 7 | 0 | 0 | 0 | 1 | 3 | 4 | 5 | 6 | 6 | 6 | 6 |
| 8 | 0 | 0 | 0 | 2 | 3 | 4 | 5 | 7 | 7 | xxxx | xxxx |
| 9 | 0 | 0 | 0 | 1 | 3 | 4 | 6 | 10* | 8 | xxxx | xxxx |
| 10 | 0 | 0 | 0 | 1 | 3 | 4 | 6 | 7 | 7 | xxxx | xxxx |
| 11 | 0 | 0 | 0 | xxxx | xxxx | 4 | xxxx | 7 | xxxx | xxxx | xxxx |
| 12 | 0 | 0 | 0 | xxxx | xxxx | 4 | xxxx | xxxx | xxxx | xxxx | xxxx |

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx | xxxx | xxxx |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | 4 | xxxx | xxxx | xxxx |
| 3 | 0 | 0 | 0 | 0 | 0 | xxxx | 4 | 4 | 4 | xxxx | xxxx |
| 4 | xxxx | 0 | 0 | 1 | xxxx | xxxx | 4 | 4 | 4 | 4 | 4 |
| 5 | 0 | 0 | 0 | 1 | 2 | 3 | 3 | 4 | 4 | 4 | 4 |
| 6 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 4 | 4 | 4 | 4 |
| 7 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 4 | 5 | 4 | 4 |
| 8 | 0 | 0 | 0 | 1 | 3 | 4 | 5 | 5 | 5 | xxxx | xxxx |
| 9 | 0 | 0 | 0 | 1 | 3 | 5 | 7* | 6 | 5 | xxxx | xxxx |
| 10 | 0 | 0 | 0 | 1 | 3 | 4 | 6 | 6 | 5 | xxxx | xxxx |
| 11 | 0 | 0 | 0 | xxxx | xxxx | 4 | xxxx | 6 | xxxx | xxxx | xxxx |
| 12 | 0 | 0 | 0 | xxxx | xxxx | 4 | xxxx | xxxx | xxxx | xxxx | xxxx |

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx | xxxx | xxxx |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | 5 | xxxx | xxxx | xxxx |
| 3 | 0 | 0 | 0 | 0 | 0 | xxxx | 5 | 5 | 5 | xxxx | xxxx |
| 4 | xxxx | 0 | 0 | 1 | xxxx | xxxx | 5 | 5 | 5 | 5 | 5 |
| 5 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 5 | 5 | 5 |
| 6 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 5 | 5 | 5 |
| 7 | 0 | 0 | 0 | 1 | 3 | 4 | 5 | 5 | 5 | 5 | 5 |
| 8 | 0 | 0 | 0 | 2 | 3 | 4 | 5 | 6 | 6 | xxxx | xxxx |
| 9 | 0 | 0 | 0 | 2 | 3 | 4 | 6 | 8 | 8 | xxxx | xxxx |
| 10 | 0 | 0 | 0 | 1 | 3 | 5 | 7 | 12* | 9 | xxxx | xxxx |
| 11 | 0 | 0 | 0 | xxxx | xxxx | 5 | xxxx | 12 | xxxx | xxxx | xxxx |
| 12 | 0 | 0 | 0 | xxxx | xxxx | 5 | xxxx | xxxx | xxxx | xxxx | xxxx |

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx | xxxx | xxxx |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | 4 | xxxx | xxxx | xxxx |
| 3 | 0 | 0 | 0 | 0 | 0 | xxxx | 4 | 4 | 4 | xxxx | xxxx |
| 4 | xxxx | 0 | 0 | 1 | xxxx | xxxx | 4 | 4 | 4 | 4 | 4 |
| 5 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 4 | 4 | 4 | 4 |
| 6 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 4 | 4 | 4 | 4 |
| 7 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 4 | 5 | 4 | 4 |
| 8 | 0 | 0 | 0 | 2 | 3 | 4 | 5 | 5 | 5 | xxxx | xxxx |
| 9 | 0 | 0 | 0 | 2 | 3 | 5 | 6 | 6 | 6 | xxxx | xxxx |
| 10 | 0 | 0 | 0 | 2 | 3 | 6 | 9* | 7 | 6 | xxxx | xxxx |
| 11 | 0 | 0 | 0 | xxxx | xxxx | 6 | xxxx | 7 | xxxx | xxxx | xxxx |
| 12 | 0 | 0 | 0 | xxxx | xxxx | 6 | xxxx | xxxx | xxxx | xxxx | xxxx |

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx | xxxx | xxxx |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | 5 | xxxx | xxxx | xxxx |
| 3 | 0 | 0 | 0 | 0 | 0 | xxxx | 5 | 5 | 5 | xxxx | xxxx |
| 4 | xxxx | 0 | 0 | 1 | xxxx | xxxx | 5 | 5 | 5 | 5 | 5 |
| 5 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 5 | 5 | 5 |
| 6 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 5 | 5 | 5 |
| 7 | 0 | 0 | 0 | 1 | 3 | 4 | 5 | 5 | 5 | 5 | 5 |
| 8 | 0 | 0 | 0 | 2 | 3 | 4 | 5 | 6 | 6 | xxxx | xxxx |
| 9 | 0 | 0 | 0 | 2 | 3 | 4 | 6 | 8 | 8 | xxxx | xxxx |
| 10 | 0 | 0 | 0 | 1 | 3 | 5 | 7 | 12 | 9 | xxxx | xxxx |
| 11 | 0 | 0 | 0 | xxxx | xxxx | 5 | xxxx | 30* | xxxx | xxxx | xxxx |
| 12 | 0 | 0 | 0 | xxxx | xxxx | 5 | xxxx | xxxx | xxxx | xxxx | xxxx |

## Figure IV-13
## Impacts of Alternative Discharge Locations - Case 2

**Simulated P Concentrations (ppb) without Hatchery**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | xxxx | xxxx | xxxx | xxxx |
| 2 | 10 | 12 | 13 | 13 | 12 | 12 | xxxx | xxxx | 13 | xxxx | xxxx |
| 3 | 9 | 12 | 14 | 14 | 13 | xxxx | xxxx | 15 | 15 | 15 | xxxx |
| 4 | xxxx | 13 | 14 | 14 | xxxx | xxxx | xxxx | 15 | 15 | 15 | 15 |
| 5 | 10 | 13 | 14 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| 6 | 11 | 13 | 14 | 14 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| 7 | 11 | 13 | 14 | 14 | 14 | 15 | 14 | 14 | 15 | 15 | 15 |
| 8 | 13 | 13 | 13 | 14 | 14 | 14 | 14 | 14 | 15 | xxxx | xxxx |
| 9 | 11 | 13 | 13 | 14 | 14 | 14 | 14 | 14 | 15 | xxxx | xxxx |
| 10 | 12 | 13 | 14 | 14 | 14 | 14 | 14 | 14 | 16 | xxxx | xxxx |
| 11 | 12 | 14 | 14 | 14 | xxxx | 14 | xxxx | 14 | xxxx | xxxx | xxxx |
| 12 | 13 | 16 | 16 | xxxx | xxxx | 14 | xxxx | xxxx | xxxx | xxxx | xxxx |

**Increases for Discharge of 150 ppb at ⊛**

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx | xxxx | xxxx |
| 2 | 0 | 1 | 1 | 1 | 0 | 0 | xxxx | xxxx | 2 | xxxx | xxxx |
| 3 | 0 | 1 | 1 | 1 | 1 | xxxx | xxxx | 2 | 2 | 2 | xxxx |
| 4 | xxxx | 1 | 2 | 2 | xxxx | xxxx | xxxx | 2 | 2 | 2 | 2 |
| 5 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 6 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 7 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 8 | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 3* | 1 | xxxx | xxxx |
| 9 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 1 | 1 | xxxx | xxxx |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx |
| 11 | 0 | 0 | 0 | 0 | xxxx | 0 | xxxx | 0 | xxxx | xxxx | xxxx |
| 12 | 0 | 0 | 0 | xxxx | xxxx | 0 | xxxx | xxxx | xxxx | xxxx | xxxx |

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx | xxxx | xxxx |
| 2 | 0 | 1 | 1 | 1 | 0 | 0 | xxxx | xxxx | 2 | xxxx | xxxx |
| 3 | 0 | 1 | 1 | 1 | 1 | xxxx | xxxx | 2 | 2 | 2 | xxxx |
| 4 | xxxx | 1 | 2 | 2 | xxxx | xxxx | xxxx | 2 | 2 | 2 | 2 |
| 5 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 6 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 7 | 0 | 0 | 1 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 2 |
| 8 | 0 | 0 | 1 | 1 | 2 | 3 | 6* | 2 | 1 | xxxx | xxxx |
| 9 | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 2 | 1 | xxxx | xxxx |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | xxxx | xxxx |
| 11 | 0 | 0 | 0 | 0 | xxxx | 0 | xxxx | 1 | xxxx | xxxx | xxxx |
| 12 | 0 | 0 | 0 | xxxx | xxxx | 0 | xxxx | xxxx | xxxx | xxxx | xxxx |

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx | xxxx | xxxx |
| 2 | 0 | 1 | 1 | 1 | 0 | 0 | xxxx | xxxx | 2 | xxxx | xxxx |
| 3 | 0 | 1 | 1 | 1 | 1 | xxxx | xxxx | 2 | 2 | 2 | xxxx |
| 4 | xxxx | 1 | 2 | 2 | xxxx | xxxx | xxxx | 2 | 2 | 2 | 2 |
| 5 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 6 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 7 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 8 | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | xxxx | xxxx |
| 9 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 1 | 1 | xxxx | xxxx |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx |
| 11 | 0 | 0 | 0 | 0 | xxxx | 0 | xxxx | 0 | xxxx | xxxx | xxxx |
| 12 | 0 | 0 | 0 | xxxx | xxxx | 0 | xxxx | xxxx | xxxx | xxxx | xxxx |

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx | xxxx | xxxx |
| 2 | 0 | 1 | 1 | 1 | 0 | 0 | xxxx | xxxx | 2 | xxxx | xxxx |
| 3 | 0 | 1 | 1 | 1 | 1 | xxxx | xxxx | 2 | 2 | 2 | xxxx |
| 4 | xxxx | 1 | 2 | 2 | xxxx | xxxx | xxxx | 2 | 2 | 2 | 2 |
| 5 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 6 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 7 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 8 | 0 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | xxxx | xxxx |
| 9 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 2 | xxxx | xxxx |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2* | 2 | xxxx | xxxx |
| 11 | 0 | 0 | 0 | 0 | xxxx | 0 | xxxx | 2 | xxxx | xxxx | xxxx |
| 12 | 0 | 0 | 0 | xxxx | xxxx | 0 | xxxx | xxxx | xxxx | xxxx | xxxx |

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx | xxxx | xxxx |
| 2 | 0 | 1 | 1 | 1 | 0 | 0 | xxxx | xxxx | 2 | xxxx | xxxx |
| 3 | 0 | 1 | 1 | 1 | 1 | xxxx | xxxx | 2 | 2 | 2 | xxxx |
| 4 | xxxx | 1 | 2 | 2 | xxxx | xxxx | xxxx | 2 | 2 | 2 | 2 |
| 5 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 6 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 7 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 8 | 0 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | xxxx | xxxx |
| 9 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 2 | xxxx | xxxx |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2* | 2 | xxxx | xxxx |
| 11 | 0 | 0 | 0 | 0 | xxxx | 0 | xxxx | 2 | xxxx | xxxx | xxxx |
| 12 | 0 | 0 | 0 | xxxx | xxxx | 0 | xxxx | xxxx | xxxx | xxxx | xxxx |

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx | xxxx | xxxx |
| 2 | 0 | 1 | 1 | 1 | 0 | 0 | xxxx | xxxx | 2 | xxxx | xxxx |
| 3 | 0 | 1 | 1 | 1 | 1 | xxxx | xxxx | 2 | 2 | 2 | xxxx |
| 4 | xxxx | 1 | 2 | 2 | xxxx | xxxx | xxxx | 2 | 2 | 2 | 2 |
| 5 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 6 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 7 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 8 | 0 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | xxxx | xxxx |
| 9 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 2 | xxxx | xxxx |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | xxxx | xxxx |
| 11 | 0 | 0 | 0 | 0 | xxxx | 0 | xxxx | 30* | xxxx | xxxx | xxxx |
| 12 | 0 | 0 | 0 | xxxx | xxxx | 0 | xxxx | xxxx | xxxx | xxxx | xxxx |

into the bay (Col 10, Row 8) would increase the localized impact from 3 to 6 ppb. Conversely, moving the discharge south (to Column 10, Row 10) would reduce the maximum impact from 3 to 2 ppb. Case 1 simulations indicate, however, that moving the offshore discharge south would increase the maximum impact from 7 and 9 ppb. The differences between Cases 1 and 2 with respect to the effects of moving the discharge cell reflect fundamental differences in the transport matrices. As discussed above, the Case 2 simulations are considered to be more realistic, but current velocity measurements in the discharge region would further help to distinguish between the two sets of simulations and to optimize outfall placement. Such measurements seem justifiable, given the considerable cost savings which would result from moving the offshore discharge cell to the south. Given its depth (8 meters), remoteness from weed beds, proximity to the hatchery, and the simulation results for Case 2, Column 10 Row 10 should be seriously considered as an alternative offshore discharge location.

Calculated water balances on the hatchery discharge cell are summarized in Table IV-4 for each case under mean flow conditions. Transport to and from the cell amounts to between 63 and 78 times the maximum hatchery discharge rate. The hydraulic residence time in the cell (volume/total outflow) is on the order of .5 to .6 days. Because of kinetic considerations, it is unlikely that algal populations would respond to localized increases in phosphorus over such a limited time scale. The reason for this is that algal cells would be flushed out of the region faster than they could respond to the localized increase

Table IV-4
Water Balances for Hatchery Offshore Discharge Cell

| Variable | Units | Case 1 | Case 2 1984 | Case 2 Mean |
|---|---|---|---|---|
| Effluent Flow | $m^3$/day | 42000 | 42000 | 42000 |
| Dispersion Coef | $m^2$/day | 70000 | 20000 | 20000 |
| Exchange Flows | $m^3$/day | | | |
| East | | 595000 | 170000 | 170000 |
| North | | 700000 | 200000 | 200000 |
| West | | 700000 | 200000 | 200000 |
| South | | 630000 | 180000 | 180000 |
| Total | | 2625000 | 750000 | 750000 |
| Advective Outflows | $m^3$/day | | | |
| To East | | 0 | 1582000 | 2197000 |
| To South | | 0 | 580000 | 270000 |
| To North | | 0 | 48000 | 0 |
| Total | | 0 | 2210000 | 2467000 |
| Advective Inflows | $m^3$/day | | | |
| From North | | 0 | 0 | 555000 |
| From West | | 0 | 2210000 | 1912000 |
| Total | | 0 | 2210000 | 2467000 |
| Total Inflow | $m^3$/day | 2667000 | 3001000 | 3259000 |
| Cell Volume | $m^3$ | 1600000 | 1600000 | 1600000 |
| Dilution Ratio | - | 63.5 | 71.5 | 77.6 |
| Residence Time | days | .61 | .54 | .50 |

Water Balance for Discharge Cell - Column 10, Row 9
Total Inflow = Exchange + Advective Inflow + Hatchery
Dilution Ratio = Total Inflow / Hatchery Discharge
Residence Time = Cell Volume / Total Inflow

in concentration. Generally, hydraulic residence times on the order of 1 to 2 weeks are required for algal populations to "equilibrate" with available nutrient levels in impoundments (Walker,1985b). Because of residence time considerations, it seems unlikely a phosphorus increase in the offshore discharge cell would result in a proportionate increase in algal density and reduction in transparency under average conditions, unless equivalent phosphorus increases were experienced in adjacent cells.

Table IV-5 presents water and mass balances for the entire bay east of Thompson's Point under mean flow conditions. For demonstration purposes, a hatchery effluent concentration of 150 ppb is assumed. Results for other assumed concentrations can be readily calculated. In constructing the phosphorus balances, an average concentration of 14 ppb is assumed for waters entering the bay from the open lake (Column 7). Based upon simulation results, this approximation is probably accurate to within 1 ppb for the cases considered. For these conditions, the hatchery discharge would amount to 9 to 12 percent of the total phosphorus loading to the bay. This provides a rough indication of the potential hatchery impacts when a spatial scale of this magnitude (7.5 km2) is considered. Computed hydraulic residence times (12 to 18 days) seem sufficient to permit algal responses to increases in bay-mean phosphorus concentrations caused by the hatchery discharge. Based upon residence time considerations, the bay scale seems to be more realistic than the single grid cell as a basis for evaluating the impacts of the hatchery

Table IV-5
Water and Mass Balances for Hawkins Bay

| Variable | Units | Case 1 | Case 2 Mean | Case 2 1984 |
|---|---|---|---|---|
| Bay Area | $m^2$ | 7520000 | 7520000 | 7520000 |
| Bay Volume | $m^3$ | 54144000 | 54144000 | 54144000 |
| Dispersion Coefficient | $m^2$/day | 70000 | 20000 | 20000 |
| Atmospheric P Load | mg/$m^2$-day | 0.055 | 0.055 | 0.055 |
| P Decay Rate | $day^{-1}$ | 0.001 | 0.001 | 0.001 |
| Inflows | $m^3$/day | | | |
| Tributaries | | 51000 | 51000 | 51000 |
| Hatchery | | 42000 | 42000 | 42000 |
| Advective Inflow | | 0 | 2539000 | 1702000 |
| Dispersive Inflow | | 4200000 | 1200000 | 1200000 |
| Total From Main Lake | | 4200000 | 3739000 | 2902000 |
| Total Bay Inflow | | 4293000 | 3832000 | 2995000 |
| Inflow Concentrations | ppb | | | |
| Tributaries | | 61 | 61 | 61 |
| Hatchery | | 150 | 150 | 150 |
| Main Lake | | 14 | 14 | 14 |
| Inflow Loads | mg/day | | | |
| Tributaries | | 3111000 | 3111000 | 3111000 |
| Hatchery | | 6300000 | 6300000 | 6300000 |
| From Main Lake | | 58800000 | 52346000 | 40628000 |
| Atmospheric | | 413600 | 413600 | 413600 |
| Total Inflow Load | | 68624600 | 62170600 | 50452600 |
| Bay Inflow Concentration | ppb | 16.0 | 16.2 | 16.8 |
| Hydraulic Residence Time | days | 12.6 | 14.1 | 18.1 |
| P Retention Coefficient | | 0.012 | 0.014 | 0.018 |
| P Residence Time | days | 12.5 | 13.9 | 17.8 |
| Outflow Loads | mg/day | | | |
| Sedimentation | | 854724 | 866197 | 895893 |
| To Main Lake | | 67769876 | 61304403 | 49556707 |
| Total Outflow Load | | 68624600 | 62170600 | 50452600 |

Calculations for Hawkins Bay, East of and Including Column 8

discharge on algal density and transparency.

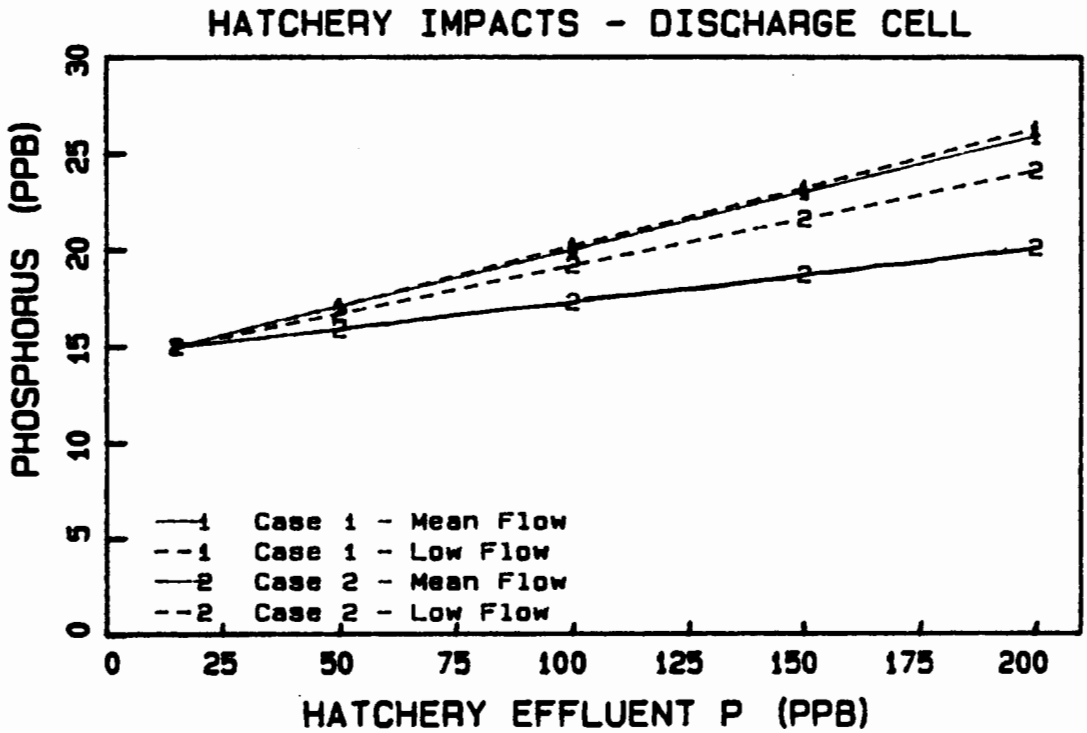
The mass balances in Table IV-5 indicate that flushing rate and transport from the open lake waters are major factors controlling phosphorus concentrations in the bay. The estimated sedimentation of phosphorus within the bay is negligible in relation to that removed by flushing. Phosphorus residence times (12 to 18 days) are similar to hydraulic residence times and provide rough indications of the time scales required for the bay concentrations to respond to changes in loading regime. Since generally 2 to 3 residence times are required for equilibration, an averaging period of 1 to 2 months appears reasonable for evaluating discharge impacts on average bay conditions.

By computing average concentrations in the bay for each case and hatchery discharge concentration, a relationship between hatchery impacts on phosphorus concentrations in the offshore discharge cell and impacts on bay-mean phosphorus concentration has been developed. This relationship indicates that bay-mean impacts average 60% of the discharge cell impacts (range 55 to 62% for the various cases and discharge concentrations considered in Figures IV-10 and IV-11). Impact is defined as the increase in phosphorus concentration caused by a given hatchery discharge concentration. A concentration of 15 ppb adequately characterizes existing conditions during August and September for both spatial scales. These relationships, combined with the phosphorus/transparency model described by Smeltzer (1985) (1/Secchi = .0093 P + .058) can be used to express model predictions in terms of phosphorus and transparency levels for various discharge concentrations and over both spatial scales.

Results are displayed in Figure IV-14 for impacts on the offshore discharge cell and in Figure IV-15 for impacts on bay-mean conditions. The plots indicate likely ranges of hatchery impacts for the various cases and flow conditions evaluated. As discussed above, it seems unlikely that effects on algal growth and transparency would be fully expressed within the discharge cell because of residence time considerations. Monitoring data from Lake Champlain (Bryant,1980) indicate seasonal transparency variations between 2 and 8 meters at Thompsons Point. In the context of these normal seasonal variations, reductions in mean transparency over the ranges shown in Figure IV-15 would be difficult to detect via casual observation or via intensive monitoring.

The Vermont Department of Water Resources has suggested that the impacts of the hatchery be limited to a 5 ppb increase in ambient phosphorus concentration during the critical August and September period, when mixing rates in Hawkins Bay are relatively low and when climatologic conditions are conducive to algal growth. It has been projected by the Vermont Department of Fish and Wildlife that, under conditions of full fish production, the hatchery effluent will contain 182 ppb of phosphorus at a flow rate of 11.5 million gallons/day during August and September. Figure IV-16 illustrates the projected impacts of this discharge on phosphorus concentrations in the bay under average flows and prevailing winds. These impacts are based upon Case 2 simulations, which are judged to be the most reliable for reasons discussed above. Results of sensitivity analyses for

Figure IV-14
Impacts on Mean Phosphorus and Transparency in Discharge Cell



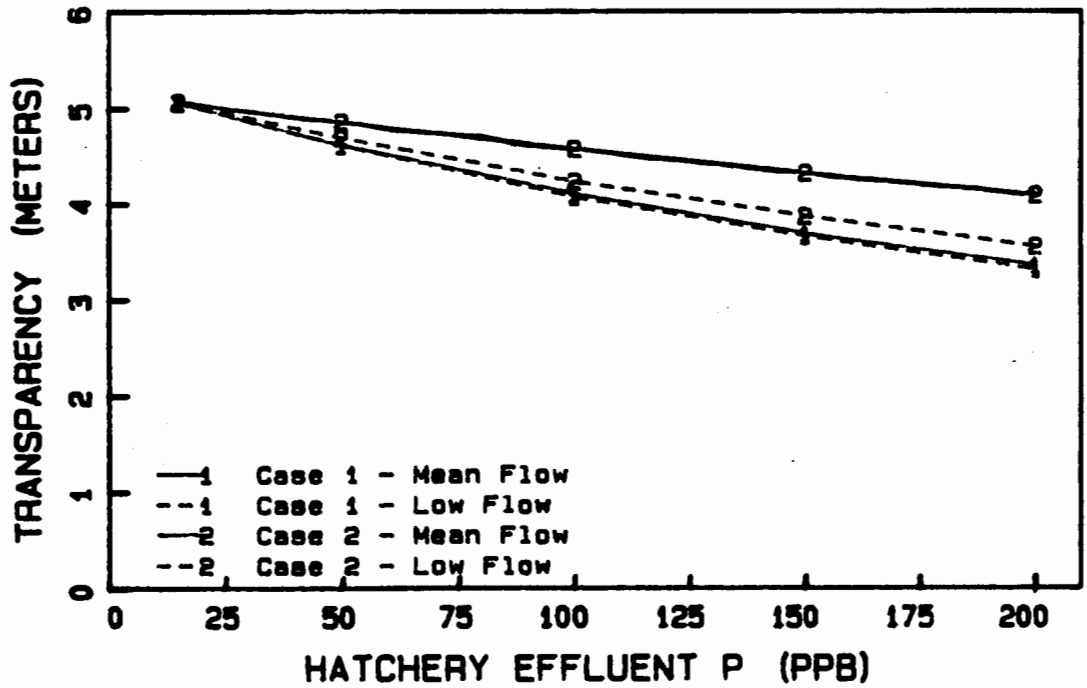
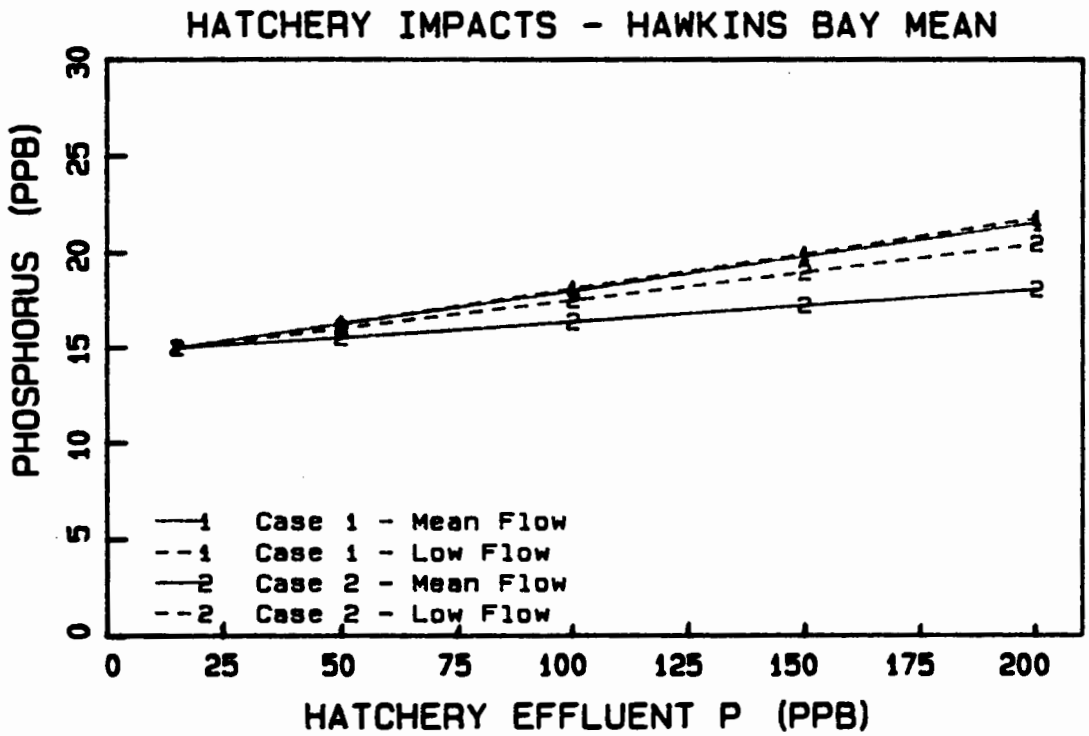



Figure IV-15
Impacts on Mean Phosphorus and Transparency in Hawkins Bay



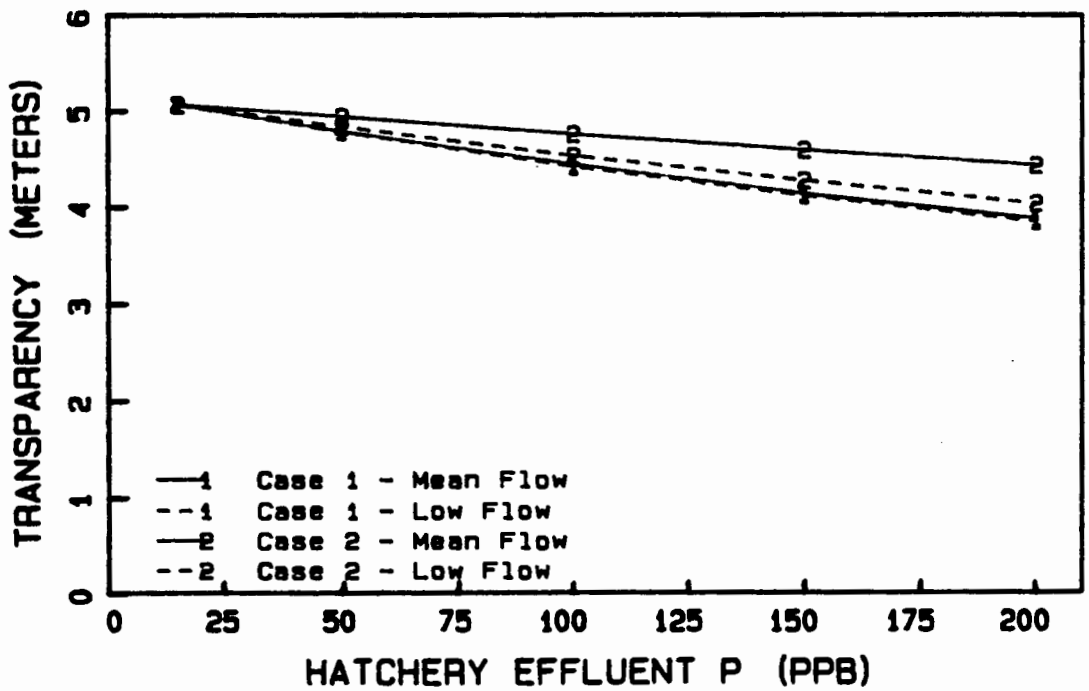



Figure IV-16
Mean Impacts of Hatchery at Full Production
Effluent P = 182 ppb, Mean Flow Conditions, Case 2

Simulated Phosphorus Concentrations (ppb) Without Hatchery

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | xxxx | xxxx | xxxx | xxxx |
| 2 | 10 | 12 | 13 | 13 | 12 | 12 | xxxx | xxxx | 15 | xxxx | xxxx |
| 3 | 9 | 12 | 14 | 14 | 13 | xxxx | xxxx | 15 | 15 | 15 | xxxx |
| 4 | xxxx | 13 | 14 | 14 | xxxx | xxxx | xxxx | 15 | 15 | 15 | 15 |
| 5 | 10 | 13 | 14 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| 6 | 11 | 13 | 14 | 14 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| 7 | 11 | 13 | 14 | 14 | 14 | 15 | 14 | 14 | 15 | 15 | 15 |
| 8 | 13 | 13 | 13 | 14 | 14 | 14 | 14 | 14 | 15 | xxxx | xxxx |
| 9 | 11 | 13 | 13 | 14 | 14 | 14 | 14 | 14 | 15 | xxxx | xxxx |
| 10 | 12 | 13 | 14 | 14 | 14 | 14 | 14 | 14 | 16 | xxxx | xxxx |
| 11 | 12 | 14 | 14 | 14 | xxxx | 14 | xxxx | 14 | xxxx | xxxx | xxxx |
| 12 | 13 | 16 | 16 | xxxx | xxxx | 14 | xxxx | xxxx | xxxx | xxxx | xxxx |

Simulated Phosphorus Concentrations (ppb) With Hatchery

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | xxxx | xxxx | xxxx | xxxx |
| 2 | 10 | 13 | 15 | 15 | 13 | 12 | xxxx | xxxx | 18 | xxxx | xxxx |
| 3 | 9 | 14 | 16 | 16 | 15 | xxxx | xxxx | 18 | 18 | 18 | xxxx |
| 4 | xxxx | 15 | 16 | 17 | xxxx | xxxx | xxxx | 18 | 18 | 18 | 18 |
| 5 | 10 | 14 | 17 | 17 | 17 | 17 | 18 | 18 | 18 | 18 | 18 |
| 6 | 11 | 14 | 16 | 17 | 17 | 18 | 18 | 18 | 18 | 18 | 18 |
| 7 | 11 | 14 | 16 | 17 | 17 | 18 | 18 | 18 | 18 | 18 | 18 |
| 8 | 13 | 13 | 15 | 16 | 17 | 17 | 18 | 18 | 17 | xxxx | xxxx |
| 9 | 11 | 13 | 14 | 15 | 16 | 17 | 19* | 18 | 17 | xxxx | xxxx |
| 10 | 12 | 13 | 14 | 14 | 14 | 15 | 15 | 15 | 17 | xxxx | xxxx |
| 11 | 12 | 14 | 14 | 14 | xxxx | 14 | xxxx | 15 | xxxx | xxxx | xxxx |
| 12 | 13 | 16 | 16 | xxxx | xxxx | 14 | xxxx | xxxx | xxxx | xxxx | xxxx |

Phosphorus Increase (ppb)

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | xxxx | xxxx | xxxx | xxxx |
| 2 | 0 | 1 | 1 | 1 | 0 | 0 | xxxx | xxxx | 2 | xxxx | xxxx |
| 3 | 0 | 1 | 2 | 2 | 1 | xxxx | xxxx | 2 | 2 | 2 | xxxx |
| 4 | xxxx | 1 | 2 | 2 | xxxx | xxxx | xxxx | 2 | 2 | 2 | 2 |
| 5 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 6 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 7 | 0 | 0 | 1 | 2 | 2 | 2 | 3 | 3 | 2 | 2 | 2 |
| 8 | 0 | 0 | 1 | 2 | 2 | 2 | 3 | 3 | 2 | xxxx | xxxx |
| 9 | 0 | 0 | 0 | 1 | 1 | 2 | 4* | 3 | 2 | xxxx | xxxx |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | xxxx | xxxx |
| 11 | 0 | 0 | 0 | 0 | xxxx | 0 | xxxx | 1 | xxxx | xxxx | xxxx |
| 12 | 0 | 0 | 0 | xxxx | xxxx | 0 | xxxx | xxxx | xxxx | xxxx | xxxx |

* Hatchery Discharge Location

alternative flow conditions, model parameters, and outfall locations are summarized in Table IV-6.

Simulations indicate that an offshore 182 ppb discharge would cause a 4.7 ppb increase in the mean phosphorus concentration of the immediate discharge zone and a 2.6 ppb increase in the mean concentration of Hawkins Bay under average flow and wind conditions for August and September. Corresponding increases under critical periods of low flow and low wind speeds occurring at a ten-year frequency are estimated to be 8.3 ppb for the immediate discharge zone and 4.9 ppb for the bay. While the increase may exceed 5 ppb within the discharge cell during periods of low wind and/or flow, it is unlikely that the bay-mean increase (considered a better indicator of potential biological and aesthetic impacts) would exceed 5 ppb more frequently than once every ten years.

Table IV-6 indicates that simulations of the 182 ppb discharge are relatively insensitive to the assumed dispersion coefficient over a relatively wide range of 1000 to 40,000 m2/day. Thus, Case 2 projections do not depend strongly upon the calibration process, but are controlled primarily by the estimates of wind-induced currents derived from the independent hydrodynamic model. Moving the offshore discharge south (to Column 10, Row 10) reduces the mean impact in the discharge cell from 4.7 to 3.5 ppb. As discussed above, additional field studies and analysis are recommended to support optimization of the offshore discharge location, given economic and water quality impact considerations.

Table IV-6
Sensitivity Analysis of Hatchery Impacts for
Discharge Concentration of 182 ppb

| Condition | Increase in Phosphorus (ppb) Discharge Cell | Bay Mean |
|---|---|---|
| **Case 2 Simulations - Including Wind Mixing** | | |
| Mean Flow * | 4.7 | 2.6 |
| 10-Year Low Flow | 8.3 | 4.9 |
| Dispersion = 1000 $m^2$/day | 5.4 | 2.6 |
| Dispersion = 40,000 $m^2$/day | 4.1 | 2.5 |
| Discharge at Col 10, Row 10 | 3.5 | 2.7 |
| Southeast Wind (Aug/Sep 1984) | 4.7 | 3.7 |
| **Case 1 Simulations - Excluding Wind Mixing** | | |
| Mean Flow | 9.9 | 5.9 |
| 10-Year Low Flow | 10.2 | 6.3 |

* Base Conditions for Hatchery Impact Evaluations
Case 2 Simulations
Discharge at Column 10, Row 9
Mean Flows
Prevailing Southwest Winds for August/September
Dispersion Coef. = 20,000 $m^2$/day

Bay Mean = Area East of and Including Column 8

E. Conclusions

(1) A hydrodynamic model has been linked with a mass-balance model to predict the impacts of an offshore hatchery discharge on phosphorus concentrations in and around Hawkins Bay. Direct consideration of wind-induced currents improves the validity of the model as a tool for evaluating the offshore discharge. The sensitivities of the projected impacts to discharge location, discharge concentration, and key modeling assumptions have been evaluated.

(2) As compared with the shoreline discharge location evaluated previously by the Vermont Department of Water Resources, an offshore discharge would provide considerably greater dilution potential and reduce the local impacts of a given effluent concentration.

(3) There is considerable latitude in the selecting a specific location for the offshore discharge. Additional field data (current measurements) would be required to support model refinements and evaluation of specific offshore locations. Such measurements seem justified, given outfall economics. Based upon hydrodynamic model simulations, it may be feasible to shorten the previously proposed 3000-ft outfall while, at the same time, reducing local impacts.

(4) Because of the limited residence time in the discharge cell (.5 to .6 days), it is unlikely that localized increases in phosphorus concentration would be fully expressed in terms of proportionate increases in mean algal concentrations and reductions in mean transparency within the discharge cell. Expressed in terms of increases in phosphorus concentration

relative to existing conditions (averaging 15 ppb), hatchery impacts on average concentrations in the entire bay east of Thompson's Point (7.5 km2) would be roughly 60% of the impacts on the offshore discharge cell (.16 km2). The mean hydraulic residence time of the bay is on the order of 12 to 18 days and is sufficient to permit algal responses to changes in nutrient concentrations.

(5) At full fish production, an offshore hatchery discharge of 11.5 mgd and 182 ppb would cause less than 5 ppb increase in the phosphorus concentration in the immediate discharge zone and less than a 3 ppb increase in the bay-mean phosphorus concentration under average August and September conditions. Corresponding increases under critical periods of low flows and low wind speeds experienced at a ten-year frequency would be less than 9 and 5 ppb, respectively.

## V. PHOSPHORUS LOADING TO LAKE CHAMPLAIN

Phosphorus has a critical and controlling influence on plant productivity (i.e. trophic state) in Lake Champlain (USEPA, 1974; Henson and Gruendling, 1977). Phosphorus loading from external sources has been found to be a good predictor of plant productivity for many lakes. Phosphorus sources are of two types, point, and nonpoint, or diffuse, sources. The principle focus of this study has been the potential near shore impact of the anticipated phosphorus load in the vincinity of the proposed hatchery discharge. In this section the annual phosphorus loading anticipated from the hatchery is considered from the perspective of the total load presently received by the entire lake.

A number of efforts have been made to estimate the annual loading of total phosphorus to Lake Champlain (e.g. Bogden, 1978; Henson and Gruendling, 1977). The estimates of Bogden (1978) are the most recent; these are utilized here to place into perspective the phosphorus loading anticipated from the hatchery. Major features of Bogden's (1978) estimates are presented in Table V-1, along with preliminary estimates of the annual discharge of phosphorus anticipated from the hatchery.

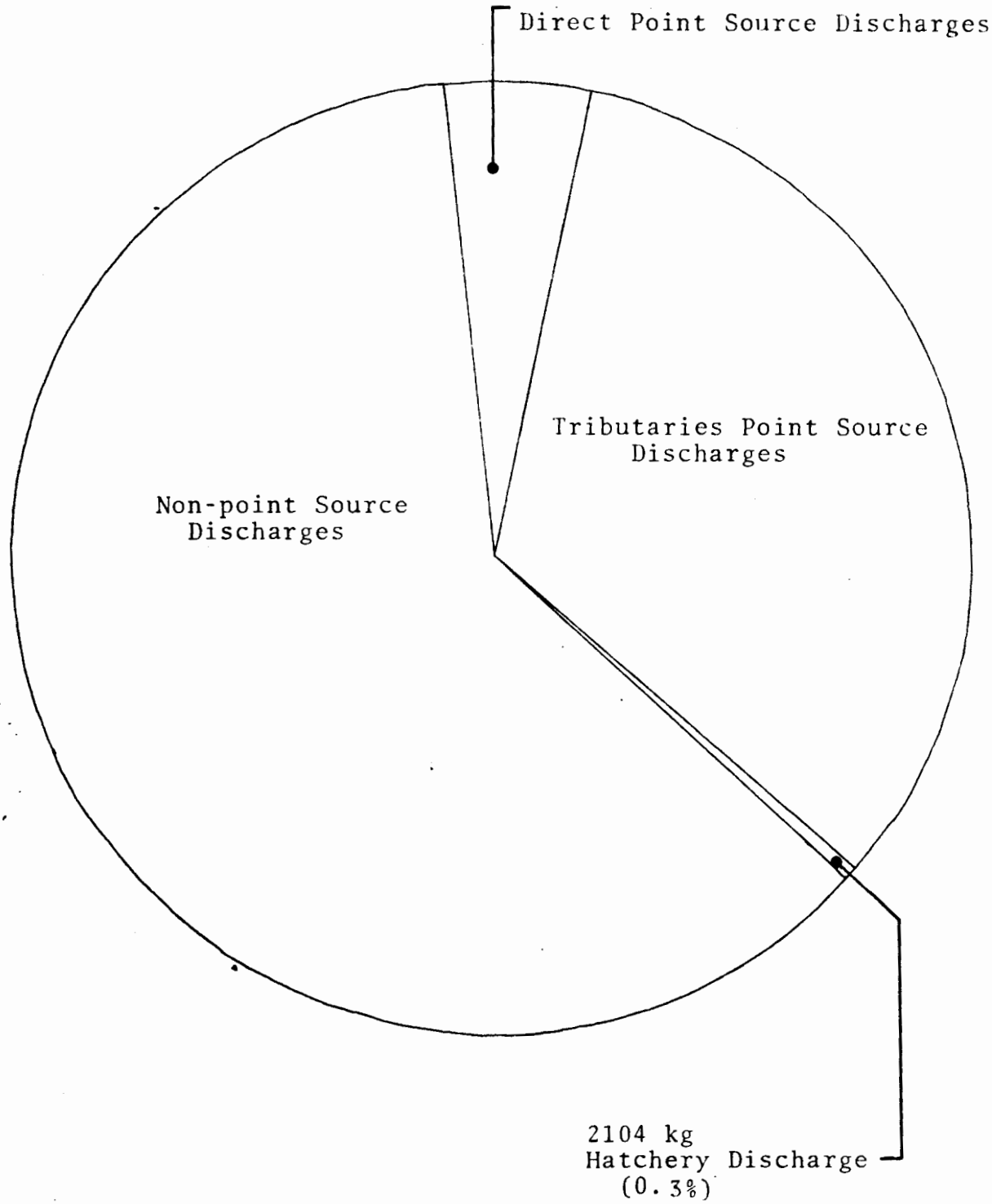
The point source discharges include municipal and industrial wastewaters. Some minor reductions in point source loading may have been achieved in the interim (i.e. since the work of Bogden (1978)), associated with the upgrading of sewage treatment plants. The range presented for nonpoint sources reflects the application of four different methods to estimate this form of loading. All the methods are believed to underestimate the

TABLE V-1

Estimates of Annual Phosphorus Loadings to Lake Champlain in 1978 (Bogden, 1978), and Estimates of Annual Phosphorus Loading from Proposed Hatchery.

| Loading Type | Load (kg/yr) |
|---|---|
| Point Sources | |
| Lake Champlain Proper | 38,800 |
| Lake Champlain Tributaries | 268,000 |
| Point Sources Sub-total | 306,800 |
| Non-point Sources* | 274,000 to 418,000 |
| Grand Total | |
| Minimum | 536,000 |
| Mean | 636,000 |
| Maximum | 804,300 |
| Hatchery | |
| Start-up | 1179 |
| Full capacity | 2104 |

* range of estimates resulting from application of four different methods.




Figuure V-1 Lake Champlain Annual Phosphorus Loadings.

nonpoint-source load to Lake Champlain (Bogden, 1978). The various total loadings presented (minimum,mean, and maximum) reflect the incorporation of various non-point estimates; the point source loading component was the same in each of the three cases. The "minimum" estimate incorporated the minimum non-point value; the "mean" incorporated the average of the four different non-point estimative techniques; the "maximum" utilized the highest of the four non-point estimates. The "maximum" loading rate may underestimate the true loading rate to Lake Champlain (Bogden, 1978) because of the sampling regime utilized to develop phosphorus loading information from the tributaries.

The two different phosphorus loads presented for the proposed fish hatchery reflect full capacity and start-up levels (60%) of fish production, and nearly proportional utilization of phosphorus containing fish food. The development of these estimates of phosphorus loading associated with different levels of fish production has been fully documented elsewhere (Wiggins, 1985).

At full-scale production the estimated increased phosphorus load to the lake would be approximately 0.30 percent. The relative contribution of the hatchery load to the total load is illustrated in Figure V-1.

## REFERENCES


1. Bogden, K.G. 1978. Estimates of the Annual Loading of Total Phosphorus to Lake Champlain. Lake Champlain Basin Study New England River Basins Commission, Burlington, Vermont.

2. Henson, E.B. and Gruendling, G.K. 1977. The Tophic Status and Phosphorus Loadings of Lake Champlain. United States Environmental Protection Agency, Ecological Reseach Series.

3. Jirka, G.H. 1982. Multiport Diffusers for Heat Disposal: A Summary. Jour. Hydraulics Div., ASCE: 108:1425-1468.

4. Lash, J. 1985. Memorandum to John Dooley, Subject: Hatchery. November 4, 1985.

5. Smeltzer, E. 1984. Eutrophication Impact of the Proposed Lake Champlain Fish Hatchery Discharge. Memorandum to V. Garrison. Vermont Dept. Water Res. Env. Eng. February 27.

6. Smeltzer, E. 1985. Lake Champlain Fish Hatchery Discharge Study. Vermont Department of Water Resources and Environmental Engineering.

7. Upstate Freshwater Institute. 1985. Enhancing Effluent Dispersion Utilizing Diffuser Technology for a Hatchery Discharge. For the State of Vermont Department of Fish and Wildlife. December.

8. United States Environmental Protection Agency (USEPA) 1974. Report on Lake Champlain, New York and Vermont Environmental Protection Agency Regions I and II. Working Paper No. 154.

9. Walker, W.W. 1984. Documentation for S2D Program for Horizontal Transport Simulation for Lake Shorelines and Embayments. Prepared for Vermont Dept. Water Res. Env. Eng.

10. Walker, W.W. 1985. Empirical Methods for Predicting Eutrophication in Impoundments - Report 3: Model Refinements. Prepared for Chief of Engineers, U.S. Army, Washington, Technical Report E-81-9, Waterways Experiment Station, Vicksburg, Mississippi, March.

11. Wiggins, T. 1985. Computer Analysis of the Proposed State Fish Hatchery on Kingsland Bay and Anticipated Phosphorus in the Effluent Stream. Memorandum to A. Incerpi, Director of Fisheries, State of Vermont, November 26, 1985.

# HYDRODYNAMIC COMPONENT OF THE LAKE CHAMPLAIN FISH HATCHERY OFFSHORE DISCHARGE STUDY

By

J. P. Laible, Ph.D., P.E.

Department of Civil and Mechanical Engineering
The University of Vermont
Burlington , Vermont 05405

February, 1986

Table of Contents


1.0 Introduction
2.0 Theoretical Basis of the Hydrodynamic Model
3.0 Finite Element and Boundary Element Numerical Model
4.0 Selection of Variable Input Parameters
5.0 Current Patterns
6.0 Preperation of Data For Transport Analysis
7.0 Transport
References
Figures
Appendix

## 1.0 Introduction

The transport of a pollutant in a natural body of water is generally governed by two processes; 1) diffusive mixing and 2) advection. Previous modeling efforts for the Lake Champlain fishery discharge have been based on a bulk diffusion coefficient that accounts for both of these processes. An alternative approach that more clearly distinguishes the role of each process can be taken, provided some assessment of the advective term can be estimated. In the study region , the advective component is primarily the result of the wind driven currents of the bay-lake system. There is also a general flow of the Lake towards the northern outlet. Lake seiche and internal waves also play a role in the transport process. In the absence of actual flow measurements in the field, an accurate quantitative assessment of the advective terms of the transport equation is difficult. Numerical modeling however, can provide reasonable bounds on the expected currents. The major objective of this portion of the study is therefore to assess the currents in the discharge region using numerical modeling. The results will subsequently be used in an analysis of transport with an offshore discharge and a recalibration of the diffusive mixing coefficient for use in predictive transport analyses.

This report primarily addresses; 1) the basis of the numerical model, 2) the selection of variable input parameters and 3) the resulting current patterns and their variability. Since the objective of this study is principally oriented towards the assessment the current field, the methodology will only be described in so far as is necessary to convey the essential assumptions and the applicability of the model to this project. The reader primarily interested in items 2 and 3 may begin with section 3.1 .

## 2.0 Theoretical Basis of the Hydrodynamic Model

The currents in a shallow bay or lake can be modeled by a reduced form of the general Navier Stokes equations of hydrodynamics. The most important assumption in the reduced model for lakes is that the currents are primarily horizontal in nature. The vertical pressure distribution is therefore hydrostatic. Furthermore, because the long term effect of the currents on pollution transport is of major concern, a steady state solution provides the most useful information. The equations that govern the current field distribution account for the conservation of mass and momentum. Under the aforementioned assumptions these equations are, after Pinder and Gray [1977]:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{2.1}$$

$$-fv=-\frac{1}{\rho}\frac{\partial P}{\partial x}+\epsilon_v\frac{\partial^2 u}{\partial z^2} \tag{2.2}$$

$$+fu = -\frac{1}{\rho}\frac{\partial P}{\partial y} + \epsilon_v \frac{\partial^2 v}{\partial z^2} \tag{2.3}$$

$$0 = \frac{\partial P}{\partial z} + \rho g \tag{2.4}$$

where:

| | | |
|---|---|---|
| $x$ and $y$ = | east and north coordinate (true) | $m$ |
| $z$ = | vertical coordinate | $m$ |
| $u$ and $v$ = | east and north velocities | $m/s$ |
| $w$ = | vertical velocity | $m/s$ |
| $f$ = | Coriolis parameter | $s^{-1}$ |
| $P$ = | pressure | $kg/m-s^2$ |
| $\epsilon_v$ = | vertical eddy viscosity | $m^2/s$ |
| $g$ = | gravity | $m/s^2$ |

Equation 2.1 expresses the conservation of mass of an incompressible fluid. Equations 2.2 and 2.3 express the conservation of momentum in the horizontal plane, while equation 2.4 is a statement of the hydrostatic condition in the vertical direction. These equations still reflect the vertical distribution of the flow. This dependence may be removed by integrating (2.1)-(2.4) over the vertical coordinate and applying the kinematic and stress conditions on the surface and bottom of the body of water. In this model a wind stress condition is used on the surface and a stress-velocity constitutive relation at the bottom is assumed. The resulting equations are, after Cheng and Tung [1970]:

$$\frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = 0 \tag{2.5}$$

$$-fV = -Hg\frac{\partial \zeta}{\partial x} + \tau_{sx} - \tau_{bx} \tag{2.6}$$

$$+fU = -Hg\frac{\partial \zeta}{\partial y} + \tau_{sy} - \tau_{by} \tag{2.7}$$

where:

| | | |
|---|---|---|
| $\zeta$ = | change in surface elevation | $m$ |
| $H$ = | total depth | $m$ |
| $U$ and $V$ = | x and y flux per unit width | $m^2/s$ |
| $\tau_{sx,sy}$ | x and y surface wind stress | $m^2/s^2$ |
| $\tau_{bx,by}$ | x and y bottom stress | $m^2/s^2$ |

The surface wind stresses are related to the wind velocity by:

$$\tau_{sx} = C_w \frac{\rho_a}{\rho_w} W^2 Cos\,\theta \qquad \tau_{sy} = C_w \frac{\rho_a}{\rho_w} W^2 Sin\,\theta \tag{2.8}$$

where:

| | | |
|---|---|---|
| $C_w =$ | wind shear coefficient | $nd.$ |
| $\rho_w =$ | density water | $kg/m^3$ |
| $\rho_a =$ | density air | $kg/m^3$ |
| $W =$ | wind velocity at $z = +10m$ | $m/s$ |
| $\theta =$ | wind direction | $degrees$ |

The bottom stress term has been dealt with in two ways. The simpler approach is to assume that the bottom stress is linearly proportional to the vertically averaged flow, that is:

$$\tau_{bx} = \gamma \bar{u} = \gamma \frac{U}{H} \qquad \tau_{by} = \gamma \bar{v} = \gamma \frac{V}{H} \tag{2.9}$$

where $\gamma =$ bottom friction parameter $m/s$

The second approach assumes that the bottom shear stress is proportional to the velocity near the bottom at the edge of the boundary layer, that is:

$$\tau_{bx} = \gamma u_b \qquad \tau_{by} = \gamma v_b \tag{2.10}$$

where $u_b$ and $v_b$ are the x and y bottom velocities.

So far the formulation has been based on either the total flux or a depth averaged velocity. To develop an expression for the bottom velocity the initial momentum equations (2.2-2.3) must be solved for $u$ and $v$ as a function of $z$. Liggett [1969] derived this relation for zero bottom velocity. Cheng [1977] developed the solution for the condition indicated by equation (2.10). The solution for the velocities as a function of depth starts with equations 2.2 and 2.3 rearranged as below:

$$\epsilon \frac{\partial^2 u}{\partial z^2} + f v = g \frac{\partial \zeta}{\partial x} \tag{2.11}$$

$$\epsilon \frac{\partial^2 v}{\partial z^2} - f u = g \frac{\partial \zeta}{\partial x} \tag{2.12}$$

These equations may be combined into one differential equation using complex notation. The result is:

$$\frac{\partial^2 W}{\partial z^2} - \lambda^2 W = G_\epsilon Q \tag{2.13}$$

with boundary conditions

$$\left(\frac{\partial W}{\partial z}\right)_s = \tau_{s\epsilon} \tag{2.14}$$

$$\left(\frac{\partial W}{\partial z}\right)_b = \gamma_\epsilon W_b \tag{2.15}$$

where:

$$i = \sqrt{-1}$$

$$W = u + iv \qquad \lambda^2 = \frac{f}{\epsilon_v} i$$

$$G_\epsilon = \frac{g}{\epsilon_v} \qquad \gamma_\epsilon = \frac{\gamma}{\epsilon_v}$$

$$Q = \frac{\partial \zeta}{\partial x} + \frac{\partial \zeta}{\partial y} i$$

$$\tau_{s\epsilon} = \frac{\tau_{sx}}{\epsilon_v} + \frac{\tau_{sy}}{\epsilon_v} i \qquad \tau_{b\epsilon} = \gamma_\epsilon (u_b + v_b i)$$

Equation (2.13) is now to be solved for $W$ subject to boundarty conditions (2.14) and (2.15). The sum of the homogeneous and particular solution is

$$W = A Sinh \lambda z + B Cosh \lambda z - Q \frac{G_\epsilon}{\lambda^2} \tag{2.16}$$

Applying the boundary conditions, $A$ and $B$ are evaluated and substituted into equation (2.16) to finally give:

$$W = \frac{\tau_{s\epsilon}}{\lambda} \left\{ Sinh \lambda z + Cosh \lambda z \frac{\lambda Cosh \lambda h + \gamma Sinh \lambda h}{\gamma Cosh \lambda h + \lambda Sinh \lambda h} \right\}$$

$$+ \frac{Q G_\epsilon}{\lambda^2} \left\{ \frac{\gamma}{\gamma Cosh \lambda h + \lambda Sinh \lambda h} Cosh \lambda z - 1 \right\} \tag{2.17}$$

Substitution of $z = -h$ into equation 2.17 will give the velocities at the bottom, now in

terms of $\tau_{s\epsilon}$ and $Q$. The form of the bottom velocity is:

$$W_b = \tau_{s\epsilon}\left(a + bi\right) + Q\left(c + di\right) = u_b + v_b i \tag{2.18}$$

as required for equations (2.10) and finally (2.6-2.7).

Equations (2.5)-(2.7) represent a closed system of three equations in the three unknowns $U$ , $V$ and $\zeta$.

Although a direct solution of these primitive equations can be accomplished by numerical techniques, a more computationally efficient procedure can be achieved by introduction of a stream function, $\Psi(x,y)$

$$U = \frac{\partial \Psi}{\partial y} \qquad V = -\frac{\partial \Psi}{\partial x} \tag{2.19}$$

Substitution of (2.19) into (2.5)-(2.7) and elimination of the terms $\frac{\partial \zeta}{\partial x}$ and $\frac{\partial \zeta}{\partial y}$ by cross differentiation results in a sigle equation in terms of the unknown stream function $\Psi$

$$\begin{aligned}
&\frac{\partial}{\partial x}(A\frac{\partial \Psi}{\partial x}) + \frac{\partial}{\partial y}(A\frac{\partial \Psi}{\partial y}) - \frac{\partial B}{\partial y}\frac{\partial \Psi}{\partial x} + \frac{\partial B}{\partial x}\frac{\partial \Psi}{\partial y} \\
&+ C\left\{\frac{\partial \tau_{sx}}{\partial y} - \frac{\partial \tau_{sy}}{\partial x}\right\} + D\left\{\frac{\partial \tau_{sx}}{\partial x} + \frac{\partial \tau_{sy}}{\partial y}\right\} \\
&+ \left\{\frac{\partial C}{\partial y}\tau_{sx} - \frac{\partial C}{\partial x}\tau_{sy}\right\} + \left\{\frac{\partial D}{\partial y}\tau_{sy} - \frac{\partial D}{\partial x}\tau_{sx}\right\} = 0
\end{aligned} \tag{2.20}$$

where for $\tau_b$ proportional to $\bar{u}$ and $\bar{v}$ :

$$A = -\frac{\gamma g}{F}\ ,\ B = \frac{fHg}{F}\ ,\ C = \frac{gH}{F}\ ,\ D = 0\ ,\ F = (Hg)^2$$

and for $\tau_b$ proportional to $u_b$ and $v_b$ :

$$A = -\frac{\gamma f d}{F}\ ,\ B = \frac{f(Hg + \gamma c)}{F}$$

$$C = \frac{(1 - \frac{\gamma}{\epsilon_v}a)(Hg + \gamma c) - d\gamma^2 \frac{b}{\epsilon_v}}{F}$$

$$D = \frac{\gamma \frac{b}{\epsilon_v}(Hg + \gamma c) + \gamma d(1 - a\frac{\gamma}{\epsilon_v})}{F}$$

$$F = (Hg + \gamma c)^2 + (\gamma d)^2$$

Once the solution of this equation for $\Psi$ is accomplished, (2.19) may be used to determine the flux values $U$ and $V$. With $U$ and $V$ determined throughout the domain, (2.6) and (2.7) may be used to compute the gradients of the surface elevation , thus defining $Q$ for use in equation 2.17 to determine the velocities as a function of depth $z$ . A second solution, using equations (2.6) and (2.7), is then done to determine $\zeta$. The computation of $\zeta$ is not necessary for transport analysis but does help in assessing the variable parameters of the model to be addressed in section 4.

## 3.0 Finite Element and Boundary Element Numerical Model

For irregular shaped domains the only feasible means of solution of the aforementioned equations is by numerical approximations. The two stage solution discussed in the previous section is accomplished by using the finite element method to solve $\Psi$ and subsequently $U$ and $V$. The boundary element method is then used to solve for $\zeta$. Both of these methods transform the continuous differential equations into sets of algebraic equations that can be solved on a digital computer. An in depth description of the numerical techniques employed are beyond the scope of this report but can be found in detail in Laible [1985]. Suffice it to say that the Galerkin finite element method using linear triangular elements is used to obtain a matrix equation of the form

$$\left[A_\Psi\right] \cdot \left\{\Psi\right\} = \left\{B_\Psi\right\} \tag{3.1}$$

from which $\Psi$ is determined. Subsequently the boundary element method using linear boundary elements is used to obtain a matrix equation of the form

$$\left[A_\zeta\right] \cdot \left\{\zeta\right\} = \left\{B_\zeta\right\} \tag{3.2}$$

from which $\zeta$ is determined.

### 3.1 Model Region and Discretization

The model region is illustrated in Figure 3.1. The finite element grid mesh used is shown in Figure 3.2. The boundary element grid mesh simply consists of the linear

segments and nodes on the boundary of the finite element mesh. The finite element mesh consists of 197 nodes and 328 elements. The finer mesh in the Hawkins Bay region is necessary due to the sharper velocity gradients in this region. Within this bay currents are determined primarily by the lateral geometry and bathymetry. For the region within the bays the annual mean water depths were used. Outside the bays the depth was set to a value of 10 m to reflect the presence of the thermocline during the summer and early fall (see Figure 3.7).

Along the land mass boundaries flow normal to the boundary is set to zero. Along the north and south boundaries of the model region two conditions are possible. The flow can be forced to be normal to the boundary but the value of the normal flow is unknown and is computed with all the interior nodal flows. This condition is typically used when the wind is the only driving force. Setting the tangential flow equal to zero may not be an accurate depiction of the actual conditions but these boundaries are remote from the area of greatest interest and consequently this condition has a minimal influence on the currents in the discharge region. The other condition is to set the normal flow to some prescribed value. This can represent river inflows or in the present situation the through flow. This assures that the normal flow will be the prescribed value but the vertical profile of the flow over the depth will still depend on the wind driven currents. The solution of equations (3.1) and (3.2) eventually yields the values of $U$ , $V$ and $\zeta$ at each of the nodes of finite element grid mesh.

The input to these models can be summarized as follows

1) The coordinates and water depth at each node point
2) The connectivity of each element to the nodes
3) The fixed parameters $\rho_a$ , $\rho_w$ , $g$ , $f$ and $\epsilon_v$
4) The variable parameters $C_w$ , $W$ , $\theta$ and $\gamma$

Data sets 1) and 2) were obtained from lake charts and previous modeling efforts Smeltzer [1985]. The fixed parameters are: $\rho_a = 1.0 kg/m^3$ , $\rho_w = 1000 kg/m^3$ , $g = 9.31 m/s^2$ , $f = .0001 s^{-1}$ and $\epsilon_v = .001 m^2/s$.

Data set 4) describes the wind conditions and bottom friction relation. As these parameters depend on seasonal conditions and are variable, a range of values must be considered. The following sections describe the assessment of these values.

## 4.0 Selection of Variable Input Parameters, $C_w$ , $W$ , $\theta$ and $\gamma$

The wind stress on the surface is the major driving mechanism for the circulation in Hawkins Bay. Equation 2.8 is an emperical relation that defines this stress in terms of the wind direction and magnitude . The coefficient $C_w$ has been determined experimentally by several investigators as discussed in section 4.1 . The selection of the wind magnitude and direction for this study is motivated by two considerations: 1) prevailing conditions will describe the long term trend for transport and 2) conditions during the time of the

previous phosphorus data collection study will assist in assessing the diffusion coefficient. These conditions are discussed in section 4.2 . The bottom friction parameter was also assessed from the literature. Two values , one for the bay region and the other for the open Lake, have been identified as discussed in section 4.3 .

## 4.1 Wind Shear Coefficient $C_w$

Numerous investigators have attemped to assess this coefficient with varying results. In general the value of $C_w$ itself depends on the wind speed. Bengtsson [1973], VanDorn [1953] and Whitaker [1973] have each investigated this coefficient for ponds and lakes. Their results differ with a minimum value of .001 for low winds , (0-5 $m/s$) to .004 for winds at 40 $m/s$. Denman [1973], Heaps [1969] and Wu [1969] determined values of $C_w$ for the opean seas. Their results also varied with values ranging from .0006 to .0025 for low and high wind speeds. Some typical values that have been used in other analytic and numerical simulations are : .00166 and .00237 for light and strong winds , Wilson [1960] ; .0030 , Simons [1974] ; 0.00260 , Allender [1976] ; .00100 and .00150 for light and strong winds , Hicks [1972] ; and .0031 , Ibrahim and McCorquodale [1985].

Wang [1975] developed an equation for $C_w$ as a function of wind speed, based on a least squares fit of the results of several of the aforementioned studies. The relation is:

$$C_w = (1.1 + 0.0536\, W_m)10^{-3} \tag{4.1}$$

where $W_m$ = wind speed in $m/s$ . This relation was used to evaluate the wind stress as given by equation (2.8).

## 4.2 Wind Magnitude $W$ , Direction $\theta$ and Surface Stresses $\tau_{sx}$ and $\tau_{sy}$

The wind stresses in the x and y directions can now be expressed in terms of the wind magnitude and direction as:

$$\tau_{sx} = (1.1 + 0.0536(.447)\, W_{mph})10^{-3} \frac{\rho_a}{\rho_h} (.447\, W_{mph})^2 Cos\,\theta$$

$$\tau_{sy} = (1.1 + 0.0536(.447)\, W_{mph})10^{-3} \frac{\rho_a}{\rho_h} (.447\, W_{mph})^2 Sin\,\theta \tag{4.2}$$

These equations can be used to obtain the resultant wind stress over a given time period of observed wind conditions.

| Dir. | # of Counts | Ave. Speed |
|---|---|---|
| 1 | 111 | 3.54 |
| 2 | 157 | 3.18 |
| 3 | 75 | 2.79 |
| 4 | 46 | 3.42 |
| 5 | 31 | 3.80 |
| 6 | 31 | 2.89 |
| 7 | 29 | 1.83 |
| 8 | 20 | 2.13 |
| 9 | 19 | 1.78 |
| 10 | 29 | 2.37 |
| 11 | 22 | 2.66 |
| 12 | 24 | 3.25 |
| 13 | 24 | 4.47 |
| 14 | 49 | 5.17 |
| 15 | 63 | 5.42 |
| 16 | 94 | 6.08 |
| 17 | 113 | 9.26 |
| 18 | 106 | 10.20 |
| 19 | 121 | 10.34 |
| 20 | 112 | 10.39 |
| 21 | 96 | 9.19 |
| 22 | 74 | 6.19 |
| 23 | 33 | 4.73 |
| 24 | 18 | 3.51 |
| 25 | 19 | 2.83 |
| 26 | 7 | 2.86 |
| 27 | 10 | 2.25 |
| 28 | 10 | 1.83 |
| 29 | 7 | 2.18 |
| 30 | 4 | 1.25 |
| 31 | 9 | 3.44 |
| 32 | 43 | 3.99 |

*Table 4.1 Number of counts and average velocity for each of 32 directions.*
*32=North (magnetic) 8=East 16=South 24=West*
*Data recorded at St. Albans Bay May - September 1983.*
*Ave. Speed (mph) = mean of all velocities in given direction.*

| Dir. | # of Counts | Ave. Speed | Dir. | # of Counts | Ave. Speed |
|---|---|---|---|---|---|
| 1 | 1 | 3.1 | 19 | 1 | 1.2 |
| 2 | 2 | 1.95 | 20 | 1 | 2.1 |
| 3 | 1 | 1.8 | 21 | 0 | 0 |
| 4 | 0 | 0 | 22 | 1 | 2.6 |
| 5 | 0 | 0 | 23 | 1 | 0.4 |
| 6 | 1 | 1.7 | 24 | 0 | 0 |
| 7 | 1 | 1.5 | 25 | 0 | 0 |
| 8 | 0 | 0 | 26 | 0 | 0 |
| 9 | 1 | 2 | 27 | 1 | 3.1 |
| 10 | 1 | 1.6 | 28 | 3 | 5.4 |
| 11 | 2 | 4.35 | 29 | 0 | 0 |
| 12 | 1 | 0.5 | 30 | 2 | 5.25 |
| 13 | 2 | 3.8 | 31 | 0 | 0 |
| 14 | 0 | 0 | 32 | 2 | 3.2 |
| 15 | 7 | 6.63 | 33 | 4 | 5.35 |
| 16 | 11 | 11.19 | 34 | 2 | 5.05 |
| 17 | 2 | 3.75 | 35 | 3 | 6.23 |
| 18 | 4 | 7.5 | 36 | 3 | 4.47 |

*Table 4.2 Number of counts and resultant velocity for each of 36 directions.*
*36=North (magnetic) 9=East 18=South 27=West*
*Data recorded at Burlington Airport August - September 1984.*
*Ave. Speed (mph) = mean of all resultant velocities in given direction.*

The two conditions of greatest significance as mentioned in section 4.0 are the prevailing conditions and the conditions during August and September 1984. Table 4.1 and 4.2 contain the data for these conditions respectively. For the prevailing conditions the recorded wind speed and direction at St. Albans Bay, Vermont were used (see Figures 4.1-4.4). While this location is remote from the study region, the collected data is representative of conditions on Lake Champlain. For the August - September 1984 period the data of Table 4.2 was obtained by examining the Burlington airport data for that period.

While these values reflect the conditions at the airport, wind speeds at the lake, especially in the lower range (0-7 mph) , are generally larger than recorded at an inland station. At St. Albans for example, wind speeds in the lower range were 80 to 100 % greater at the bay location compared to recordings at the St. Albans radio station (see Figure 4.1). A conservative increase of 50% was therefore used to define the Hawkins Bay loading based on Burlington airport data.

The effective time averaged wind stress $\tau_{sx}$ and $\tau_{sy}$ were determined by computing the mean of all x and y components of the recorded wind velocities using equation (4.2) . The results of this computation are given in Table 4.3 .

| - | *Prevailing Wind*[1] | *Aug. – Sept.* 1984[2] |
|---|---|---|
| $\tau_x$ | .000002419 | -.000005457 |
| $\tau_y$ | .000008237 | .000008642 |
| $\theta$ | 73.6 | 122.3 |
| $W_{eff}$[3] | 6.55 | 5.83 |

*Table 4.3 Effective Wind Stress* $(m/s)^2$
1 *St. Albans Bay Data*
2 *Burlington Airport Data Adjusted* +50%
3 *Effective Wind Speed (mph) with* $C_w = 0.001$

In addition to these two wind loads, six loadings with a unit surface stress were run to observe the general current patterns. The six loading directions are shown in Figure 4.5 and defined in Table 4.4.

| Load # | | Bearing | $\tau_x$ | $\tau_y$ |
|---|---|---|---|---|
| 1 | SE | 122 | -.0000005300 | +.0000008480 |
| 2 | SSW | 75 | +.0000002588 | +.0000009659 |
| 3 | W | 15 | +.0000009659 | +.0000002588 |
| 4 | NW | 330 | +.0000008667 | -.0000005000 |
| 5 | N | 285 | +.0000002588 | -.0000009659 |
| 6 | S | 105 | -.0000002588 | +.0000009659 |

*Table 4.4 Unit Wind Stress loads* $(m/s)^2$
$W_m = 1 m/s$ *and* $C_w = 0.001$

### 4.3 Bottom Friction Parameters

The treatment of the bottom friction in the formulation of the reduced equations of hydrodynamics assumed a realtion of the form

$$\tau_x = \epsilon \frac{\partial u}{\partial z} = \gamma u \qquad \tau_y = \epsilon \frac{\partial v}{\partial z} = \gamma v \tag{4.3}$$

Before the advent of computer simulation of multi-dimensional flow, the friction factors commonly used in hydraulics were based on empirical expressions, i.e. Manning, Chezy and Darcy Weisbach equations, Daily [1966]. In general a quadratic relation between bottom friction and mean velocity has been found to be appropriate. This is somewhat questionable for wind driven flows, as there are often reverse flow conditions that yield zero mean velocity but strong bottom currents. We may however draw upon the extensions of the classical fluid mechanics relations to estimate this factor. The most commonly used expressions for two dimensional flow are:

$$\tau_x = C_f (u^2 + v^2)^{1/2} u \tag{4.4}$$

$$\tau_y = C_f (u^2 + v^2)^{1/2} v \tag{4.5}$$

where , $C_f$ = dimensionless bottom friction parameter. $C_f$ is related to the several classical drag coefficients by

$$C_f = \frac{1}{8} f_{dw} \qquad Darcy - Weisbach \tag{4.6}$$

$$C_f = \frac{g}{C^2} \qquad Chezy \tag{4.7}$$

$$C_f = \frac{n^2}{H^{1/3}} g \qquad Manning \tag{4.8}$$

The value of $n$ normally ranges from .025 for stone bottoms to .040 for dunes, Wang [1975]. The effect of weed growth has also been studied. Two such studies are by Kao [1977] and Stephans [1963]. The effect of suspended sediment has also been explored by Lau [1983]. Weed growth will dominate in the shallow regions of Hawkins Bay. Stephans reports that Manning's number is less than .036 for light vegetation growth, between .036 and .052 for moderate growth and greater than .052 for heavy growth.

In order to relate these values to the parameter $\gamma$ used in the model, a characteristic velocity for the Hawkins Bay region must be asssumed i.e., $\bar{v}$. This gives

$$\tau_x = \bar{v} C_f u \qquad \tau_y = \bar{v} C_f v \tag{4.9}$$

We therefore have from equation 4.3

$$\gamma = \bar{v} C_f \tag{4.10}$$

From Manning's relation (4.8) , using $n = 0.04 sec/m^{1/3}$ and a characteristic depth $H = 6m$ , we have

$$C_f = 9.81 \frac{.04^2}{6^{1/3}} = .00864$$

$$\text{and for } \bar{v} = .05 m/s \qquad \gamma = .000432 \ m/s$$

For tidal studies the values are generally higher as given by Wang [1975] who used $C_f = .0063$ for a tidal study in the west passage of Narragansett Bay and values of $.01 - .02$ for a tidal model of Massachusetts Bay. Huang [1977] used a value of $C_f = .0025$ for a layered model of Lake Ontario. Cheng and Tung [1970] set $\gamma/\rho = .0025 dyne - sec/cm^3$ , for a Lake Erie simulation. This equates to $\gamma = .000025 m/s$ which is in agreement with the value computed here adjusting for depth.

Friction at the interface of the epilimnion and the thermocline is difficult to assess since it depends on a relative motion and in general may depend on the local Reynolds number $\bar{u} \cdot l/\nu$. Blasius' emperical friction law for turbulent boundary layer flow has been used to quantify the interfacial coefficient, Schlichting [1968]. Codell [1973] directly relates the friction factor to the Reynolds number but the uncertainty about this factor is quite large. A report by Karelse, N. [1974] suggests some average values for the interfacial friction factor to be

$C_f = 4 \cdot 10^{-4}$ for a stagnant bottom layer
$C_f = 15 \cdot 10^{-4}$ for a stagnant top layer
$C_f = 7 \cdot 10^{-4}$ for counter flow

In this study the assumption is made that the primary transport is in the upper layer above the thermocline, and that the thermocline and hypolimnion experience little motion. Under these conditions $C_f = .0004$ seems to be a reasonable value. This must be equated to $\gamma$ by equation 4.10. For the main lake where the model is terminated at the thermocline ($H = 10m$), the characteristic flow is less than in the bay. Using a value of $\bar{v} = 0.01 m/s$ we find

$$\gamma = .01 x .0004 = .000004 \quad m/s$$

## 5.0 Current Patterns

The currents in the model region can be classified into the following types;

1) Wind Driven Topographic Currents
2) Lake Through Flow
3) River Inflow
4) Lake Seiche
5) Internal Waves

The currents in the shallow bay areas are primarily topograhic flows. These flows are dictated by the bathymetry, the shore line geometry and the direction and magnitude of the wind. Inflows from rivers can create currents in the shallow regions but this is generally restricted to the spring run off season. Most of the summer the flows in the shallow regions are due to the momentum input from the wind.

In the broader lake section of the model region wind driven flows will combine with through flow. Circulations that transport material out of the bays into broader lake region can be swept north by the through flow. The finite element analyses carried out used a combined wind and through flow loading. During the late summer months the river inflow into Hawkins Bay has a negligible effect on the flows.

The last two types of flows are transient in nature. They are considered here first in section 5.1 to provide a comparison with the wind driven flows and the through flow. These flows reflect the general motion of the main lake above Thompson's point.

### 5.1 Lake Seiche

The computations to determine the seiche action in the main lake are done by using a greatly simplified model of the lake as an enclosed box with constant depth. While this is clearly a great simplification the analysis helps to define the possible maximum currents that could be expected. These computations reflect the response of the lake excluding the northeast arm. The model consists of a two layered system subjected to a wind load along the major axis of the lake. The equations are given by Mortimer [1982]. The quantities of interest are the maximum horizontal velocities. Two results are obtained from the analysis ;
$U_{1max}$ and $U_{2max}$ , the velocities in the epilimnion and the hypolimnion respectively. The equations are:

$$U_{1max} = \frac{SlC}{2h_1} \tag{5.1}$$

$$U_{2max} = -\frac{SlC}{2h_2} \tag{5.2}$$

where:

$$S = \frac{0.0025\, C_0 (.45\, W)^{1.8}}{g h_t \Delta\rho} \tag{5.3}$$

$$C = \left(g \frac{h_1 h_2}{h_1 + h_2} \frac{\Delta\rho}{\rho}\right)^{1/2} \tag{5.4}$$

with all terms defined in Table 5.1 .

| Symbol | Definition | Units | Value |
|---|---|---|---|
| $l$ | Length of Lake | $ft$ | 132000.0000 |
| $h_1$ | Thickness of Epilimnion | $ft$ | 40.0000 |
| $h_2$ | Thickness of Hypolimnion | $ft$ | 200.0000 |
| $\rho$ | Density | $\frac{lb}{ft^3}$ | 62.4000 |
| $\Delta\rho$ | Density Difference | $\frac{lb}{ft^3}$ | .1248 |
| $h_t$ | Depth of Thermocline | $ft$ | 50.0000 |
| $W$ | Wind Velocity | $mph$ | 5 |
| $g$ | Gravity | $\frac{ft}{\sec^2}$ | 32.2000 |
| $C_0$ | Constant $1.0 < C_0 < 1.5$ | $nd$ | 1.2500 |
| $S$ | Slope Eq. 5.3 | $\frac{ft}{\sec}$ | .0000669 |
| $C$ | Celerity (Wave Speed) Eq. 5.4 | $\frac{ft}{\sec}$ | 1.4650 |
| $U_{1max}$ | Velocity, Epilimnion Eq. 5.1 | $\frac{ft}{\sec}$ | .1618 |
| $U_{2max}$ | Velocity, Hypolimnion Eq. 5.2 | $\frac{ft}{\sec}$ | -.0324 |
| $T$ | Period $= 2\frac{l}{C}$ | sec | 180186.0000 |
| $T$ | Period | $hr$ | 50.0500 |
| $T$ | Period | $days$ | 2.0850 |

*Table 5.1 Computation of Lake Champlain Maximum Flow and Fundamental Period - Two Layer System*

Table 5.1 for several other values of the parameters are contained in the Appendix.

Figure 3.7 illustrates the layered model. Under a steady wind the water piles up at the down wind end of the lake. The plane of the thermocline however is tilted downward at the down wind end. The tilt of the thermocline is of the order $\frac{\rho}{\Delta\rho}$ times the surface tilt. This ratio is large and the change in the surface elevation is typically several centimeters while the displacement of the thermocline can be several meters. When the wind stops blowing, the epilimnion will will rock back and forth with a period T. This action induces flows in the horizontal plane with maximum flows in the epilimnion and much smaller flows in the hypolimnion. The flows in the hypolimnion are actually $-\frac{h_1}{h_2}$ times the flows in the epilimnion. A range of values of the parameters in the table were assumed. The result is that flows in the epilimnion could reach maximum values anywhere from .06 to $.25 ft/sec$. The fundamental period of the entire lake in this stratified condition is about two days. The model is weakly sensitive to the depth of the hypolimnion and strongly sensitive to the wind velocity $W$.

In addition to the lake seiche there are also internal waves. Internal waves are distinguished from an internal lake seiche by the fact that in a seiche the fluid particles displace different amounts at different locations along the axis of the lake , while in an internal wave each particle displaces the same amount but at different times. Seiches have variable displacement but are in phase whereas internal waves cause the same displacements everywhere but out of phase. Internal waves have much smaller periods, typically measured in minutes while an internal seiche, as demonstrated above, has periods measured in days. For Lake Champlain the flows associated with the internal waves are quite small compared with the lake seiche.

Both the lake seiche and internal waves contribute to a cyclic back and forth motion of the fluid in the lake. This back and forth action contributes to the diffusive mixing process and should be reflected in the diffusion coefficient obtainded from the transport model calibration.

## 5.2 Local Current : Finite Element Analysis

Finite element analyses were done using prescribed wind stresses with and without lake through flow. Because of the variability of the parameters required for the finite element analysis, computer runs with a range of values were considered .

The first set of runs were done with just the wind load, but with different values for the bottom roughness. These runs were done to assess the sensitivity of the model to the bottom roughness $\gamma$ . Using a range of values for $\gamma$ (see Table 5.2) , the maximum vertically integrated velocities were determined and compared with the assumed characteristic velocity used to evaluate $\gamma$. Because the flows in the bay under prevailing winds where generally less than the assumed value of 5 cm/s the results using $\gamma_{bay} = .00043$ are considered to be a lower bound, that is, flows will generally by greater than those generated using $\gamma_{bay} = .00043$. This value was used for all subsequent analyses.

| RUN>>> | B1 | B2 | B3 | B4 | *UNITS* |
|---|---|---|---|---|---|
| $\theta$ | 75 | 75 | 75 | 75 | *degrees* |
| $W$ | 7.25 | 7.25 | 7.25 | 7.25 | *mph* |
| $C_w$ | .0005 | .0005 | .0005 | .0005 | |
| $\tau_{sx}$ | .000001358 | .000001358 | .000001358 | .000001358 | $(m/s)^2$ |
| $\tau_{sy}$ | .000005070 | .000005070 | .000005070 | .000005070 | $(m/s)^2$ |
| $\gamma_{lake}$ | .0000040 | .0000040 | .0000040 | .0000040 | $m/s$ |
| $\gamma_{bay}$ | .0004320 | .0002160 | .0001080 | .0000250 | $m/s$ |
| $V_{max}$ | .0084600 | .0174600 | .0350000 | .1360000 | $m/s$ |

*Table 5.2 Parameter variables for study of variability of currents due to variation of the bay bottom friction parameter* $\gamma_{bay}$
$V_{max}$ = *maximum depth averaged velocity*

From these results it can be seen that the magnitude of the flows are nearly inversly proportional to $\gamma_{bay}$. The directions however were unaffected.

The next set of runs were done using the unit surface stress loadings defined in Table 4.4. The general structure of the local wind induced currents are illustrated in Figures 5.1-5.6. The currents shown in these plots are the vertically averaged velocities. While the velocity magnitudes are not significant due to the unit stress loads, the patterns (directions) remain unaffected by the magnitude of the wind load. Consequently it is possible to scale the velocities obtained from unit stress loads to obtain actual magnitudes for an assumed surface stress.

One interesting feature of these patterns is the behavior just to the northeast of the gyre . In this region the vertically averaged flows are almost entirely out of the bay. Even for the north wind (load #5) , the flows are tangent to the Hawkins Bay boundary then gradually sweet out into the main lake.

| Year | June | July | August | September |
|---|---|---|---|---|
| 1984 | 2,130.00 | 801.00 | 336.00 | 341.00 |
| 1983 | 1,151.00 | 261.00 | 528.00 | 235.00 |
| 1982 | 796.00 | 427.00 | 227.00 | 168.00 |
| 1981 | 691.00 | 479.00 | 745.00 | 1,037.00 |
| 1980 | 561.00 | 330.00 | 325.00 | 456.00 |
| 1979 | 885.00 | 361.00 | 271.00 | 452.00 |
| 1978 | 1,156.00 | 374.00 | 437.00 | 311.00 |
| 1977 | 531.00 | 311.00 | 249.00 | 489.00 |
| 1976 | 1,360.00 | 1,723.00 | 2,624.00 | 930.00 |
| 1975 | 938.00 | 425.00 | 499.00 | 919.00 |
| 1974 | 718.00 | 745.00 | 592.00 | 1,046.00 |
| 1973 | 1,168.00 | 1,559.00 | 337.00 | 300.00 |
| 1972 | 976.00 | 1,432.00 | 780.00 | 364.00 |
| 1971 | 525.00 | 312.00 | 566.00 | 508.00 |
| 1970 | 483.00 | 413.00 | 211.00 | 317.00 |
| 1969 | 725.00 | 368.00 | 590.00 | 279.00 |
| 1968 | 918.00 | 529.00 | 265.00 | 211.00 |
| 1967 | 790.00 | 321.00 | 248.00 | 272.00 |
| 1966 | 486.00 | 269.00 | 419.00 | 473.00 |
| 1965 | 208.00 | 126.00 | 129.00 | 273.00 |
| 1964 | 288.00 | 241.00 | 268.00 | 171.00 |
| Mean *cfs* | 832.57 | 562.24 | 506.95 | 454.86 |
| Mean $m^3/s$ | 23.58 | 15.92 | 14.36 | 12.88 |
| T.F. Mean *cfs* | 3,203.81 | 2,163.54 | 1,950.80 | 1,750.33 |
| T.F. Mean $m^3/s$ | 90.73 | 61.27 | 55.25 | 49.57 |
| T.F. 1984 *cfs* | 8,196.44 | 3,082.32 | 1,292.96 | 1,312.20 |
| T.F. 1984 $m^3/s$ | 232.12 | 87.29 | 36.62 | 37.16 |

*Table 5.3 Computation of Lake Champlain Through Flow (T.F.)*
*T.F. = (6257/1626) x Gage Flow*
*Monthly Ave. At Otter Creek , Middlebury, Vt. (cfs).*

The last set of analyses used the wind conditions of Table 4.3 with and without through flow. The through flow was computed using data from the U.S. Geological Survey Water-Data Reports . To obtain the estimates of the through flow the Otter Creek gage at Middlebury was used. The drainage area above the Middlebury gage is 1626 $km^2$ . The total drainage area into Lake Champlain below Thompson's point is 6257 $km^2$. Assuming a uniform drainage for all areas , the flows at the Middlebury gage are multiplied by (6257/1626) to approximate the anticipated through flow. Flows for Little Otter Creek and Lewis Creek are orders of magnitude lower than the computed through flow and can be neglected. Table 5.3 lists the average monthly flows for June, July, August and September for the years 1964-1984. For the 1984 field study period of August - September the average flow is approximately 37 $m^3/s$ . For the prevailing wind load case the mean value of the flows during August and September over the years 1964-1984 were used. If all years are used the mean flow is 52 $m^3/s$ . Since through flow during this period is benificial to the transport of phosphorus out of Hawkins Bay, a more conservative estimate of the flow can be computed by excluding the unusual events of August - September 1976 . Excluding 1976 data, the through flow for the months of August - September is computed to be 45 $m^3/s$. This loading was used with the prevailing wind load.

For the prevailing wind load and the Aug.-Sept. 1984 loadings (without through flow), the current patterns correspond to load # 2 and load #1 respectively (Figures 5.2 and 5.1). The maximum vertically averaged velocities were found to be $1.81 cm/s$ at node 182 and $1.77 cm/s$ at node 102 respectively. The maximum surface flow and counter flows for both cases were found to be about $3-6 cm/sec$ and $2-3 cm/sec$ , respectively.

The patterns due to the combined wind and through flow were essentially the same in the shallow regions but showed a definite current northward throughout the broad lake portion of the model. The vertical profiles of the flow in the center of the main lake at node 28 (see Figure 3.6) are shown in figures 5.7-5.8.

The vertical flow profile and vector plots for the region to the northeast of the gyre at nodes 91 and 92 (see Figure 3.6) are shown in Figures 5.9-5.12. These flows were essentially the same for the loading with and without through flow. For the vector plots the largest vectors indicate the direction and magnitude of the surface water. Thes plots show the direction of the flow at successively lower depths (@ 1/20 H increments). At nodes 91 flow is out of the bay , while at node 92 the flow is into the bay. These plots are all for the prevailing SW wind load.

## 6.0 Preperation of Data for Transport Analysis

The current velocities obtained from the finite element analysis provide a point wise description of the flow field. The transport model previously used for this discharge study however was based on a cell model, Figure 6.1. The cell model requires the specification of the flow on each face of a rectangular cell . The velocities obtained from the finite element analysis were integrated along cell boundaries to obtain the net inflow and outflow along each face. Figure 6.2 illustrates the orientation of the rectangular grid mesh over

the finite element mesh. Six regions were defined with cells numbered as shown in Figure 6.2. Figure 6.3 shows the region 1 circulation pattern and the vertically integrated flows on the cell faces for the preliminary load case B1 defined in Table 5.1. These flows were then integrated along each cell face to obtain the net inflow and outflow in units of $m^3/sec$ .

The inflow and outflow values for all cells is contained in the Appendix. The cases included are :

| | | |
|---|---|---|
| 1) | FLOWSWN | Prevaling wind without through flow . |
| 2) | FLOWSEN | Aug. - Sept. 1984 wind without through flow. |
| 3) | FLOWSWNF | Prevailing wind with through flow. |
| 4) | FLOWSENF | Aug. - Sept. 1984 wind with through flow. |

A balance of flows is generally well achieved, but some imbalance exits in the cells near the shoreline. This can be attributed to numerical modeling approximations. The fact that continuity is satisfied exactly on a point wise basis does not enforce a satisfaction of continuity on a cell wise basis. These flows will be balanced and then used in the transport cell model.

## 7.0 Transport

Two transport analyses were carried out to provide an initial assessment of the effect of the wind driven circulations. The first case was a zero wind load condition using the largest diffusion coefficient obtained from the previous modeling and field data. A value of $200000 m^2/day$ was used. The second run was done with the prevailing wind stresses defined in Table 4.3. The same value for the diffusion coefficient was used. The transport model used is also a finite element program compatible with the flow analysis program , Laible [1985]. For both of the runs the applied load was an internal source spread out over element 237 (see Figure 3.4). The loading rate represented a phosphorus concentration of 100 ppb at a flow rate of 11.5 mgd . Decay for both runs was set to zero.

Figure 7.1 illustrates the isoconcentration lines for these two cases. The currents tend to transport phosphorus out of the bay, decreasing values obtained by the zero wind case. For example the concentrations near the shore line at the proposed fishery for the prevailing wind and no wind case were found to be 16 ppb and 28 ppb respectively. At this location removing the wind load results in a 75% increase in concentration.

# REFERENCES

## References


Bengtsson, L., "Wind Stress on Small Lakes", Tekniska Hogsholun, Lund, 1973

Denman, K.L., Miyake, M., "Behavior of the Mean Wind, The Drag Coefficient and Wave Field in Open Ocean", Journal of Geophysical Research, Vol. 78, No. 12, April 20, 1973

Heaps, N.S., "A Two-Dimensional Numerical Sea Model", Royal Society of London, Philosophical Transactions, Ser. A. Vol. 265, No. 1160, Oct. 1969

Van Dorn, W., "Wind Stress on an Artificial Pond" Journal of Marine Research, Vol. 12, No. 3, 1953

Whittaker, R.E., et al., "Drag Coefficients at Hurrican Wind Speeds as Deduced from Numerical Simulations of Dynamical Water Level Changes in Lake Okeechobee", Ref. 73-13-5, Texas A&M, August 1973

Nu, J., "Wind Stress and Surface Roughness at Air-Sea Interface", Journal of Geophysical Research, Vol. 74, No. 2, January 1969

Wilson, B.W., "Note on Surface Wind Stress Over Water at Low and High Speeds", Journal of Geophysical Research, 65, 1960

Simon, T.J., "Verification of Numerical Models of Lake Ontario, Part I: Circulation in Spring and Early Summer", Journal of Physical Oceanography, 4, 1974

Allender, J.H. "Review and Appraisal of Numerical Circulation Models for Lake Michigan", Argonne National Laboratory Report, 1976

Hicks, B.B., "Some Evaluation of Drag and Bulk Transfer Coefficients Over Water Bodies of Different Siges", Boundary Layer Meteor, 8, 1972

Ibrahim, K. A., McCorquodale, J.A., "Finite Element Circulation Model for Lake St. Clair", Journal of Great Lakes Research, Volume 11, No. 3, 1985

Daity, J.W., Hasleman, D.R.F., "Fluid Dynamics", Addison-Wesley 1966

Stephens, M., Blackburn, R.D., Seaman, D.E. and Weldon, L.W., "Flow Retardance By Channel Weeds and Their Control", Journal of Irrigation and Drainage, ASCE proceedings, Vol 80, No. IR2, June 1983

Lau, Y.L., "Suspended Sediment Effect on Flow Resistance", Journal of Hydraulics Engineering, ASCE, Vol 109, No. 5; May 1983

Kao, D.T., and Barfield, B.J., "Hydraulic Resistance of Grass Media on Shallow Overland Flow", Research Report No. 107, University of Kentucky, Water Resources Research Institute, 1977

Wang, J.D., and Connor., J.J., "Mathematical Modeling of Near Coastal Circulation", MIT Research Report R75-19, Department of Civil Engineering, Massachusetts Institute of Technology, April 1975

Huanq, J.C.K., "A General Circulation Model for Lakes", NOAA Technical Memorandum, ERL

GLERL-16, Great Lakes Environmental Research Laboratory, Aug. 1977

Cheng, R.T. and Tung C., "Wind Driven Lake Circulation by the Finite Element Method", Proc. Conf. Great Lakes Res., 13th, 891, 1970

Schlichting, H., "Boundary-Layer Theory", McGraw-Hill, 1968

Codell, R.B., "Digital Computer Simulation of Thermal Effluent Dispersion in Rivers, Lakes and Estuaries", TR-73-16, U.S.. Army Missile Command, Redstone Arsenal, Alabama, 1973

Karelse, M. et al., "Momentum and Mass Transfer in Stratified Flows", R880, Delft Hydrualics Laboratory, Dec 1974

Laible, J.P., "Phosphorus Transport in Stevens Brook Wetland and St. Albans Bay Vermont" , Progress Report to UVM Water Resources Research Center, June 1985

Smeltzer, E., "Lake Champlain Fish Hatchery Discharge Study", Vermont Department of Water Resources: Lake and Reservoir Modeling Series, Report No. 7, April, 1985

Pinder, G.P. and Gray, W.G., "Finite Element Simulation in Surface and Subsurface Hydrology", Academic Press, New York, 1977

Cheng, R.T. , "Transient Three Dimensional Circulation of Lakes", Journal of Enginering Mechanics Devision , ASCE, EM1 , February 1977

Liggett, J.A. , and Hadjitheodorou, C., "Circulation in Shallow Homogeneous Lakes", Journal of the Hydraulics Division, ASCE, Vol 95, Proc. Paper 6454, March , 1969

Cornell Aeronautical Laboratories , Inc. "Cayuga Lake and Bell Station :Physical Effects and Final Report Summary", Cornell University , Buffalo , N.Y. , Cal No. - VT-2616-0-1, November, 1969

Mortimer, C.H. "Water Movement in Lakes During Summer Stratification; Evidence from the Distribution of Temperature in Windermere" , Phil. Trans. Roy. Soc. London 236B, 355, 1952

# FIGURES

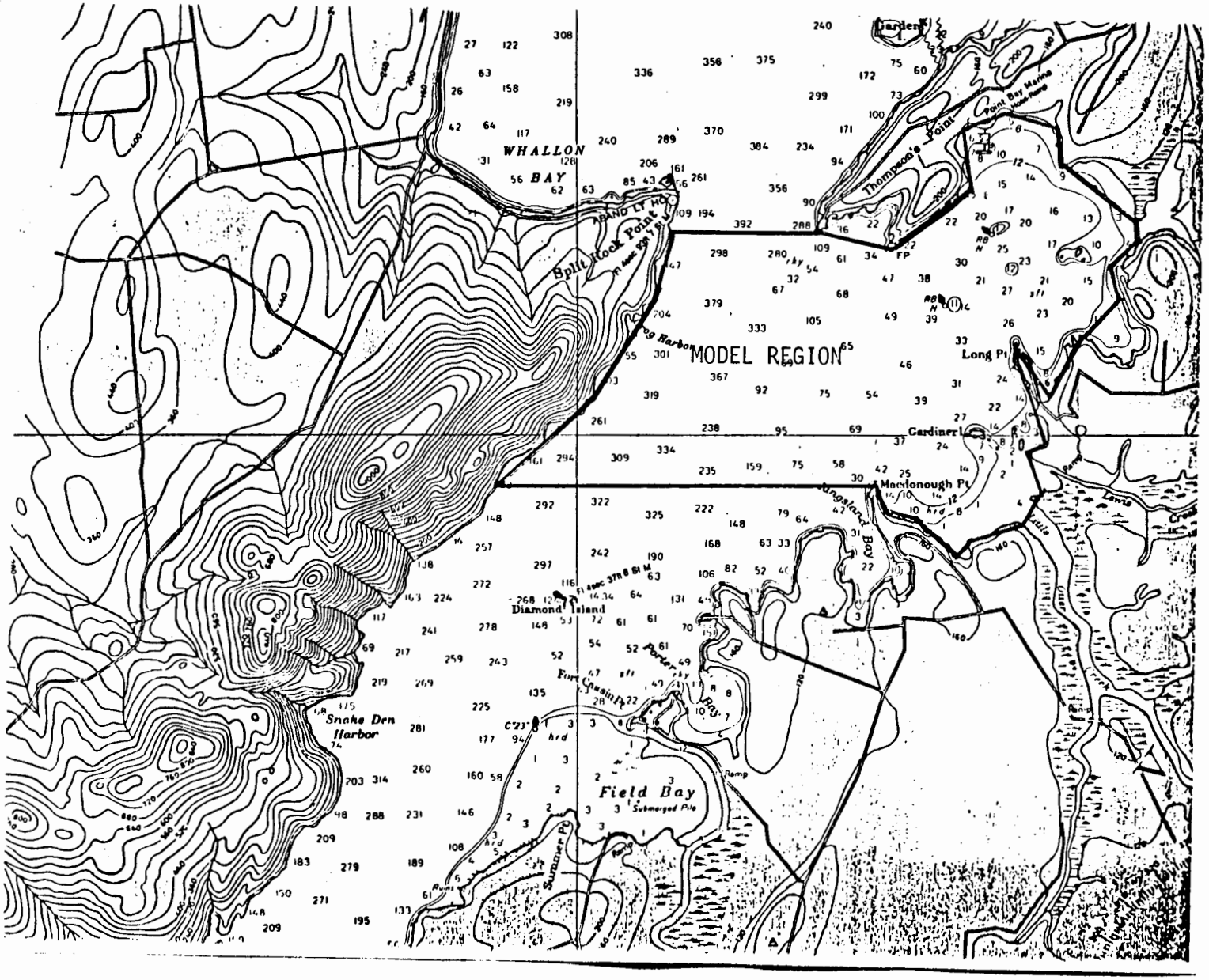



*Figure 3.1 Lake Champlain - Hawkins Bay Region : Model Region.*

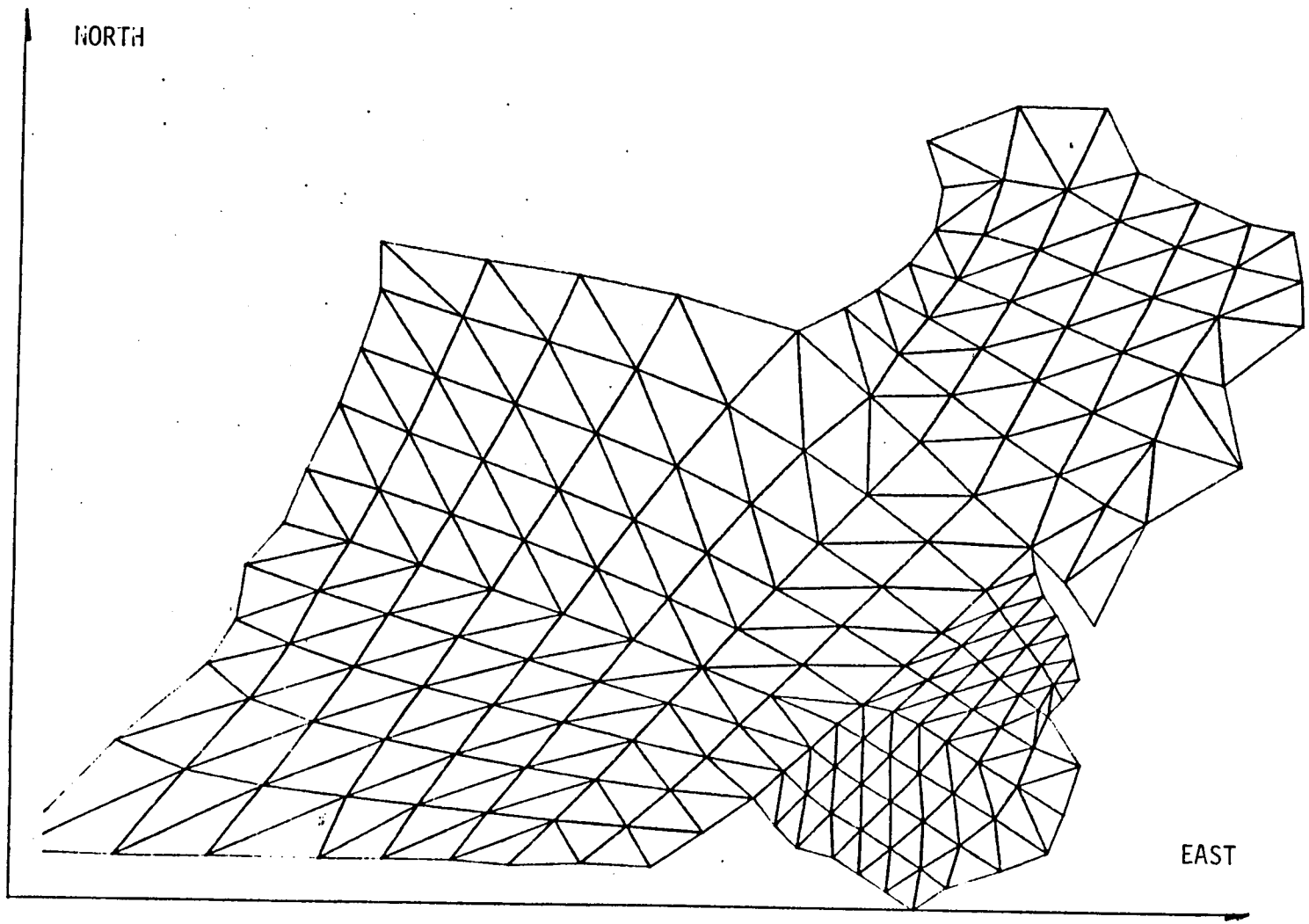



*Figure 3.2 Finite Element Mesh : 197 Nodes , 328 Elements.*

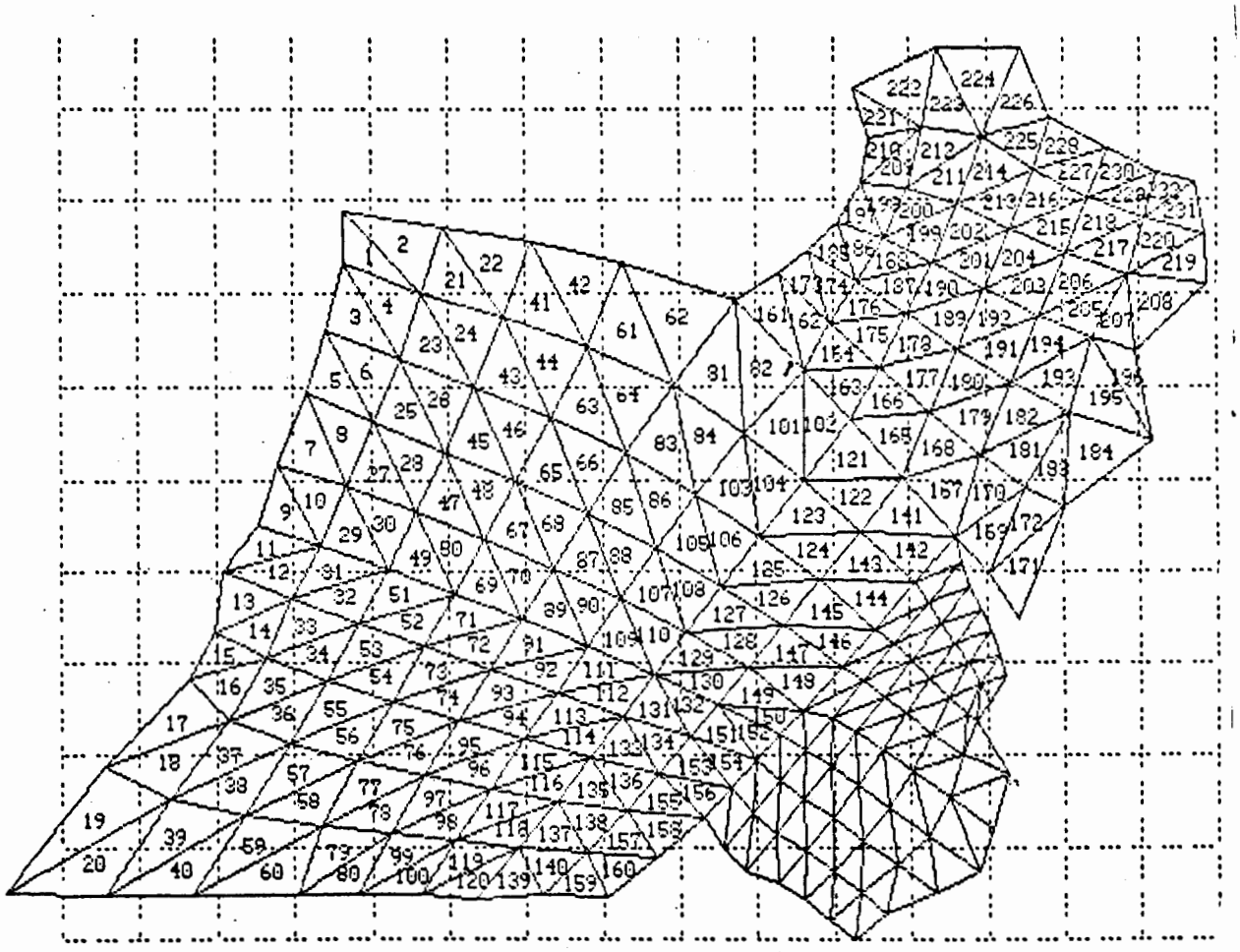


*Figure 3.3 Finite Element Mesh : Element Numbers.*

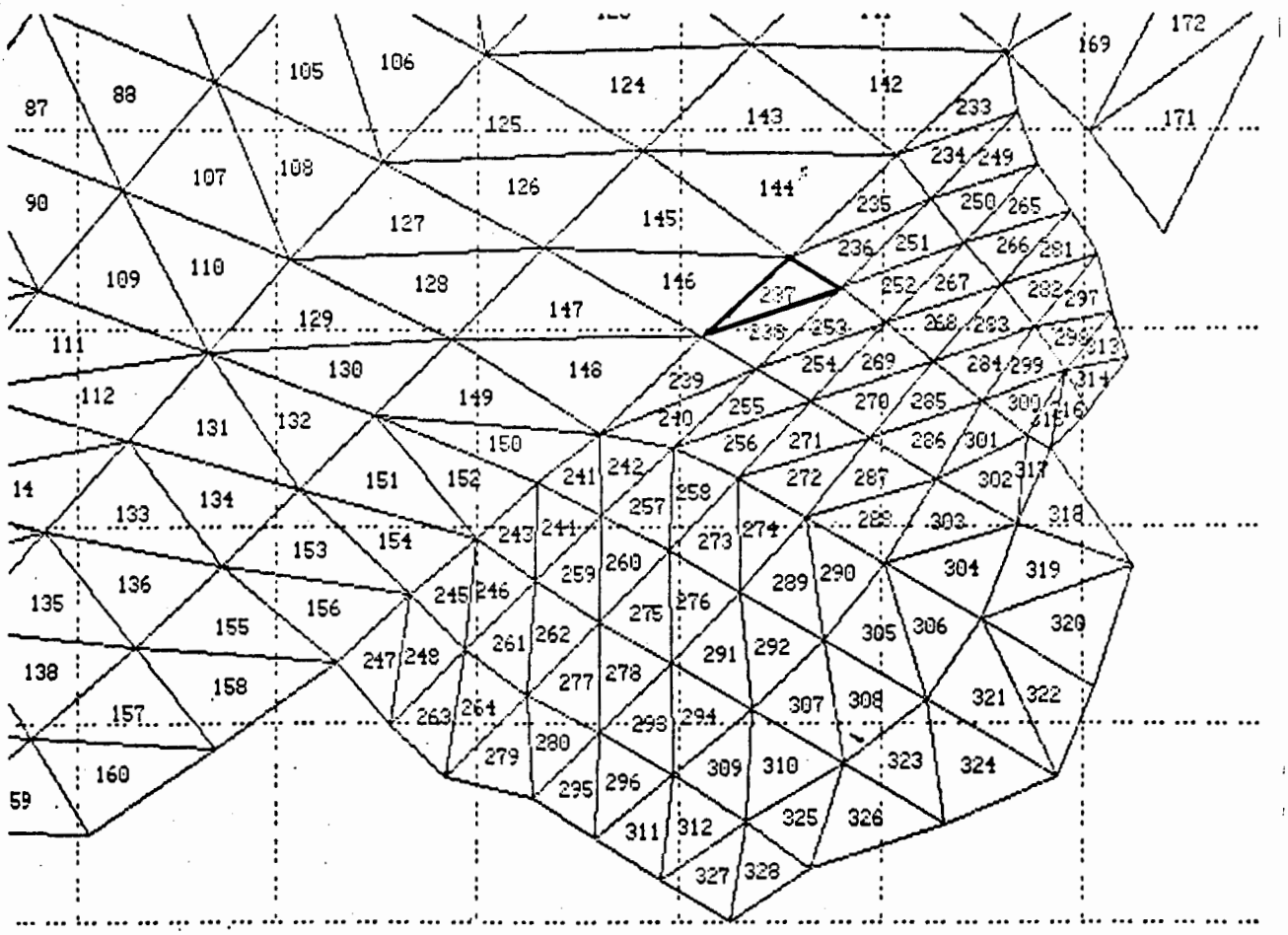



*Figure 3.4 Hawkins Bay Region : Location of internal source load. Element 237 .*

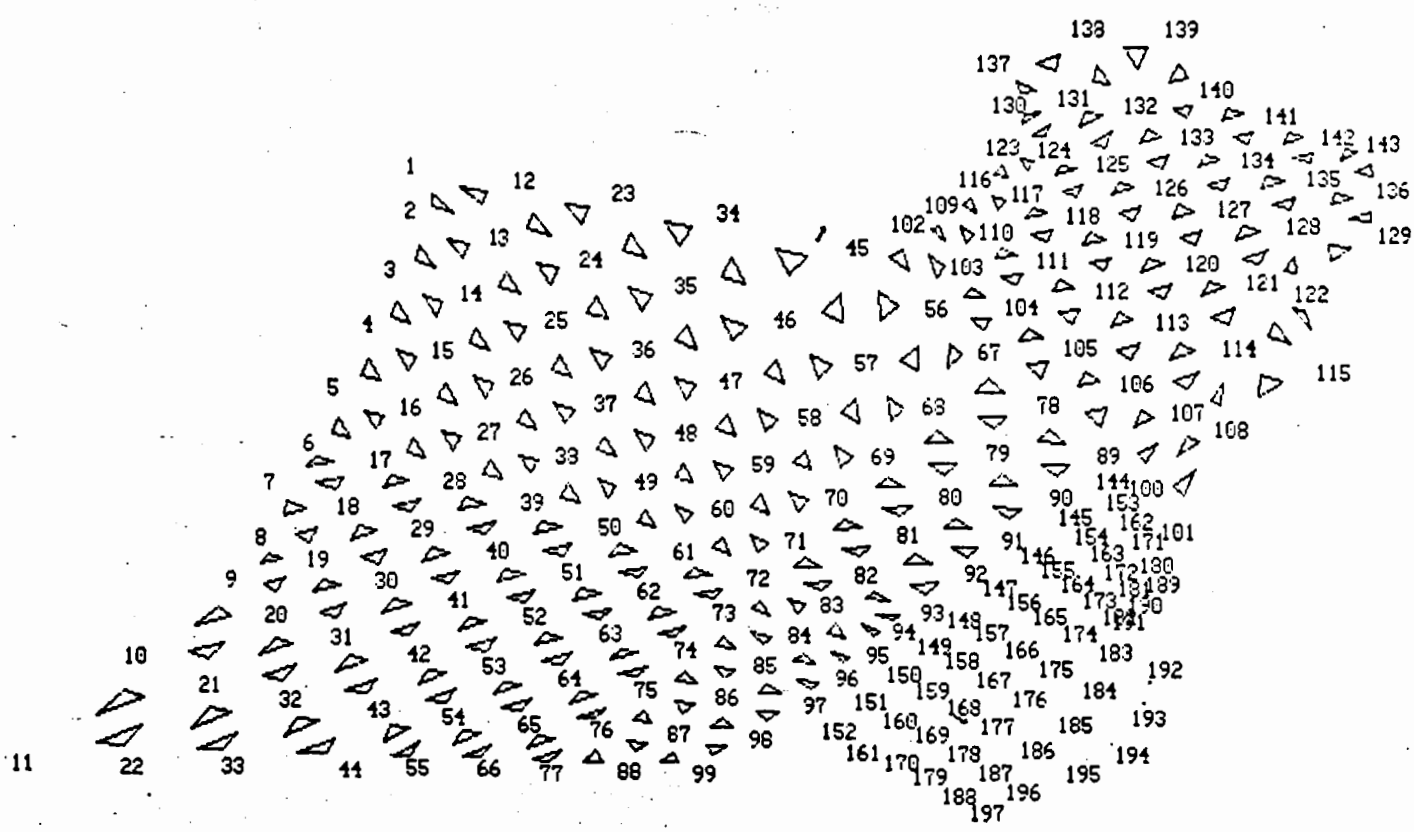


*Figure 3.5 Finite Element Mesh : Node Numbers.*

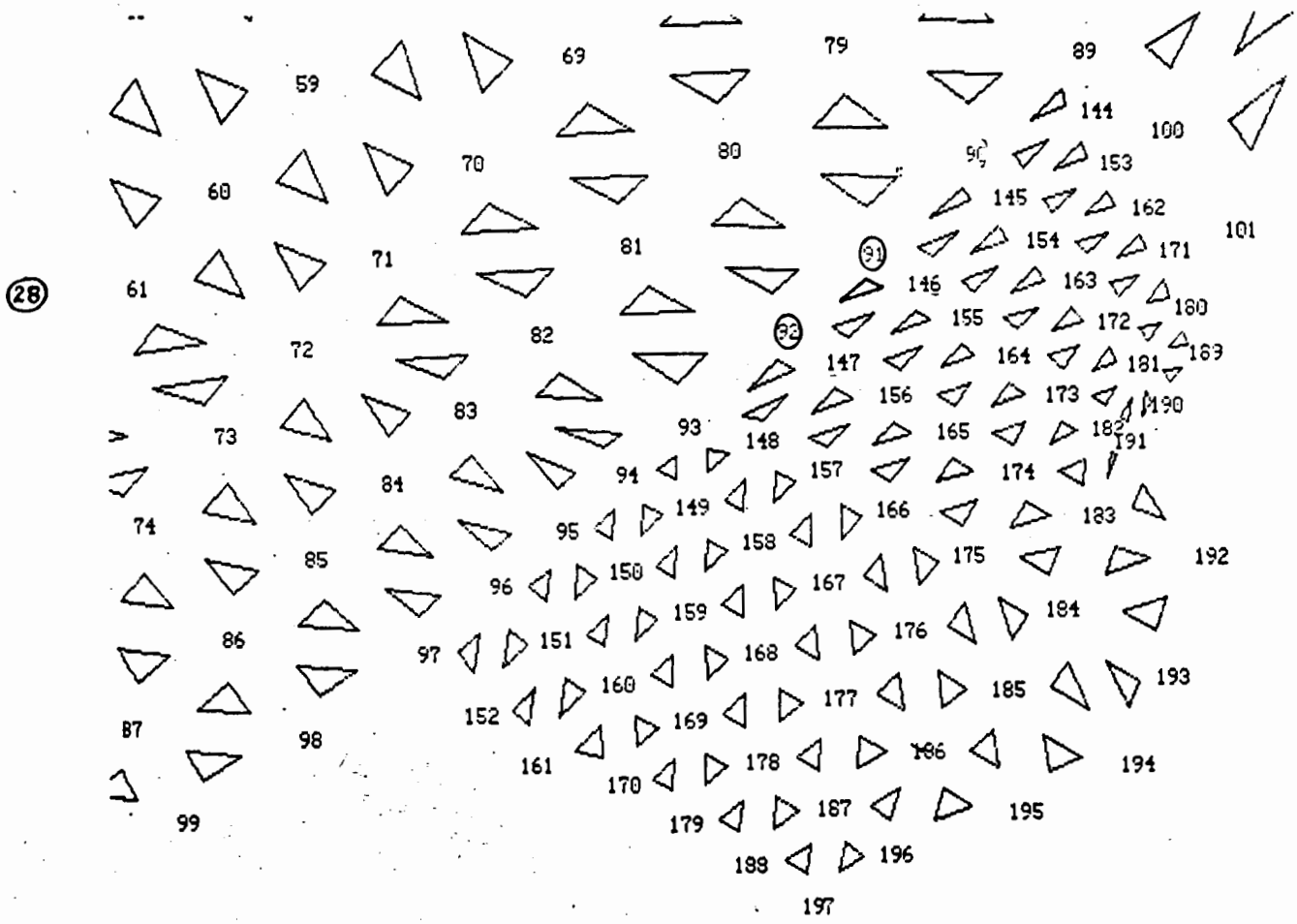



*Figure 3.6 Hawkins Bay Region : Location for vertical profile plots of Figures 5.7-5.13 .*

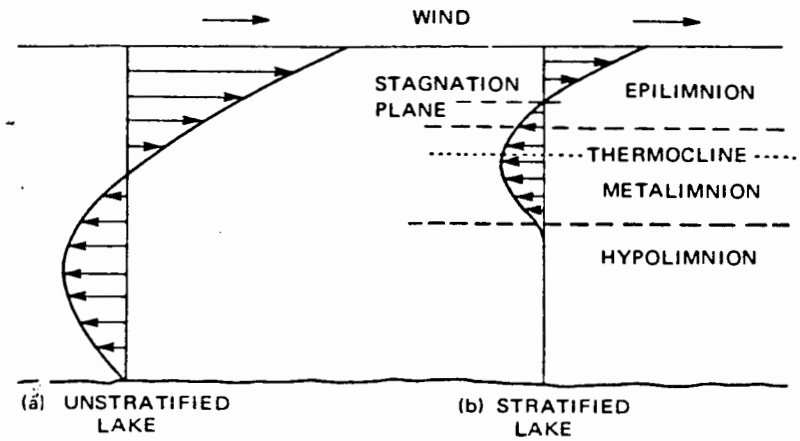



Figure 12 PROFILE OF WIND INDUCED CURRENTS

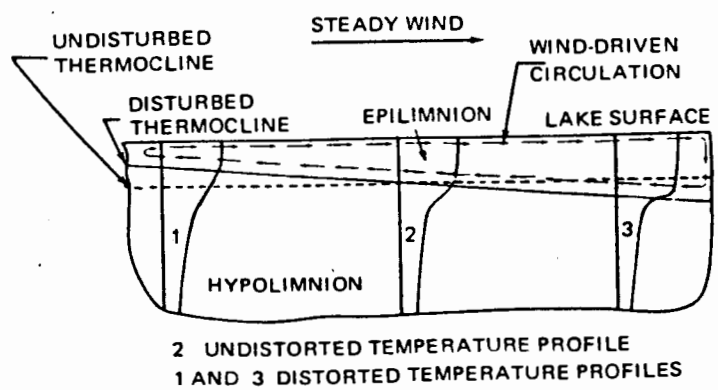



Figure 13 SCHEMATIC VIEW OF THE TILTING OF THE THERMOCLINE DUE TO WIND STRESS

*Figure 3.7 General Character of Wind Driven Flows in Lakes .*
*a) Profile of Wind Induced Current*
*b) Tilting of The Thermocline Due to Wind Stress*
*From : Cornell Aeronautical Laboratory Report [1969]*

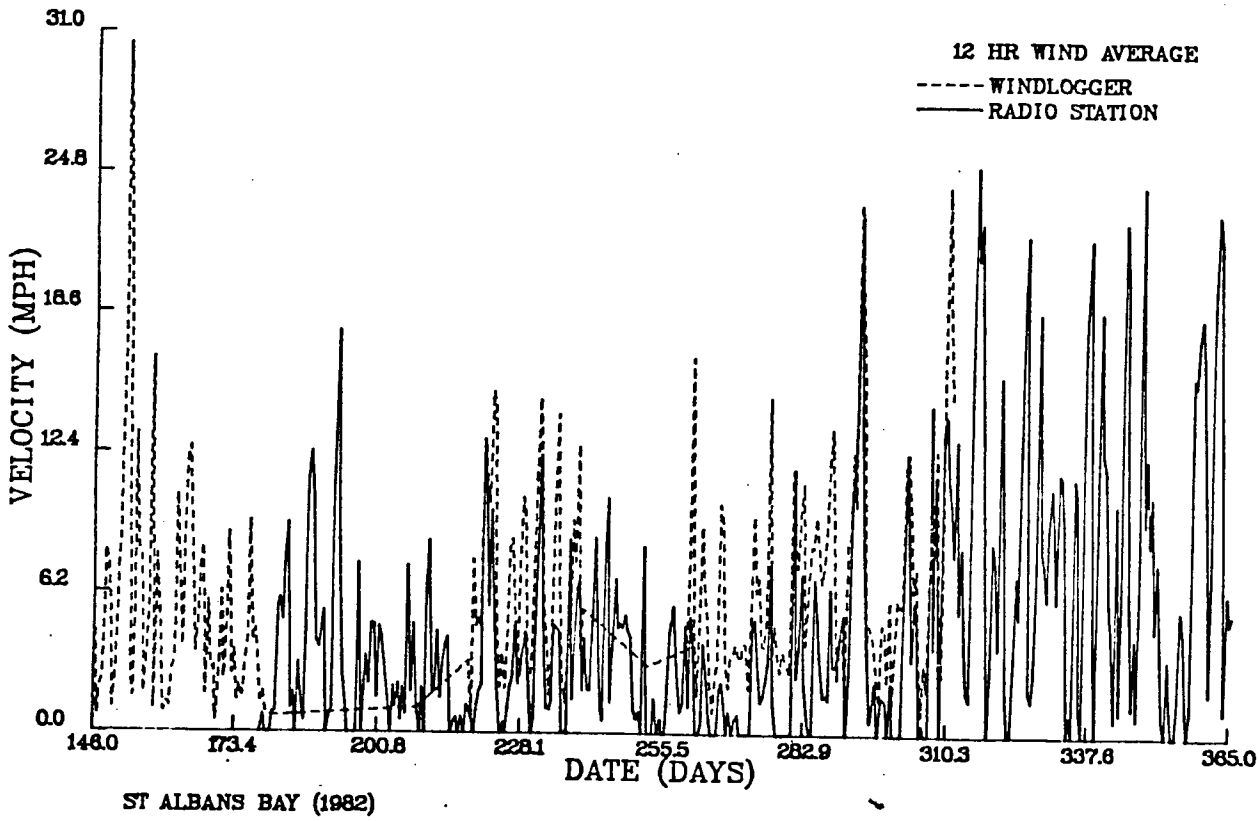



*Figure 4.1 St. Albans Wind Magnitude Time History.*

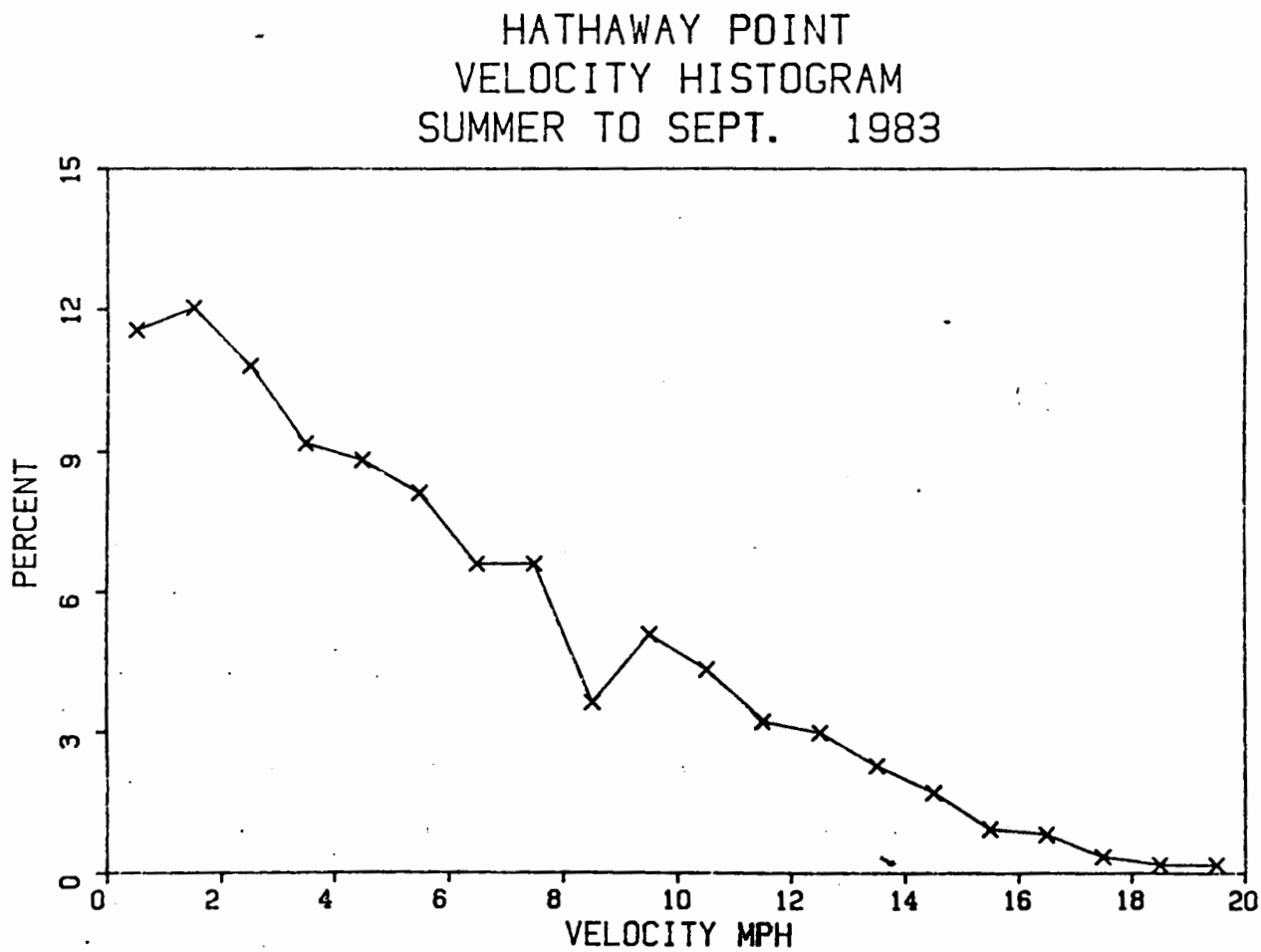



*Figure 4.2 St. Albans Wind Magnitude Histogram : Bay Station .*

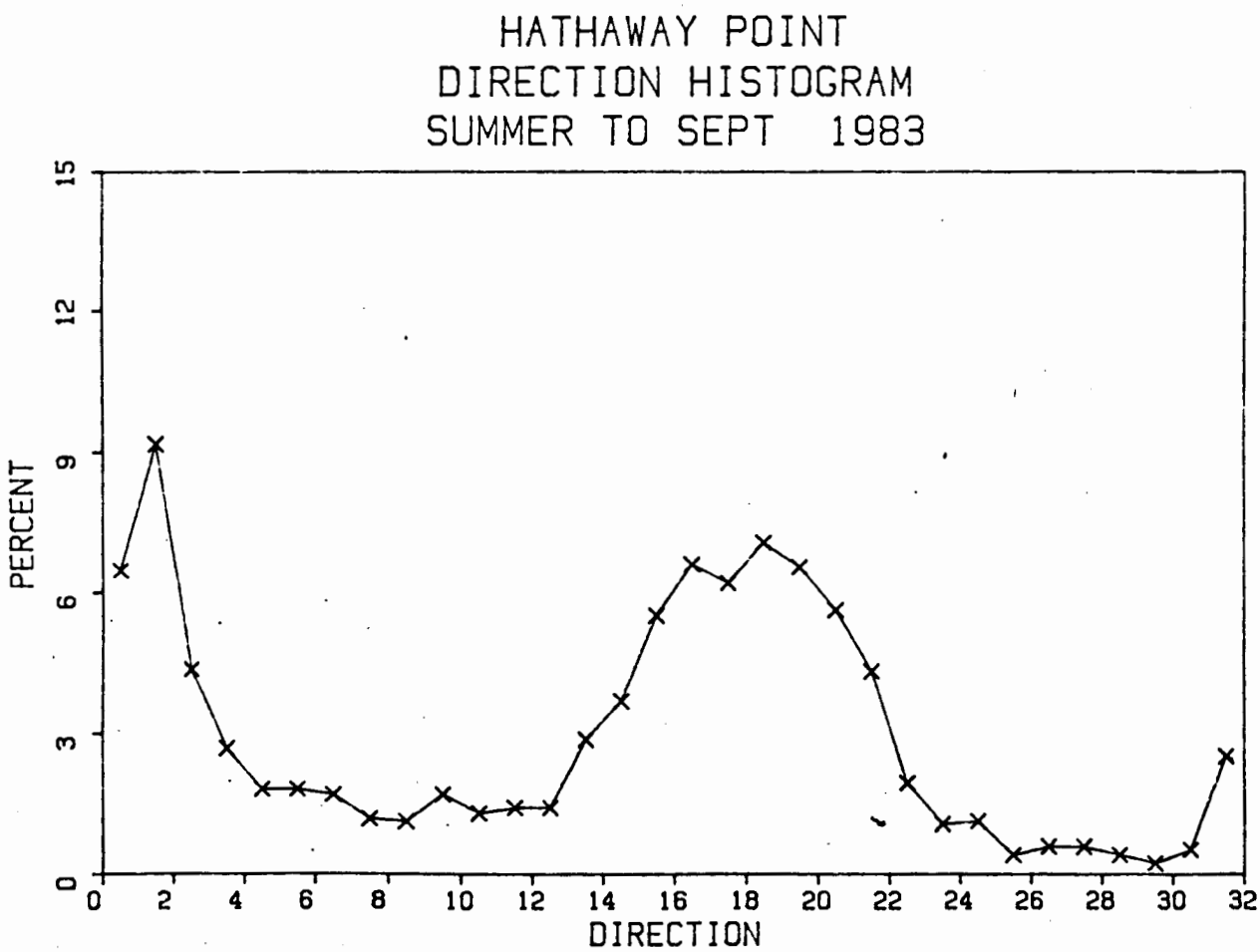



*Figure 4.3 St. Albans Wind Direction Histogram : Bay Station .*

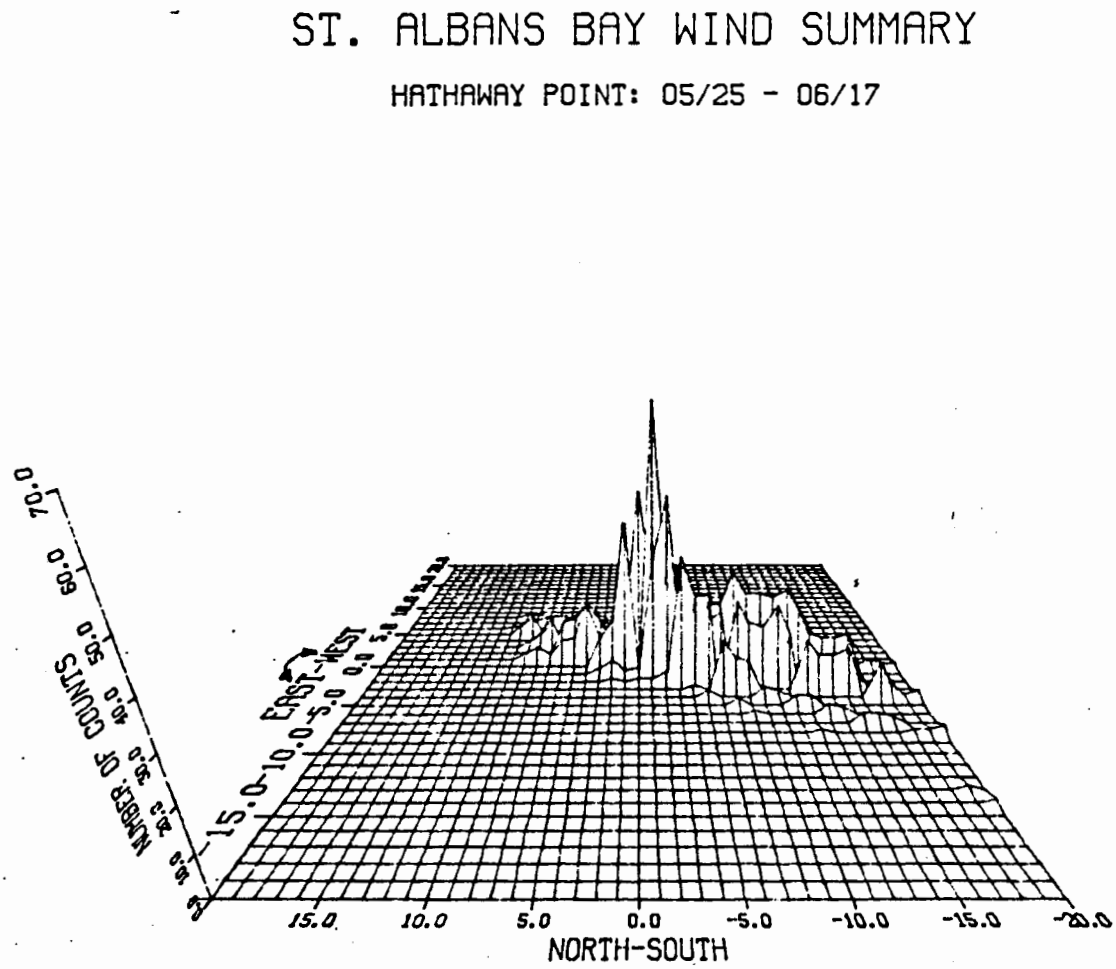



*Figure 4.4 St. Albans 3D Wind Rose : Bay Station .*

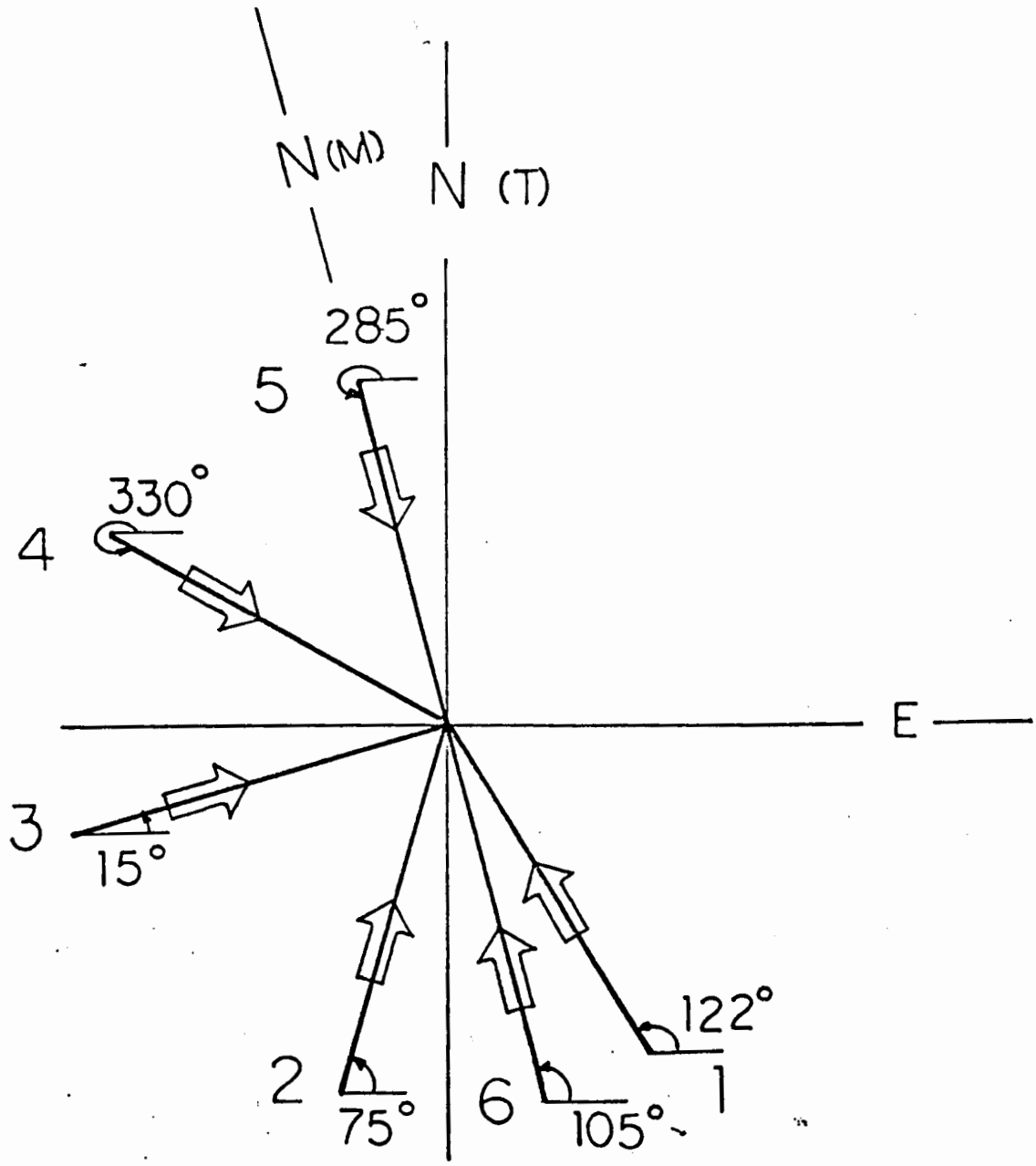



*Figure 4.5 Definition of Wind Load Cases 1-6.*
*Definition of θ .*

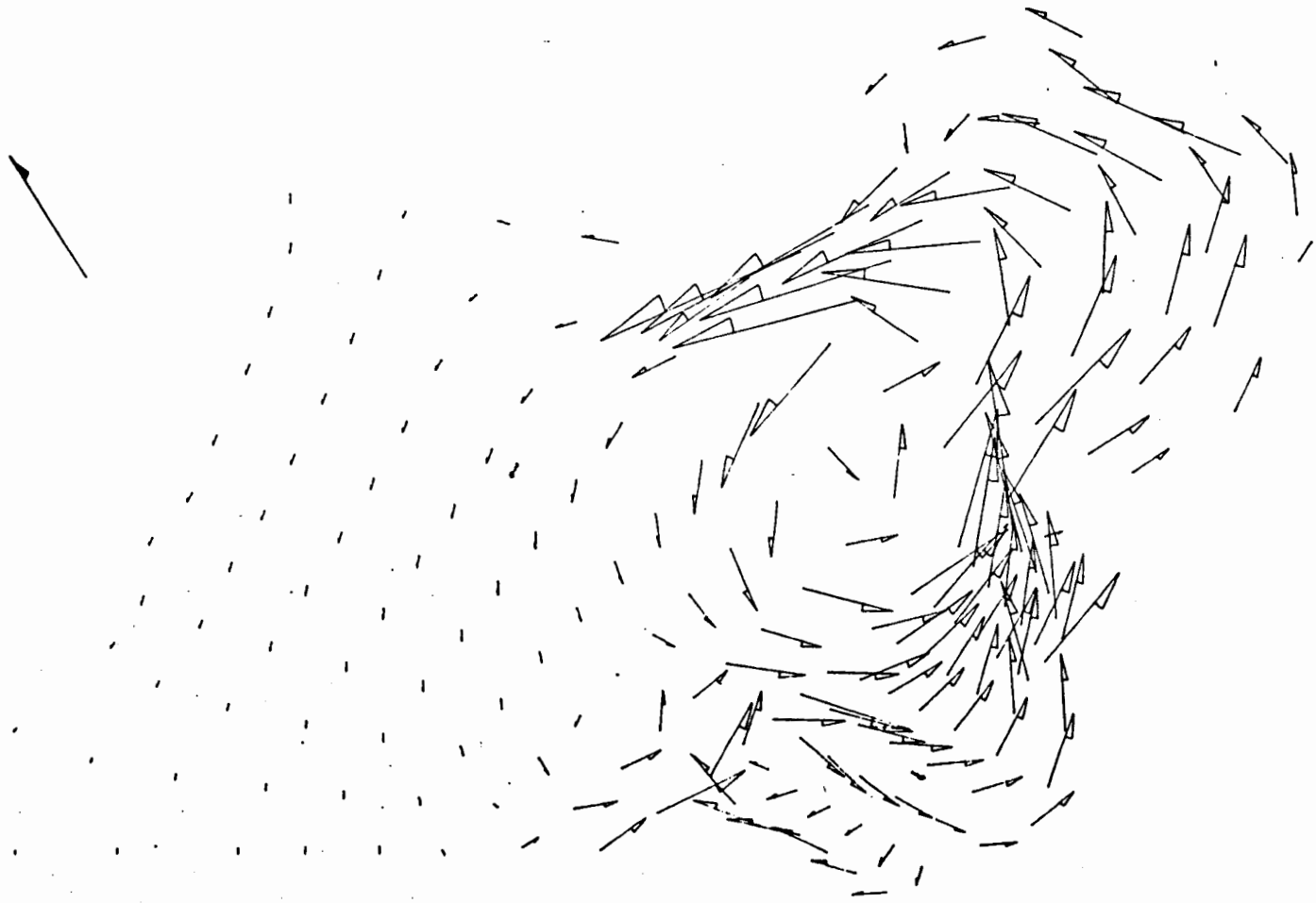


*Figure 5.1 Circulation Pattern for Wind Load Case 1 .*
*SE Bearing.*

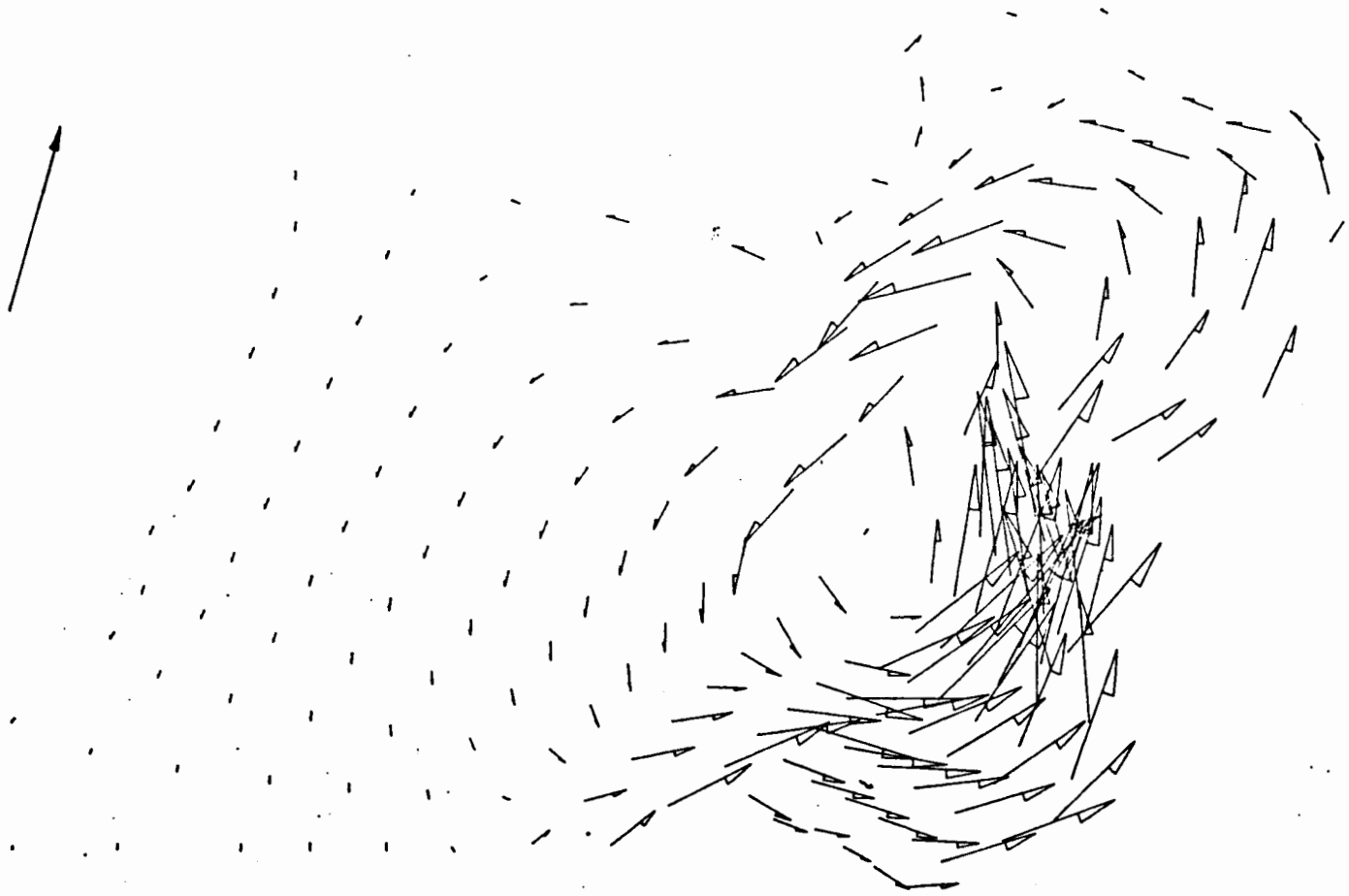


*Figure 5.2 Circulation Pattern for Wind Load Case 2 .*
*SSW Bearing.*

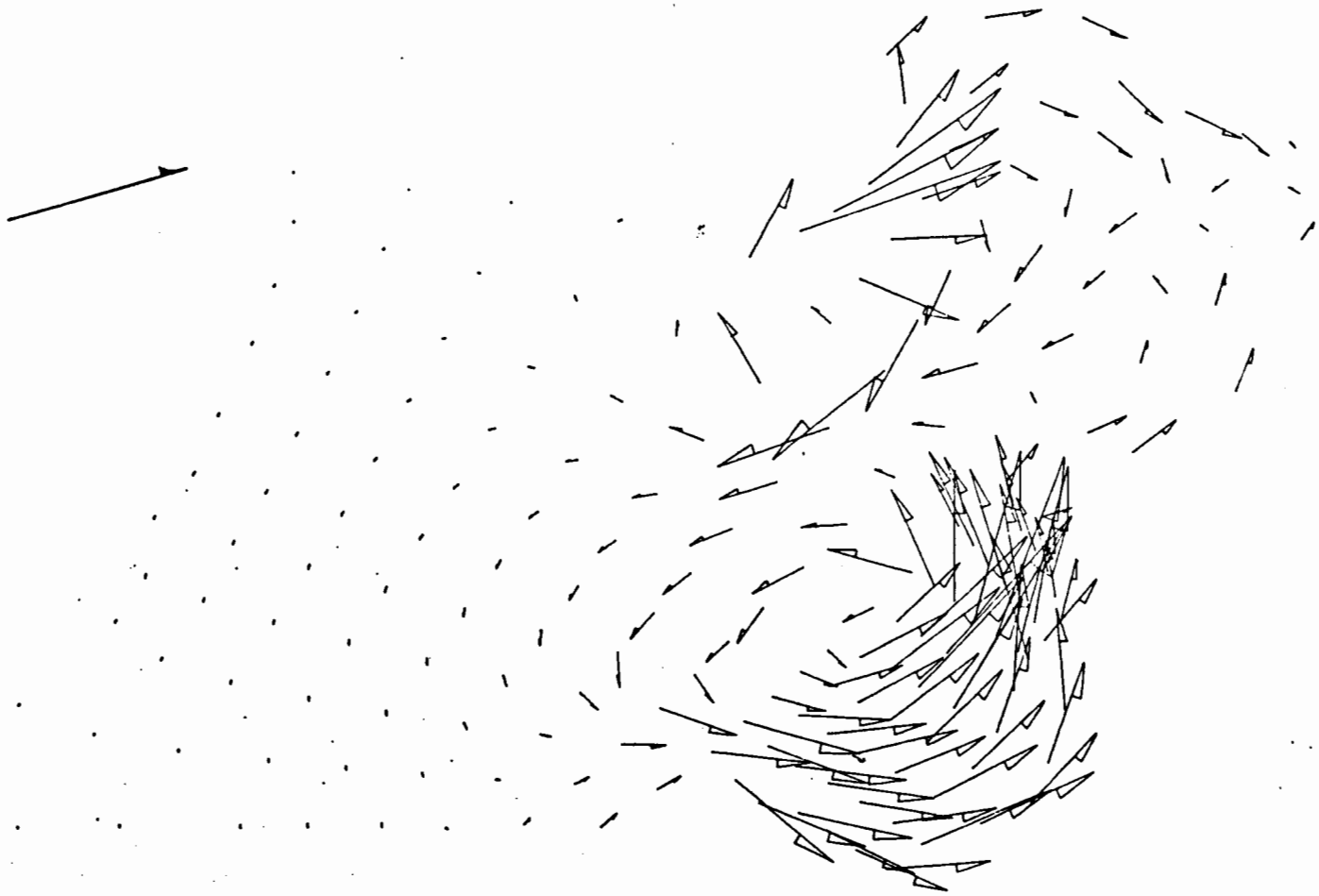


*Figure 5.3 Circulation Pattern for Wind Load Case 3 .*
*W Bearing.*

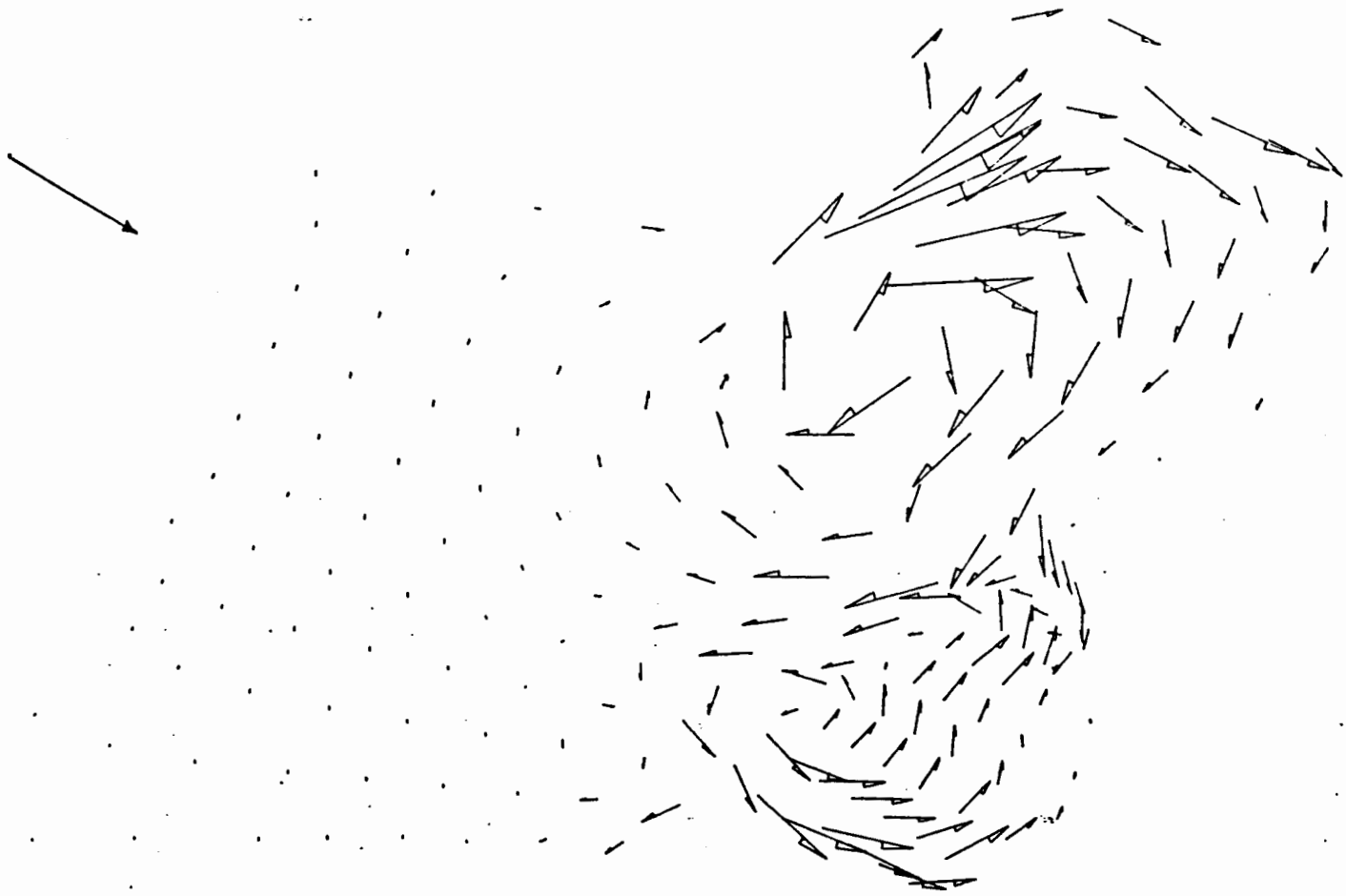


*Figure 5.4 Circulation Pattern for Wind Load Case 4 .*
*NW Bearing.*

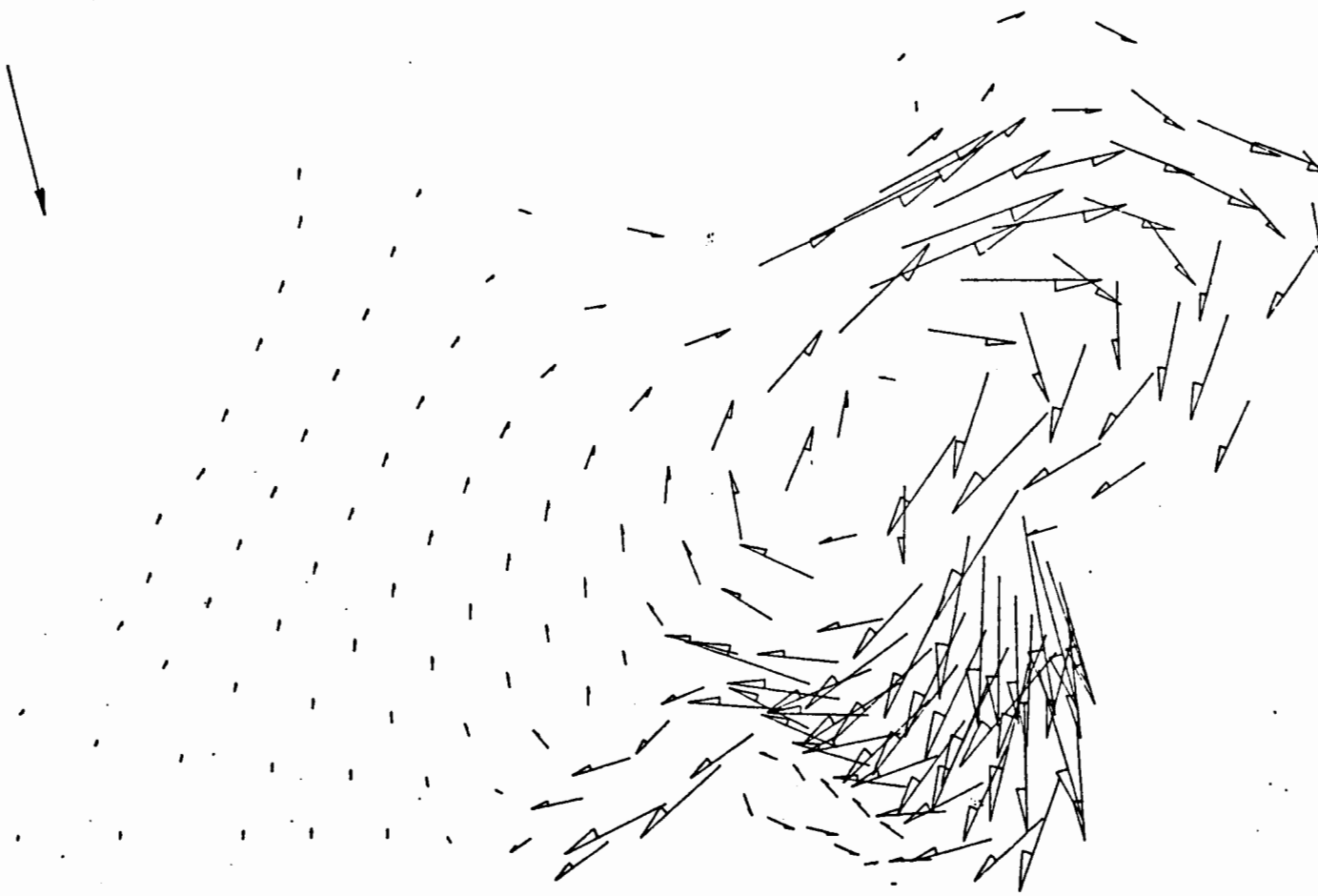


*Figure 5.5 Circulation Pattern for Wind Load Case 5 .*
*N Bearing.*

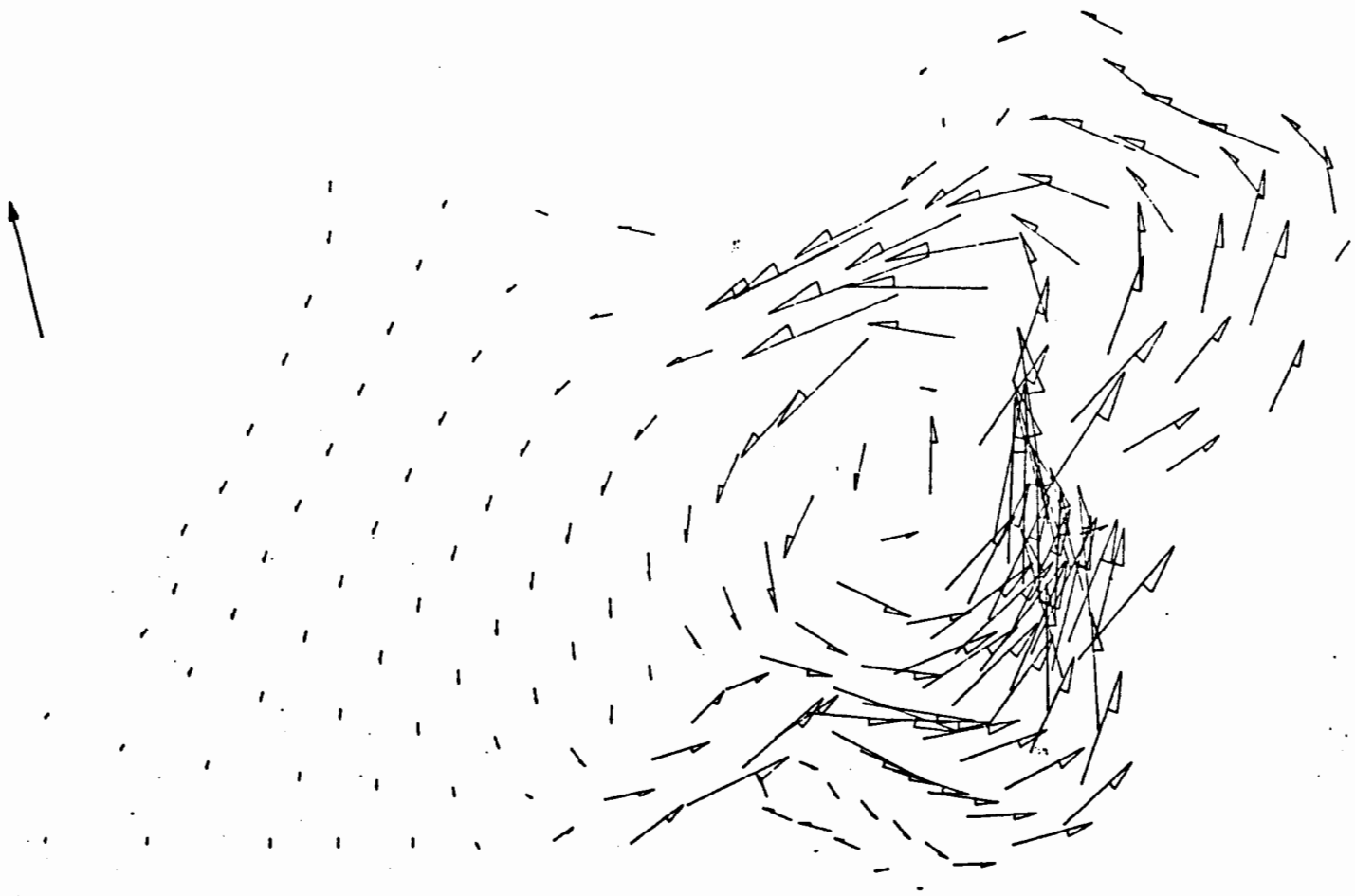


*Figure 5.6 Circulation Pattern for Wind Load Case 6 .*
*S Bearing.*

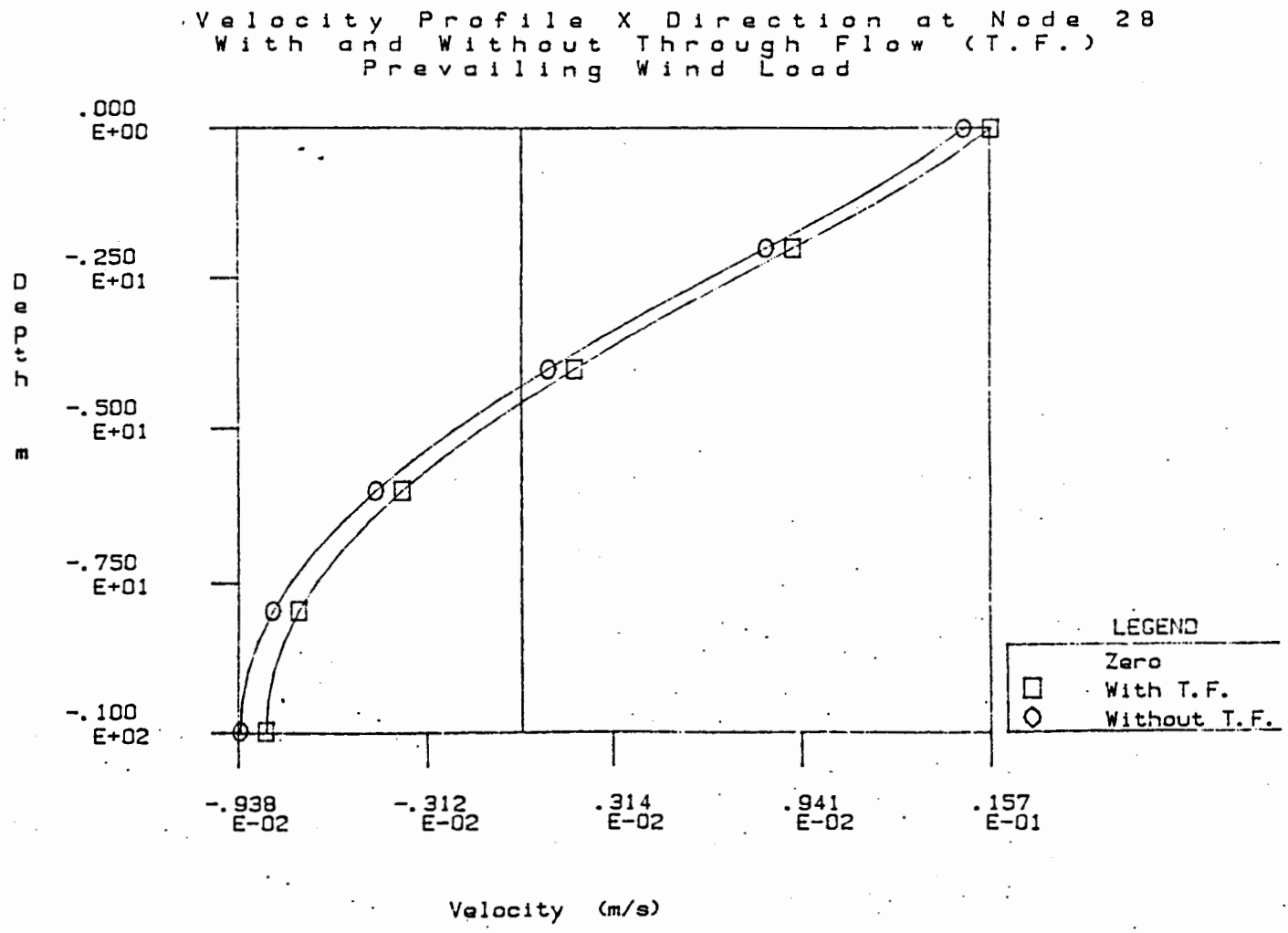



Figure 5.7 Effect of Through Flow X Velocity : Node 28

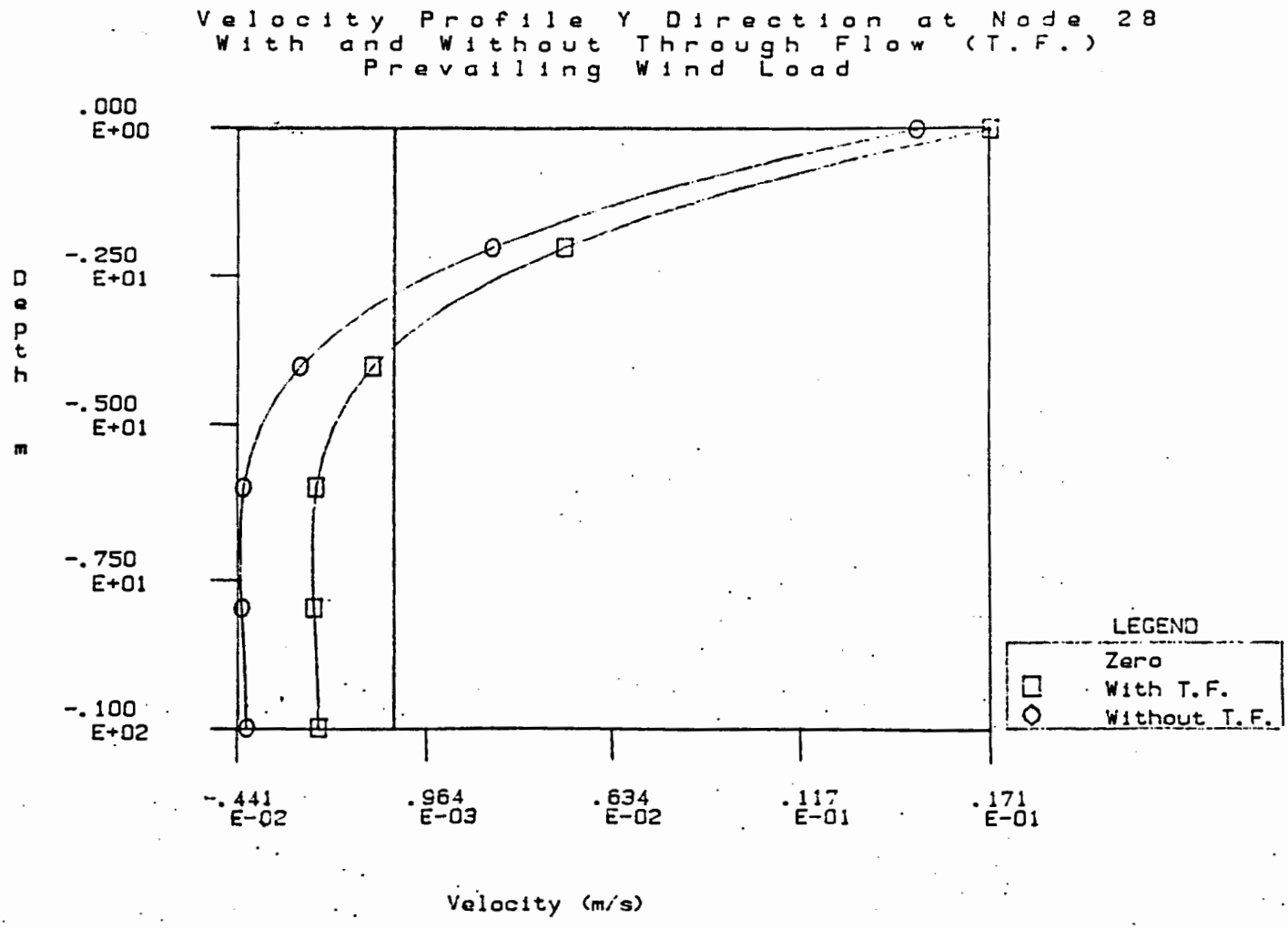



Figure 5.8 Effect of Through Flow Y Velocity : Node 28

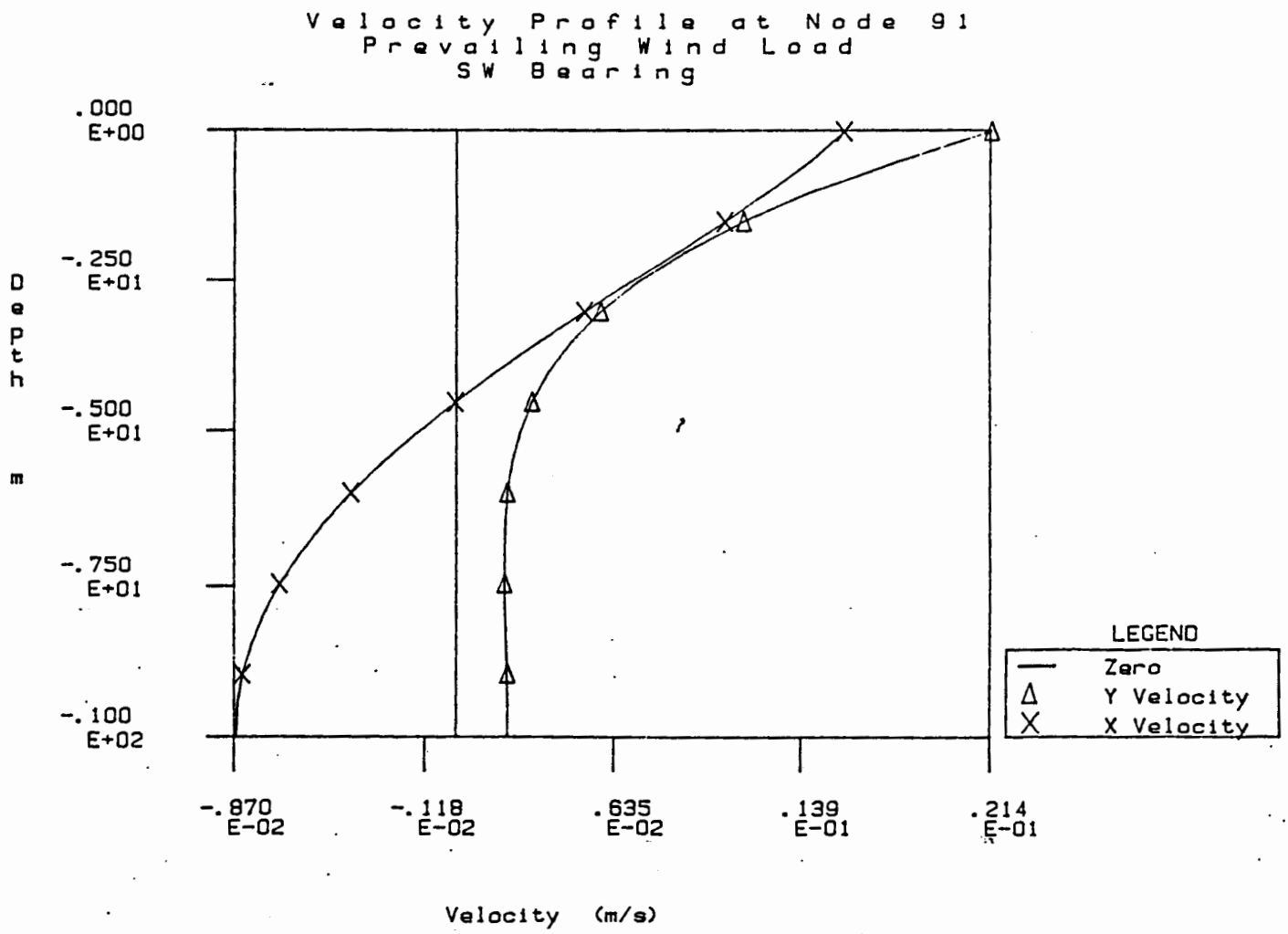



*Figure 5.9 Velocity Profile : Node 91 .*

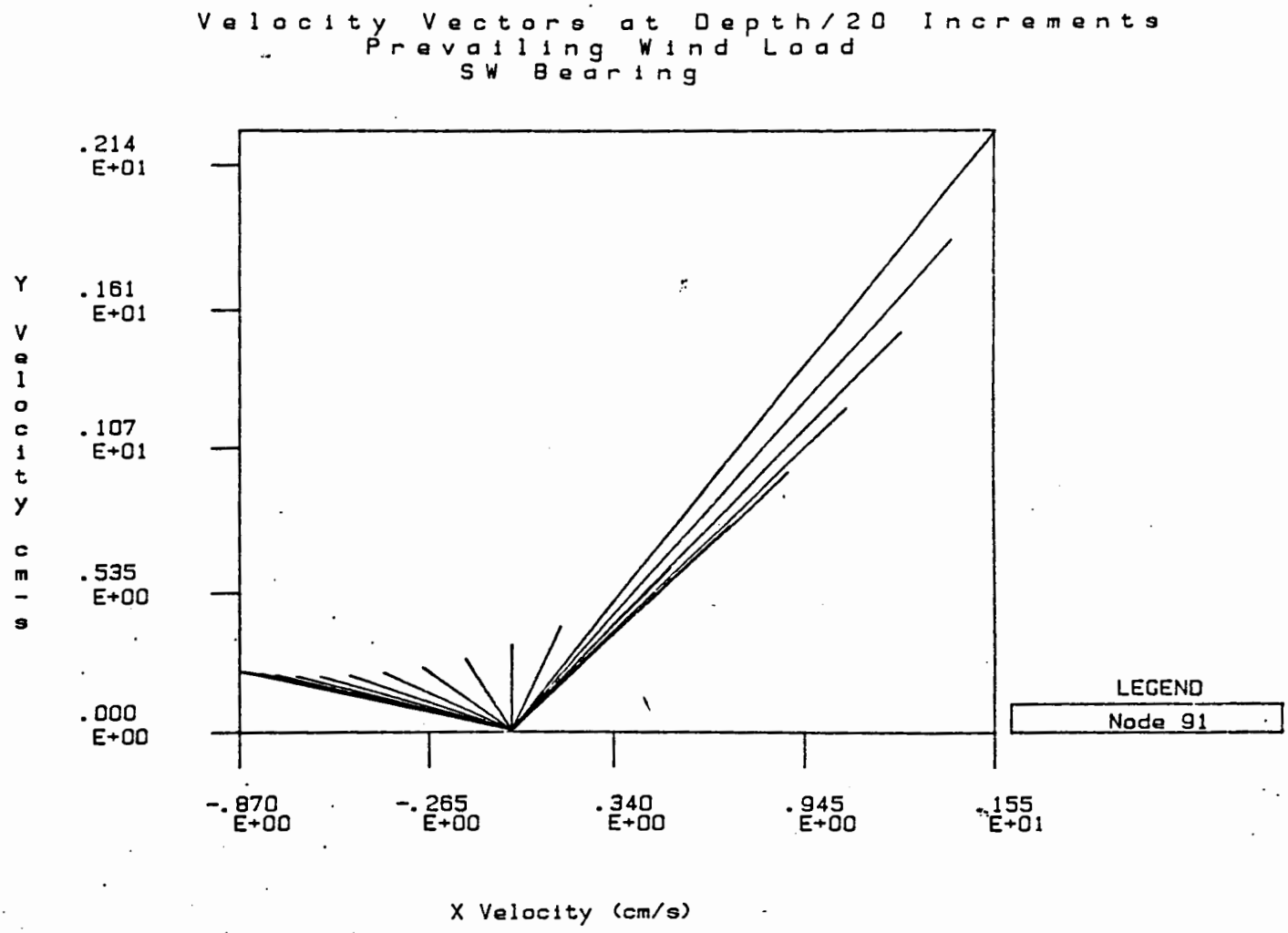



*Figure 5.10 Velocity Vectors at increments of H/20 : Node 91 . Largest vectors are surface velocities.*

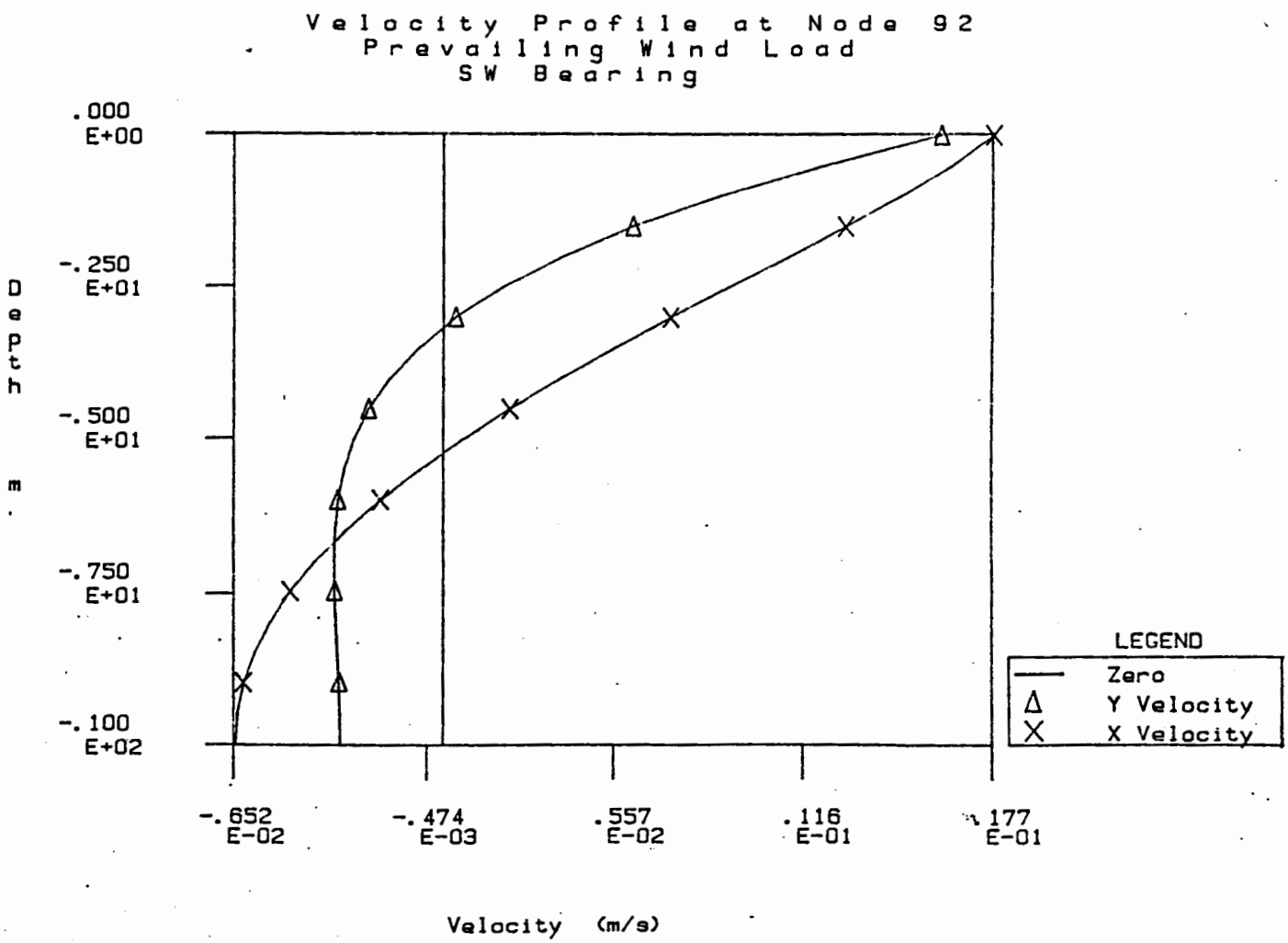



*Figure 5.11 Velocity Profile : Node 92 .*

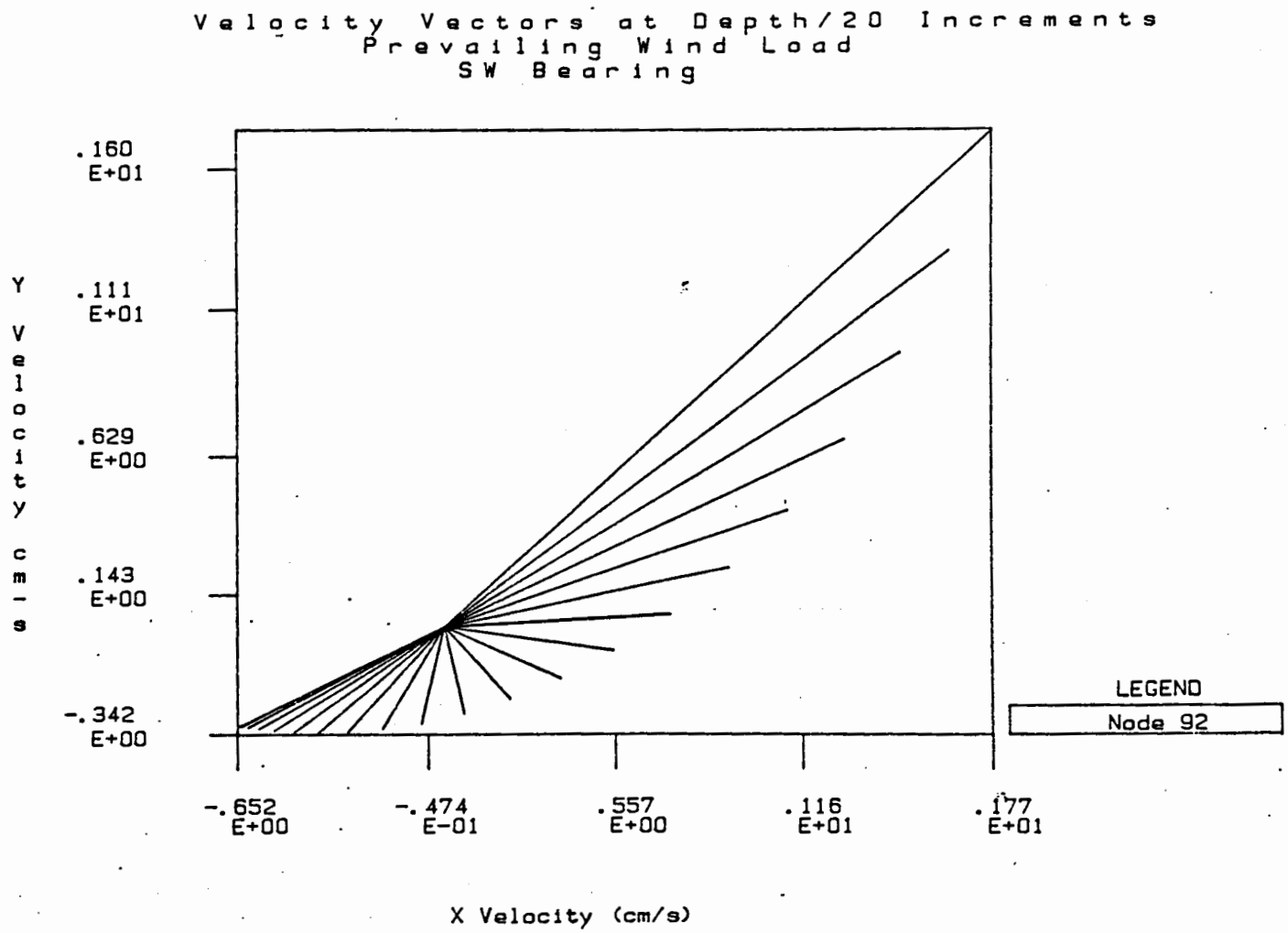



*Figure 5.12 Velocity Vectors at increments of H/20 : Node 92 .*
*Largest vectors are surface velocities.*

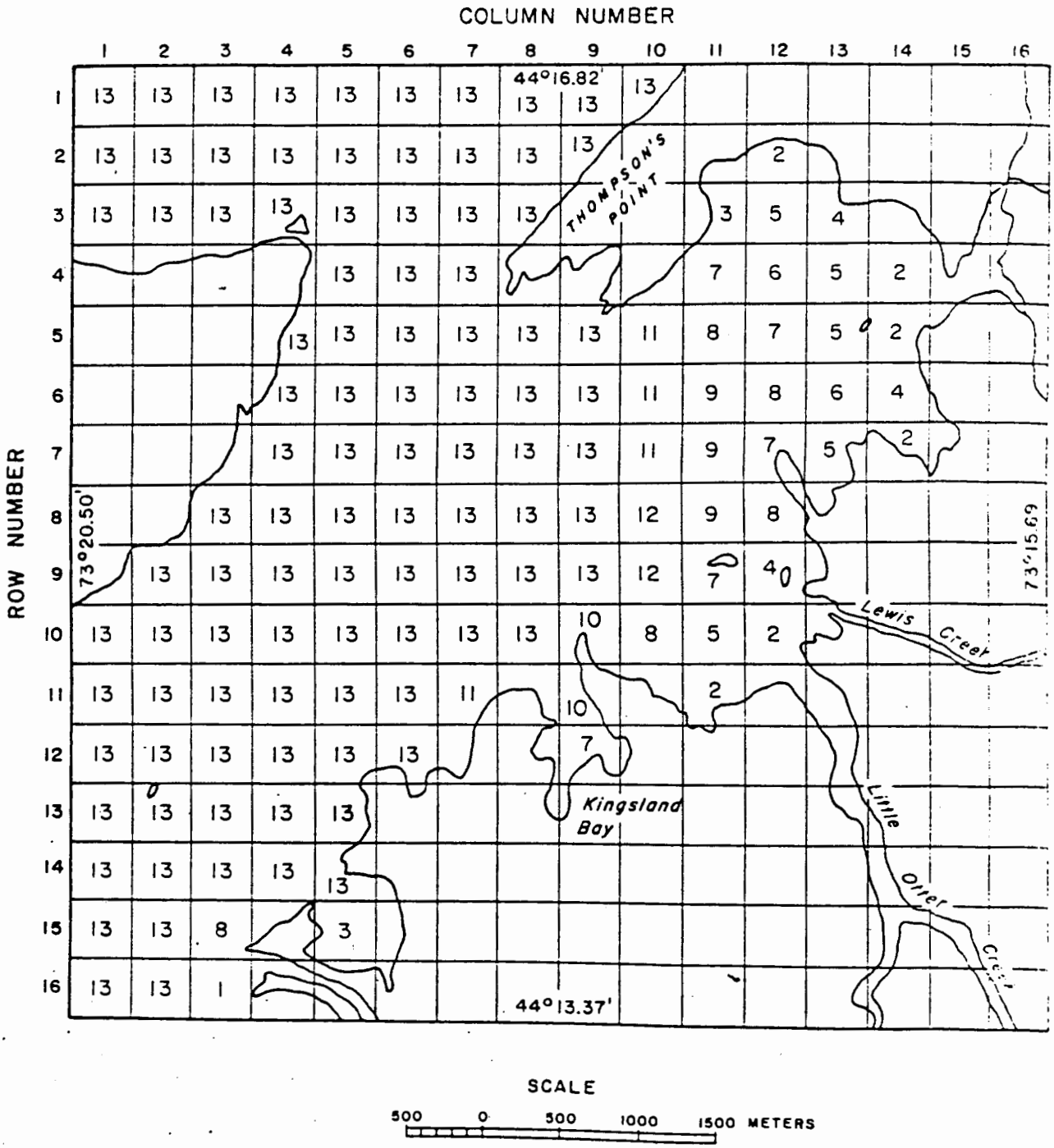



Figure 28. Depth grid (meters) used for modeling.

*Figure 6.1 Cell Model : from Smeltzer [1985] .*

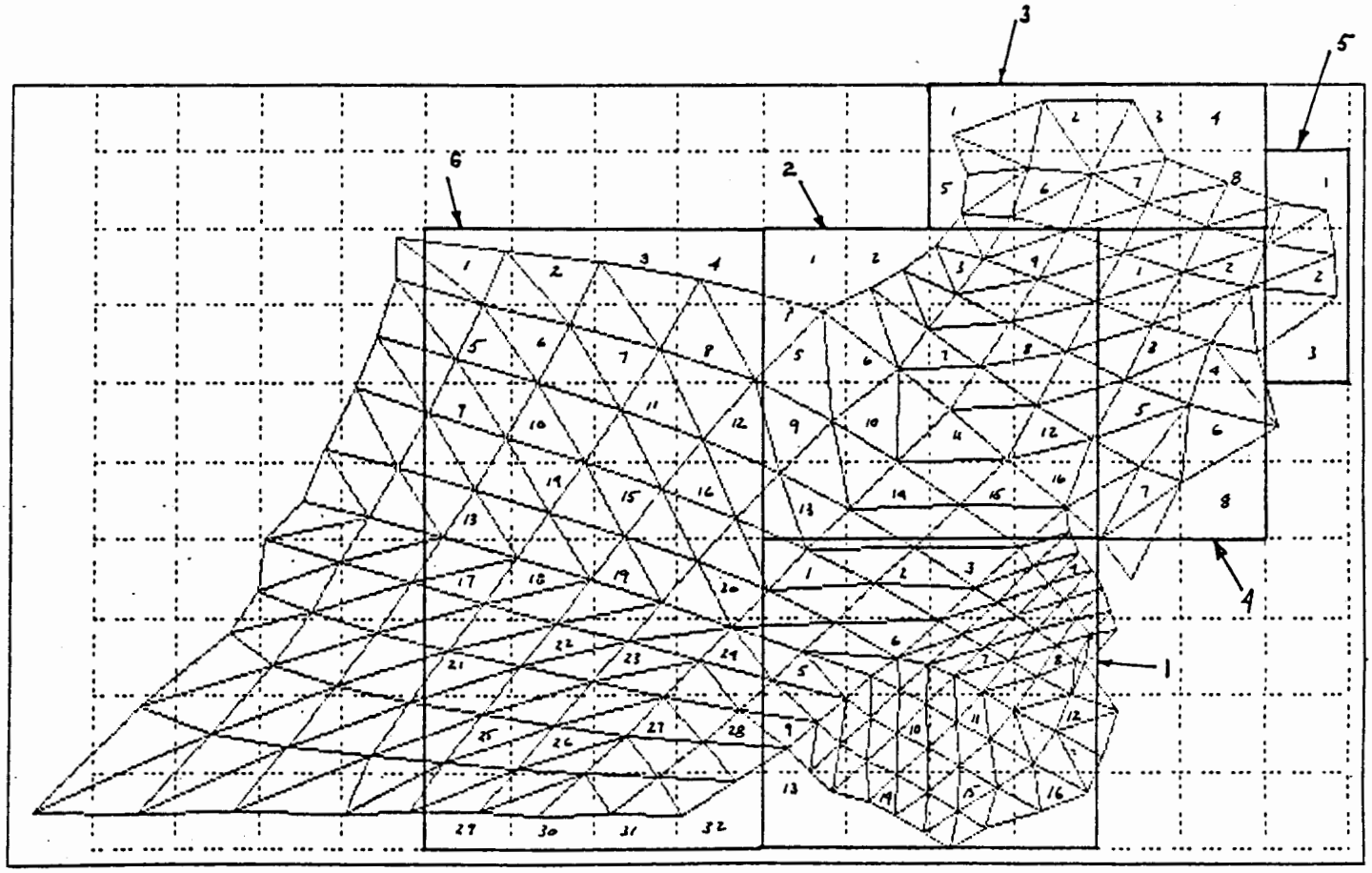



*Figure 6.2 Finite Element Mesh and Transport Cell Regions .*

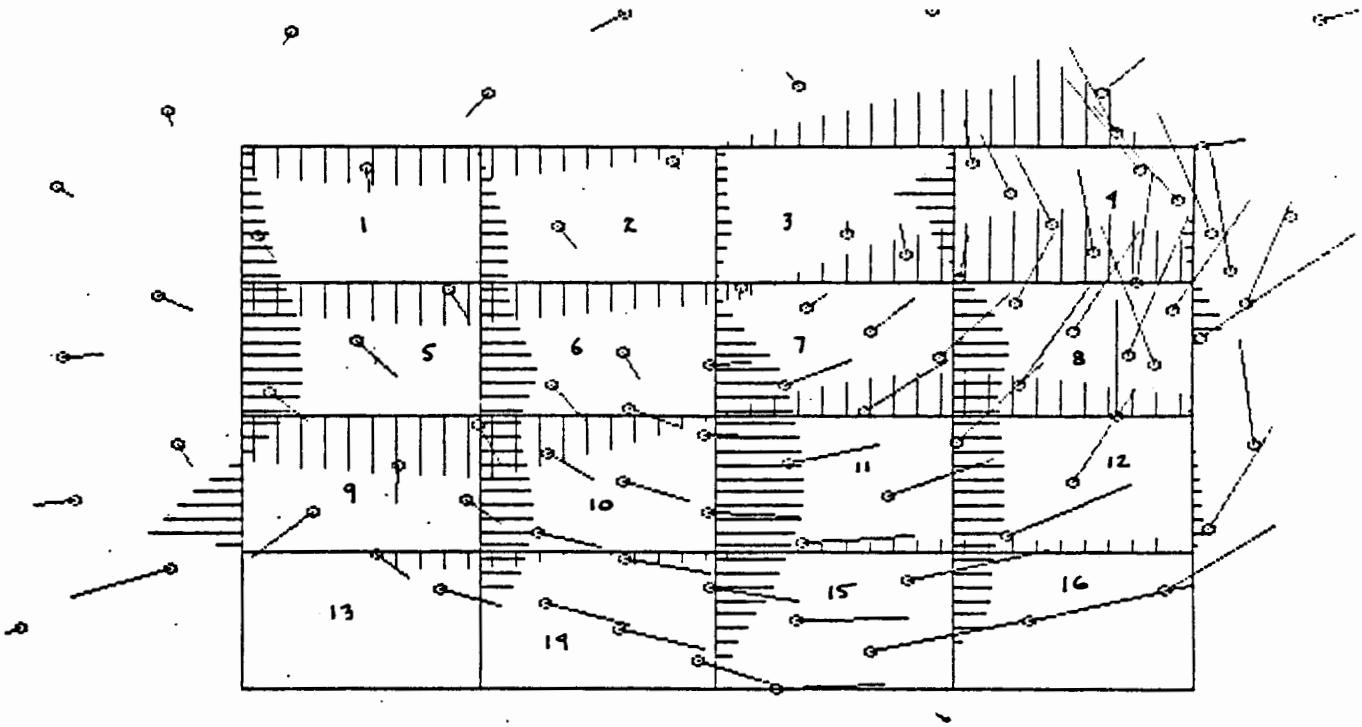



*Figure 6.3 Nodal Velocities (F.E. Analysis) and Integrated flow for each cell face.*

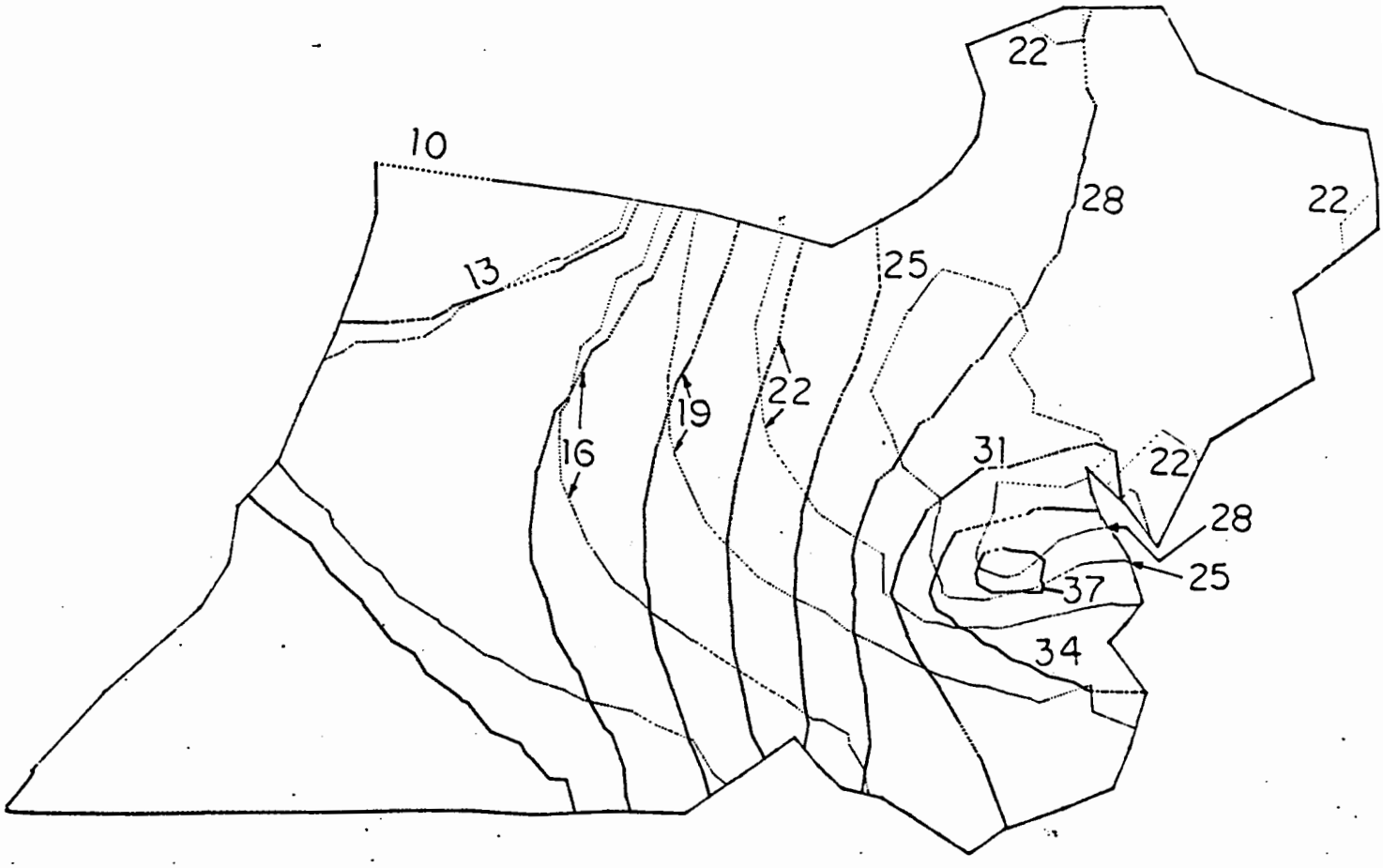



*Figure 7.1 Isoconcentration Lines .*
*Internal release at element 237 , 100ppb @ 11.5 mgd .*
*Dotted lighter lines are for SW Wind Load and* $D = 200000. \frac{m^2}{days}$ .
*Heavy solid lines are for No Wind Load and* $D = 200000. \frac{m^2}{days}$ .

# APPENDIX

APPENDIX FLOWSWN

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 3.85 | 0.76 | 0.00 | 16.42 | 1.78 | 0.08 | 12.80 | 0.00 | +1.16 |
| 1 | 2 | 4.01 | 0.00 | 0.98 | 5.34 | 0.76 | 3.85 | 6.97 | 0.00 | +3.54 |
| 1 | 3 | 2.60 | 5.99 | 25.66 | 0.00 | 0.00 | 4.02 | 0.01 | 23.83 | -5.57 |
| 1 | 4 | 0.00 | 0.50 | 28.11 | 0.00 | 5.99 | 2.60 | 0.00 | 27.85 | +3.15 |
| 1 | 5 | 19.91 | 0.00 | 0.00 | 12.80 | 0.00 | 8.25 | 1.52 | 0.42 | -0.04 |
| 1 | 6 | 26.37 | 0.00 | 0.00 | 6.97 | 0.00 | 19.91 | 4.19 | 1.67 | +2.01 |
| 1 | 7 | 16.21 | 0.00 | 23.83 | 0.01 | 0.00 | 26.37 | 0.00 | 15.51 | -1.86 |
| 1 | 8 | 1.02 | 0.11 | 27.85 | 0.00 | 0.00 | 16.21 | 0.00 | 10.68 | +1.87 |
| 1 | 9 | 21.16 | 0.00 | 0.41 | 1.52 | 0.00 | 21.20 | 1.47 | 0.00 | +0.32 |
| 1 | 10 | 22.63 | 0.00 | 1.67 | 4.19 | 0.00 | 21.16 | 1.68 | 0.48 | +0.15 |
| 1 | 11 | 9.03 | 0.00 | 15.51 | 0.00 | 0.00 | 22.63 | 0.16 | 1.94 | +0.14 |
| 1 | 12 | 0.79 | 0.05 | 10.68 | 0.00 | 0.00 | 9.03 | 0.00 | 3.12 | -0.73 |
| 1 | 13 | 1.93 | 0.00 | 0.00 | 1.47 | 0.00 | 0.00 | 0.00 | 0.00 | +0.46 |
| 1 | 14 | 5.02 | 0.00 | 0.48 | 1.68 | 0.00 | 1.93 | 0.00 | 0.00 | +1.90 |
| 1 | 15 | 3.22 | 0.00 | 1.94 | 0.16 | 0.00 | 5.02 | 0.00 | 0.00 | -0.03 |
| 1 | 16 | 0.00 | 0.00 | 3.12 | 0.00 | 0.00 | 3.22 | 0.00 | 0.00 | -0.10 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1 | 0.00 | 0.13 | 0.00 | 0.00 | 1.15 | 0.00 | 0.00 | 2.36 | -1.34 |
| 2 | 2 | 0.00 | 5.13 | 0.00 | 0.00 | 0.13 | 0.00 | 7.55 | 0.00 | +2.55 |
| 2 | 3 | 0.00 | 14.41 | 0.28 | 1.06 | 5.13 | 0.00 | 10.75 | 0.00 | +0.70 |
| 2 | 4 | 0.00 | 14.05 | 0.00 | 3.98 | 14.41 | 0.00 | 3.14 | 0.83 | -1.32 |
| 2 | 5 | 0.00 | 14.54 | 2.36 | 0.00 | 9.89 | 0.00 | 0.80 | 0.02 | -1.51 |
| 2 | 6 | 0.00 | 21.04 | 0.00 | 7.55 | 14.54 | 0.00 | 13.78 | 0.00 | -0.27 |
| 2 | 7 | 0.00 | 24.26 | 0.00 | 10.75 | 21.04 | 0.00 | 9.78 | 0.46 | -4.66 |
| 2 | 8 | 0.00 | 6.57 | 0.83 | 3.14 | 24.26 | 0.00 | 0.00 | 13.84 | +1.54 |
| 2 | 9 | 0.00 | 19.82 | 0.02 | 0.80 | 10.39 | 0.00 | 8.65 | 0.00 | -1.56 |
| 2 | 10 | 0.00 | 17.52 | 0.00 | 13.78 | 19.82 | 0.00 | 13.22 | 0.00 | +1.73 |
| 2 | 11 | 2.82 | 3.47 | 0.46 | 9.78 | 17.52 | 0.00 | 0.43 | 11.29 | -3.32 |
| 2 | 12 | 10.92 | 0.00 | 13.84 | 0.00 | 3.47 | 2.82 | 0.00 | 22.81 | +2.60 |
| 2 | 13 | 0.00 | 15.37 | 0.00 | 8.65 | 7.56 | 0.00 | 16.42 | 0.00 | -0.04 |
| 2 | 14 | 0.00 | 7.40 | 0.00 | 13.22 | 15.21 | 0.00 | 5.34 | 0.98 | -1.05 |
| 2 | 15 | 8.58 | 0.00 | 11.29 | 0.43 | 7.42 | 0.00 | 0.00 | 25.66 | +1.20 |
| 2 | 16 | 11.68 | 0.00 | 22.81 | 0.00 | 0.00 | 8.58 | 0.00 | 24.67 | +1.23 |

APPENDIX FLOWSWN

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 1 | 0.46 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.58 | -0.12 |
| 3 | 2 | 0.00 | 0.29 | 0.00 | 0.00 | 0.00 | 0.46 | 0.36 | 0.11 | -0.50 |
| 3 | 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.29 | 0.00 | 0.16 | 0.05 | +0.40 |
| 3 | 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | +0.00 |
| 3 | 5 | 0.60 | 1.36 | 0.58 | 0.00 | 0.00 | 0.00 | 1.06 | 0.28 | +0.59 |
| 3 | 6 | 0.00 | 4.84 | 0.11 | 0.36 | 1.36 | 0.60 | 3.98 | 0.00 | -0.34 |
| 3 | 7 | 0.00 | 3.37 | 0.05 | 0.16 | 4.84 | 0.00 | 0.21 | 1.22 | +0.35 |
| 3 | 8 | 0.00 | 1.13 | 0.00 | 0.00 | 3.37 | 0.00 | 0.00 | 2.20 | +0.05 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 1 | 0.00 | 7.58 | 1.22 | 0.21 | 14.05 | 0.00 | 0.00 | 7.37 | +0.12 |
| 4 | 2 | 0.43 | 1.92 | 2.19 | 0.00 | 7.58 | 0.00 | 0.00 | 8.47 | -0.20 |
| 4 | 3 | 1.18 | 0.55 | 7.37 | 0.00 | 6.57 | 0.00 | 0.00 | 14.28 | +0.29 |
| 4 | 4 | 1.08 | 0.00 | 8.47 | 0.00 | 0.55 | 1.18 | 0.00 | 10.63 | -1.70 |
| 4 | 5 | 8.04 | 0.00 | 14.28 | 0.00 | 0.00 | 10.95 | 0.00 | 10.93 | +0.44 |
| 4 | 6 | 1.52 | 0.00 | 10.63 | 0.00 | 0.00 | 8.04 | 0.00 | 1.97 | +2.15 |
| 4 | 7 | 1.71 | 0.00 | 10.93 | 0.00 | 0.00 | 11.68 | 0.00 | 0.88 | +0.08 |
| 4 | 8 | 0.00 | 0.00 | 1.97 | 0.00 | 0.00 | 1.70 | 0.00 | 0.00 | +0.27 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.98 | 0.00 | 0.00 | 1.44 | -0.46 |
| 5 | 2 | 0.00 | 0.00 | 1.66 | 0.00 | 1.92 | 0.43 | 0.00 | 3.18 | -0.02 |
| 5 | 3 | 0.00 | 0.00 | 3.18 | 0.00 | 0.00 | 1.08 | 0.00 | 0.15 | +1.95 |

APPENDIX FLOWSWN

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 1 | 0.00 | 0.85 | 0.00 | 0.00 | 0.51 | 0.00 | 2.50 | 0.00 | +2.16 |
| 6 | 2 | 0.00 | 1.47 | 0.00 | 0.00 | 0.85 | 0.00 | 1.23 | 0.00 | +0.60 |
| 6 | 3 | 0.00 | 2.86 | 0.00 | 0.00 | 1.47 | 0.00 | 0.01 | 0.60 | -1.97 |
| 6 | 4 | 0.00 | 1.15 | 0.00 | 0.00 | 2.86 | 0.00 | 0.00 | 1.88 | -0.17 |
| 6 | 5 | 0.00 | 1.68 | 0.00 | 2.50 | 1.27 | 0.00 | 3.01 | 0.00 | +0.10 |
| 6 | 6 | 0.00 | 3.07 | 0.00 | 1.23 | 1.68 | 0.00 | 2.57 | 0.00 | -0.05 |
| 6 | 7 | 0.00 | 6.38 | 0.60 | 0.01 | 3.07 | 0.00 | 1.93 | 0.00 | -0.79 |
| 6 | 8 | 0.00 | 9.89 | 1.88 | 0.00 | 6.38 | 0.00 | 1.57 | 0.00 | -0.06 |
| 6 | 9 | 0.00 | 2.06 | 0.00 | 3.03 | 1.54 | 0.00 | 3.50 | 0.00 | -0.04 |
| 6 | 10 | 0.00 | 3.43 | 0.00 | 2.57 | 2.06 | 0.00 | 3.83 | 0.00 | -0.12 |
| 6 | 11 | 0.00 | 6.01 | 0.00 | 1.93 | 3.43 | 0.00 | 4.58 | 0.00 | +0.07 |
| 6 | 12 | 0.00 | 10.39 | 0.00 | 1.57 | 6.01 | 0.00 | 6.42 | 0.00 | +0.48 |
| 6 | 13 | 0.00 | 1.81 | 0.00 | 3.50 | 1.49 | 0.00 | 3.76 | 0.00 | -0.06 |
| 6 | 14 | 0.00 | 2.65 | 0.00 | 3.82 | 1.81 | 0.00 | 4.59 | 0.00 | -0.07 |
| 6 | 15 | 0.00 | 4.31 | 0.00 | 4.58 | 2.65 | 0.00 | 6.24 | 0.00 | +0.01 |
| 6 | 16 | 0.00 | 7.56 | 0.00 | 6.42 | 4.31 | 0.00 | 9.43 | 0.00 | -0.24 |
| 6 | 17 | 0.00 | 1.10 | 0.00 | 3.76 | 1.03 | 0.00 | 3.92 | 0.00 | +0.10 |
| 6 | 18 | 0.00 | 1.42 | 0.00 | 4.59 | 1.10 | 0.00 | 5.03 | 0.00 | +0.12 |
| 6 | 19 | 0.00 | 1.85 | 0.00 | 6.24 | 1.42 | 0.00 | 6.57 | 0.00 | -0.10 |
| 6 | 20 | 0.08 | 1.78 | 0.00 | 9.44 | 1.85 | 0.00 | 9.45 | 0.00 | +0.16 |
| 6 | 21 | 0.14 | 0.13 | 0.00 | 3.92 | 0.43 | 0.00 | 3.47 | 0.00 | -0.01 |
| 6 | 22 | 0.63 | 0.06 | 0.00 | 5.03 | 0.13 | 0.14 | 4.56 | 0.00 | +0.10 |
| 6 | 23 | 1.26 | 0.08 | 0.00 | 6.62 | 0.06 | 0.63 | 6.46 | 0.00 | +0.44 |
| 6 | 24 | 8.41 | 0.00 | 0.00 | 9.45 | 0.08 | 1.26 | 2.12 | 0.19 | -0.28 |
| 6 | 25 | 0.80 | 0.00 | 0.00 | 3.47 | 0.03 | 0.02 | 2.72 | 0.00 | +0.06 |
| 6 | 26 | 2.98 | 0.00 | 0.00 | 4.46 | 0.00 | 0.81 | 1.74 | 0.00 | -0.54 |
| 6 | 27 | 13.25 | 0.00 | 0.00 | 6.44 | 0.00 | 2.99 | 0.03 | 2.04 | +1.81 |
| 6 | 28 | 21.20 | 0.00 | 0.17 | 2.12 | 0.00 | 13.25 | 0.00 | 8.01 | -2.00 |
| 6 | 29 | 0.43 | 0.00 | 0.00 | 2.72 | 0.01 | 0.02 | 0.00 | 0.00 | -2.31 |
| 6 | 30 | 2.01 | 0.00 | 0.00 | 1.74 | 0.00 | 0.35 | 0.00 | 0.00 | -0.09 |
| 6 | 31 | 8.56 | 0.00 | 2.04 | 0.03 | 0.00 | 2.00 | 0.00 | 0.00 | +8.58 |
| 6 | 32 | 0.00 | 0.00 | 9.30 | 0.00 | 0.00 | 8.56 | 0.00 | 0.00 | +0.74 |

APPENDIX FLOWSEN

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 19.01 | 0.00 | 0.00 | 16.98 | 0.00 | 7.35 | 6.00 | 0.00 | +0.67 |
| 1 | 2 | 24.08 | 0.00 | 1.55 | 4.67 | 0.00 | 19.01 | 1.35 | 1.06 | +2.24 |
| 1 | 3 | 15.75 | 0.00 | 25.68 | 0.00 | 0.00 | 24.08 | 0.00 | 14.82 | +2.54 |
| 1 | 4 | 0.00 | 0.30 | 25.34 | 0.00 | 0.00 | 15.75 | 0.00 | 12.79 | -3.50 |
| 1 | 5 | 24.76 | 0.00 | 0.00 | 6.00 | 0.00 | 10.93 | 0.09 | 6.83 | +1.09 |
| 1 | 6 | 20.43 | 0.00 | 1.06 | 1.35 | 0.00 | 24.76 | 6.62 | 0.00 | +2.00 |
| 1 | 7 | 7.19 | 0.00 | 14.82 | 0.00 | 0.00 | 20.43 | 0.06 | 4.12 | -2.48 |
| 1 | 8 | 0.87 | 0.06 | 12.78 | 0.00 | 0.00 | 7.19 | 0.00 | 4.64 | +1.76 |
| 1 | 9 | 6.42 | 2.78 | 6.82 | 0.09 | 0.00 | 7.09 | 0.00 | 1.87 | +1.41 |
| 1 | 10 | 9.73 | 0.00 | 0.00 | 6.62 | 2.78 | 6.42 | 1.09 | 1.22 | -0.66 |
| 1 | 11 | 4.24 | 0.00 | 4.12 | 0.06 | 0.00 | 9.73 | 1.80 | 0.00 | +0.38 |
| 1 | 12 | 0.44 | 0.04 | 4.64 | 0.00 | 0.00 | 4.24 | 0.00 | 0.96 | -0.17 |
| 1 | 13 | 0.00 | 2.27 | 1.87 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.40 |
| 1 | 14 | 0.08 | 1.29 | 1.22 | 1.09 | 2.27 | 0.00 | 0.00 | 0.00 | +1.18 |
| 1 | 15 | 0.94 | 0.00 | 0.00 | 1.80 | 1.29 | 0.08 | 0.00 | 0.00 | +0.35 |
| 1 | 16 | 0.00 | 0.00 | 0.96 | 0.00 | 0.00 | 0.94 | 0.00 | 0.00 | +0.02 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1 | 0.00 | 0.98 | 0.00 | 0.00 | 2.52 | 0.00 | 9.77 | 0.00 | +11.30 |
| 2 | 2 | 0.00 | 27.16 | 0.00 | 0.00 | 0.98 | 0.00 | 21.77 | 0.00 | -4.41 |
| 2 | 3 | 0.00 | 28.35 | 0.00 | 6.53 | 27.16 | 0.00 | 9.32 | 0.00 | +1.60 |
| 2 | 4 | 0.00 | 17.37 | 0.06 | 4.49 | 28.35 | 0.00 | 0.00 | 8.07 | -1.52 |
| 2 | 5 | 0.00 | 26.61 | 0.00 | 9.77 | 17.50 | 0.00 | 18.89 | 0.00 | +0.02 |
| 2 | 6 | 0.00 | 41.47 | 0.00 | 21.77 | 26.61 | 0.00 | 24.34 | 0.00 | -12.29 |
| 2 | 7 | 0.00 | 22.00 | 0.00 | 9.32 | 41.47 | 0.00 | 0.88 | 11.89 | -0.86 |
| 2 | 8 | 1.69 | 3.33 | 8.07 | 0.00 | 22.00 | 0.00 | 0.00 | 26.11 | +2.32 |
| 2 | 9 | 0.00 | 11.21 | 0.00 | 18.89 | 8.96 | 0.00 | 19.85 | 0.00 | -1.29 |
| 2 | 10 | 9.45 | 0.63 | 0.00 | 24.34 | 11.22 | 0.00 | 11.53 | 0.06 | +7.16 |
| 2 | 11 | 16.35 | 0.00 | 11.87 | 0.88 | 0.63 | 9.45 | 0.00 | 18.09 | +0.43 |
| 2 | 12 | 18.53 | 0.00 | 26.11 | 0.00 | 0.00 | 16.36 | 0.00 | 26.72 | +1.56 |
| 2 | 13 | 1.25 | 2.54 | 0.00 | 19.85 | 0.92 | 1.33 | 16.98 | 0.00 | -4.57 |
| 2 | 14 | 7.62 | 0.00 | 0.06 | 11.53 | 2.45 | 1.25 | 4.67 | 1.55 | +0.48 |
| 2 | 15 | 14.51 | 0.00 | 18.09 | 0.00 | 0.00 | 7.61 | 0.00 | 25.68 | -0.68 |
| 2 | 16 | 10.32 | 0.00 | 26.72 | 0.00 | 0.00 | 14.51 | 0.00 | 22.81 | -0.28 |

APPENDIX FLOWSEN

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 1 | 0.00 | 1.14 | 0.00 | 0.00 | 0.00 | 0.00 | 1.21 | 0.00 | +0.07 |
| 3 | 2 | 0.00 | 2.71 | 0.00 | 0.00 | 1.14 | 0.00 | 1.37 | 0.10 | -0.30 |
| 3 | 3 | 0.00 | 0.00 | 0.00 | 0.00 | 2.71 | 0.00 | 0.00 | 1.46 | +1.26 |
| 3 | 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | +0.00 |
| 3 | 5 | 0.00 | 8.38 | 0.00 | 1.21 | 0.00 | 0.00 | 6.53 | 0.00 | -3.07 |
| 3 | 6 | 0.00 | 12.31 | 0.10 | 1.37 | 8.38 | 0.00 | 4.48 | 0.06 | -0.78 |
| 3 | 7 | 0.00 | 7.11 | 1.46 | 0.00 | 12.31 | 0.00 | 0.00 | 5.64 | +1.02 |
| 3 | 8 | 0.00 | 1.94 | 0.00 | 0.00 | 7.11 | 0.00 | 0.00 | 5.59 | -0.43 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 1 | 0.00 | 7.31 | 5.64 | 0.00 | 17.36 | 0.00 | 0.00 | 15.34 | +0.35 |
| 4 | 2 | 0.82 | 1.76 | 5.58 | 0.00 | 7.31 | 0.00 | 0.00 | 11.24 | +0.71 |
| 4 | 3 | 4.11 | 0.00 | 15.34 | 0.00 | 3.33 | 1.69 | 0.00 | 20.35 | +0.74 |
| 4 | 4 | 1.25 | 0.00 | 11.24 | 0.00 | 0.00 | 4.11 | 0.00 | 10.45 | -2.07 |
| 4 | 5 | 8.37 | 0.00 | 20.35 | 0.00 | 0.00 | 18.57 | 0.00 | 10.45 | -0.30 |
| 4 | 6 | 1.34 | 0.00 | 10.45 | 0.00 | 0.00 | 8.37 | 0.00 | 1.30 | +2.13 |
| 4 | 7 | 1.09 | 0.00 | 10.45 | 0.00 | 0.00 | 10.32 | 0.00 | 0.46 | +0.77 |
| 4 | 8 | 0.00 | 0.00 | 1.30 | 0.00 | 0.00 | 1.09 | 0.00 | 0.00 | +0.21 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 1.61 | 0.00 | 0.00 | 2.51 | -0.89 |
| 5 | 2 | 0.00 | 0.00 | 2.80 | 0.00 | 1.76 | 0.82 | 0.00 | 3.37 | +0.37 |
| 5 | 3 | 0.00 | 0.00 | 3.37 | 0.00 | 0.00 | 1.25 | 0.00 | 0.13 | +1.99 |

APPENDIX FLOWSEN

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 1 | 0.00 | 0.89 | 0.00 | 0.00 | 0.49 | 0.00 | 2.87 | 0.00 | +2.47 |
| 6 | 2 | 0.00 | 1.79 | 0.00 | 0.00 | 0.89 | 0.00 | 1.74 | 0.00 | +0.83 |
| 6 | 3 | 0.00 | 4.12 | 0.00 | 0.00 | 1.79 | 0.00 | 0.26 | 0.11 | -2.18 |
| 6 | 4 | 0.00 | 2.52 | 0.00 | 0.00 | 4.12 | 0.00 | 2.64 | 0.18 | +4.07 |
| 6 | 5 | 0.00 | 1.52 | 0.00 | 2.87 | 1.18 | 0.00 | 3.30 | 0.00 | +0.09 |
| 6 | 6 | 0.00 | 3.15 | 0.00 | 1.74 | 1.52 | 0.00 | 3.30 | 0.00 | -0.06 |
| 6 | 7 | 0.00 | 7.97 | 0.11 | 0.26 | 3.15 | 0.00 | 3.60 | 0.00 | -1.37 |
| 6 | 8 | 0.00 | 17.50 | 0.17 | 2.64 | 7.97 | 0.00 | 6.00 | 0.00 | -6.00 |
| 6 | 9 | 0.00 | 1.59 | 0.00 | 3.31 | 1.32 | 0.00 | 3.53 | 0.00 | -0.06 |
| 6 | 10 | 0.00 | 2.68 | 0.00 | 3.30 | 1.59 | 0.00 | 4.20 | 0.00 | -0.19 |
| 6 | 11 | 0.00 | 4.82 | 0.00 | 3.60 | 2.68 | 0.00 | 5.92 | 0.00 | +0.17 |
| 6 | 12 | 0.00 | 8.96 | 0.00 | 6.00 | 4.82 | 0.00 | 10.62 | 0.00 | +0.49 |
| 6 | 13 | 0.00 | 1.10 | 0.00 | 3.53 | 1.18 | 0.00 | 3.43 | 0.00 | -0.02 |
| 6 | 14 | 0.00 | 1.07 | 0.00 | 4.19 | 1.10 | 0.00 | 4.14 | 0.00 | -0.01 |
| 6 | 15 | 0.20 | 1.09 | 0.00 | 5.92 | 1.07 | 0.00 | 5.72 | 0.00 | -0.01 |
| 6 | 16 | 1.33 | 0.91 | 0.00 | 10.62 | 1.09 | 0.20 | 9.54 | 0.00 | +0.22 |
| 6 | 17 | 0.00 | 0.51 | 0.00 | 3.43 | 0.74 | 0.00 | 3.25 | 0.00 | +0.05 |
| 6 | 18 | 0.16 | 0.12 | 0.00 | 4.14 | 0.51 | 0.00 | 3.68 | 0.00 | +0.08 |
| 6 | 19 | 2.23 | 0.00 | 0.00 | 5.72 | 0.12 | 0.16 | 3.87 | 0.00 | +0.35 |
| 6 | 20 | 7.35 | 0.00 | 0.00 | 9.54 | 0.00 | 2.23 | 4.56 | 0.00 | +0.15 |
| 6 | 21 | 0.08 | 0.01 | 0.00 | 3.25 | 0.33 | 0.00 | 2.83 | 0.00 | -0.02 |
| 6 | 22 | 0.56 | 0.00 | 0.00 | 3.68 | 0.01 | 0.08 | 3.11 | 0.00 | -0.08 |
| 6 | 23 | 1.53 | 0.23 | 0.00 | 3.87 | 0.00 | 0.55 | 3.15 | 0.00 | +0.02 |
| 6 | 24 | 11.51 | 0.00 | 0.00 | 4.56 | 0.23 | 1.55 | 0.00 | 6.78 | -1.14 |
| 6 | 25 | 0.51 | 0.00 | 0.00 | 2.83 | 0.04 | 0.00 | 2.33 | 0.00 | +0.05 |
| 6 | 26 | 1.48 | 0.00 | 0.00 | 3.11 | 0.00 | 0.52 | 1.65 | 0.00 | -0.50 |
| 6 | 27 | 7.70 | 0.07 | 0.00 | 3.18 | 0.00 | 1.48 | 0.10 | 1.31 | +1.76 |
| 6 | 28 | 7.09 | 0.00 | 6.77 | 0.00 | 0.07 | 7.70 | 0.00 | 8.13 | -1.89 |
| 6 | 29 | 0.31 | 0.00 | 0.00 | 2.33 | 0.01 | 0.01 | 0.00 | 0.00 | -2.03 |
| 6 | 30 | 1.73 | 0.00 | 0.00 | 1.65 | 0.00 | 0.25 | 0.00 | 0.00 | -0.17 |
| 6 | 31 | 8.31 | 0.00 | 1.31 | 0.10 | 0.00 | 1.73 | 0.00 | 0.00 | +7.80 |
| 6 | 32 | 0.00 | 0.00 | 9.63 | 0.00 | 0.00 | 8.31 | 0.00 | 0.00 | +1.32 |

APPENDIX FLOWSWNF

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 4.51 | 0.63 | 0.00 | 13.56 | 0.92 | 0.71 | 10.59 | 0.00 | +1.11 |
| 1 | 2 | 4.32 | 0.00 | 1.35 | 4.07 | 0.63 | 4.51 | 5.76 | 0.00 | +3.48 |
| 1 | 3 | 2.61 | 5.93 | 26.26 | 0.00 | 0.00 | 4.32 | 0.00 | 24.09 | -5.48 |
| 1 | 4 | 0.00 | 0.50 | 28.12 | 0.00 | 5.93 | 2.61 | 0.00 | 27.85 | +3.09 |
| 1 | 5 | 21.18 | 0.00 | 0.00 | 10.59 | 0.00 | 10.72 | 1.26 | 0.96 | +0.16 |
| 1 | 6 | 26.61 | 0.00 | 0.00 | 5.76 | 0.00 | 21.18 | 4.07 | 1.68 | +2.06 |
| 1 | 7 | 16.21 | 0.00 | 24.09 | 0.00 | 0.00 | 26.61 | 0.00 | 15.52 | -1.83 |
| 1 | 8 | 1.02 | 0.11 | 27.86 | 0.00 | 0.00 | 16.21 | 0.00 | 10.69 | +1.87 |
| 1 | 9 | 21.43 | 0.00 | 0.96 | 1.26 | 0.00 | 22.08 | 1.47 | 0.00 | +0.51 |
| 1 | 10 | 22.64 | 0.00 | 1.68 | 4.07 | 0.00 | 21.43 | 1.68 | 0.48 | +0.02 |
| 1 | 11 | 9.03 | 0.00 | 15.52 | 0.00 | 0.00 | 22.64 | 0.16 | 1.94 | +0.14 |
| 1 | 12 | 0.79 | 0.05 | 10.69 | 0.00 | 0.00 | 9.03 | 0.00 | 3.12 | -0.73 |
| 1 | 13 | 1.93 | 0.00 | 0.00 | 1.47 | 0.00 | 0.00 | 0.00 | 0.00 | +0.46 |
| 1 | 14 | 5.02 | 0.00 | 0.48 | 1.68 | 0.00 | 1.93 | 0.00 | 0.00 | +1.90 |
| 1 | 15 | 3.22 | 0.00 | 1.94 | 0.16 | 0.00 | 5.02 | 0.00 | 0.00 | -0.03 |
| 1 | 16 | 0.00 | 0.00 | 3.12 | 0.00 | 0.00 | 3.22 | 0.00 | 0.00 | -0.10 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1 | 0.00 | 0.16 | 0.00 | 0.00 | 1.59 | 0.00 | 0.00 | 3.88 | -2.45 |
| 2 | 2 | 0.00 | 5.13 | 0.00 | 0.00 | 0.16 | 0.00 | 7.39 | 0.05 | +2.37 |
| 2 | 3 | 0.00 | 14.41 | 0.28 | 1.06 | 5.13 | 0.00 | 10.75 | 0.00 | +0.70 |
| 2 | 4 | 0.00 | 14.05 | 0.00 | 3.98 | 14.41 | 0.00 | 3.14 | 0.83 | -1.32 |
| 2 | 5 | 0.00 | 16.09 | 3.88 | 0.00 | 12.96 | 0.00 | 0.13 | 1.91 | -1.03 |
| 2 | 6 | 0.00 | 21.27 | 0.05 | 7.39 | 16.09 | 0.00 | 12.62 | 0.00 | +0.10 |
| 2 | 7 | 0.00 | 24.28 | 0.00 | 10.75 | 21.27 | 0.00 | 9.56 | 0.47 | -4.67 |
| 2 | 8 | 0.00 | 6.58 | 0.83 | 3.14 | 24.28 | 0.00 | 0.00 | 13.85 | +1.54 |
| 2 | 9 | 0.00 | 20.78 | 1.91 | 0.13 | 12.11 | 0.00 | 5.69 | 0.00 | -1.21 |
| 2 | 10 | 0.00 | 17.94 | 0.00 | 12.62 | 20.78 | 0.00 | 11.64 | 0.00 | +1.86 |
| 2 | 11 | 2.80 | 3.50 | 0.46 | 9.56 | 17.94 | 0.00 | 0.28 | 11.80 | -3.38 |
| 2 | 12 | 10.92 | 0.00 | 13.85 | 0.00 | 3.50 | 2.80 | 0.00 | 22.92 | +2.55 |
| 2 | 13 | 0.00 | 15.29 | 0.00 | 5.69 | 7.39 | 0.00 | 13.56 | 0.00 | -0.03 |
| 2 | 14 | 0.00 | 7.28 | 0.00 | 11.64 | 15.14 | 0.00 | 4.07 | 1.35 | -1.06 |
| 2 | 15 | 8.65 | 0.00 | 11.80 | 0.28 | 7.29 | 0.00 | 0.00 | 26.26 | +1.21 |
| 2 | 16 | 11.69 | 0.00 | 22.92 | 0.00 | 0.00 | 8.65 | 0.00 | 24.71 | +1.25 |

APPENDIX FLOWSWNF

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 1 | 0.46 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.58 | -0.12 |
| 3 | 2 | 0.00 | 0.29 | 0.00 | 0.00 | 0.00 | 0.46 | 0.36 | 0.11 | -0.50 |
| 3 | 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.29 | 0.00 | 0.16 | 0.05 | +0.40 |
| 3 | 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | +0.00 |
| 3 | 5 | 0.60 | 1.36 | 0.58 | 0.00 | 0.00 | 0.00 | 1.06 | 0.28 | +0.59 |
| 3 | 6 | 0.00 | 4.84 | 0.11 | 0.36 | 1.36 | 0.60 | 3.98 | 0.00 | -0.34 |
| 3 | 7 | 0.00 | 3.37 | 0.05 | 0.16 | 4.84 | 0.00 | 0.21 | 1.23 | +0.35 |
| 3 | 8 | 0.00 | 1.13 | 0.00 | 0.00 | 3.37 | 0.00 | 0.00 | 2.20 | +0.05 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 1 | 0.00 | 7.58 | 1.23 | 0.21 | 14.05 | 0.00 | 0.00 | 7.37 | +0.12 |
| 4 | 2 | 0.43 | 1.92 | 2.19 | 0.00 | 7.58 | 0.00 | 0.00 | 8.47 | -0.20 |
| 4 | 3 | 1.18 | 0.55 | 7.37 | 0.00 | 6.58 | 0.00 | 0.00 | 14.28 | +0.29 |
| 4 | 4 | 1.08 | 0.00 | 8.47 | 0.00 | 0.55 | 1.18 | 0.00 | 10.63 | -1.70 |
| 4 | 5 | 8.04 | 0.00 | 14.28 | 0.00 | 0.00 | 10.95 | 0.00 | 10.93 | +0.44 |
| 4 | 6 | 1.52 | 0.00 | 10.63 | 0.00 | 0.00 | 8.04 | 0.00 | 1.97 | +2.15 |
| 4 | 7 | 1.71 | 0.00 | 10.93 | 0.00 | 0.00 | 11.69 | 0.00 | 0.88 | +0.08 |
| 4 | 8 | 0.00 | 0.00 | 1.97 | 0.00 | 0.00 | 1.70 | 0.00 | 0.00 | +0.27 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.98 | 0.00 | 0.00 | 1.44 | -0.46 |
| 5 | 2 | 0.00 | 0.00 | 1.66 | 0.00 | 1.92 | 0.43 | 0.00 | 3.18 | -0.02 |
| 5 | 3 | 0.00 | 0.00 | 3.18 | 0.00 | 0.00 | 1.08 | 0.00 | 0.15 | +1.95 |

APPENDIX FLOWSWNF

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 1 | 0.00 | 1.39 | 0.00 | 0.00 | 0.16 | 0.21 | 0.00 | 10.24 | -11.68 |
| 6 | 2 | 0.00 | 3.19 | 0.00 | 0.00 | 1.39 | 0.00 | 0.00 | 10.42 | -12.23 |
| 6 | 3 | 0.00 | 4.73 | 0.00 | 0.00 | 3.19 | 0.00 | 0.00 | 9.38 | -10.92 |
| 6 | 4 | 0.00 | 1.59 | 0.00 | 0.00 | 4.73 | 0.00 | 0.00 | 6.51 | -3.36 |
| 6 | 5 | 0.00 | 1.38 | 10.24 | 0.00 | 0.00 | 1.17 | 0.00 | 7.68 | +0.01 |
| 6 | 6 | 0.00 | 5.03 | 10.42 | 0.00 | 1.38 | 0.00 | 0.00 | 7.08 | -0.30 |
| 6 | 7 | 0.00 | 9.98 | 9.38 | 0.00 | 5.03 | 0.00 | 0.00 | 5.80 | -1.37 |
| 6 | 8 | 0.00 | 12.96 | 6.51 | 0.00 | 9.98 | 0.00 | 0.00 | 3.29 | +0.24 |
| 6 | 9 | 0.00 | 0.64 | 7.68 | 0.00 | 0.00 | 1.51 | 0.00 | 5.55 | -0.02 |
| 6 | 10 | 0.00 | 3.61 | 7.08 | 0.00 | 0.64 | 0.00 | 0.00 | 4.24 | -0.13 |
| 6 | 11 | 0.00 | 7.37 | 5.80 | 0.00 | 3.61 | 0.00 | 0.00 | 1.95 | +0.09 |
| 6 | 12 | 0.00 | 12.11 | 3.29 | 0.00 | 7.37 | 0.00 | 1.80 | 0.03 | +0.33 |
| 6 | 13 | 0.58 | 0.00 | 5.55 | 0.00 | 0.00 | 1.96 | 0.00 | 4.33 | -0.16 |
| 6 | 14 | 0.00 | 1.26 | 4.25 | 0.00 | 0.00 | 0.58 | 0.00 | 2.58 | -0.17 |
| 6 | 15 | 0.00 | 3.69 | 1.95 | 0.00 | 1.26 | 0.00 | 0.73 | 0.24 | +0.01 |
| 6 | 16 | 0.00 | 7.39 | 0.03 | 1.80 | 3.69 | 0.00 | 5.21 | 0.00 | -0.26 |
| 6 | 17 | 2.21 | 0.00 | 4.33 | 0.00 | 0.00 | 2.75 | 0.00 | 3.48 | +0.31 |
| 6 | 18 | 1.31 | 0.00 | 2.58 | 0.00 | 0.00 | 2.20 | 0.00 | 1.44 | +0.25 |
| 6 | 19 | 0.62 | 0.28 | 0.24 | 0.72 | 0.00 | 1.31 | 1.26 | 0.00 | -0.19 |
| 6 | 20 | 0.71 | 0.92 | 0.00 | 5.21 | 0.28 | 0.62 | 5.73 | 0.00 | -0.03 |
| 6 | 21 | 4.36 | 0.00 | 3.48 | 0.00 | 0.00 | 3.94 | 0.00 | 3.88 | +0.02 |
| 6 | 22 | 4.73 | 0.00 | 1.44 | 0.00 | 0.00 | 4.36 | 0.00 | 1.71 | +0.10 |
| 6 | 23 | 4.85 | 0.00 | 0.00 | 1.33 | 0.00 | 4.73 | 1.75 | 0.00 | +0.54 |
| 6 | 24 | 10.89 | 0.00 | 0.00 | 5.73 | 0.00 | 4.84 | 0.40 | 1.17 | -0.45 |
| 6 | 25 | 6.50 | 0.00 | 3.87 | 0.00 | 0.00 | 4.85 | 0.00 | 5.46 | +0.06 |
| 6 | 26 | 9.16 | 0.00 | 1.78 | 0.00 | 0.00 | 6.49 | 0.00 | 4.78 | -0.33 |
| 6 | 27 | 16.72 | 0.00 | 0.00 | 1.74 | 0.00 | 9.17 | 0.00 | 4.10 | +1.72 |
| 6 | 28 | 22.08 | 0.00 | 1.15 | 0.40 | 0.00 | 16.72 | 0.00 | 8.22 | -2.11 |
| 6 | 29 | 5.49 | 0.00 | 5.46 | 0.00 | 0.00 | 3.71 | 0.00 | 0.00 | +7.23 |
| 6 | 30 | 6.65 | 0.00 | 4.78 | 0.00 | 0.00 | 4.47 | 0.00 | 0.00 | +6.96 |
| 6 | 31 | 10.00 | 0.00 | 4.10 | 0.00 | 0.00 | 6.64 | 0.00 | 0.00 | +7.45 |
| 6 | 32 | 0.00 | 0.00 | 9.51 | 0.00 | 0.00 | 10.00 | 0.00 | 0.00 | -0.49 |

APPENDIX FLOWSENF

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 19.64 | 0.00 | 0.00 | 14.69 | 0.00 | 8.55 | 4.23 | 0.00 | +0.63 |
| 1 | 2 | 24.32 | 0.00 | 1.87 | 3.68 | 0.00 | 19.64 | 0.81 | 1.49 | +2.19 |
| 1 | 3 | 15.81 | 0.00 | 26.15 | 0.00 | 0.00 | 24.32 | 0.00 | 15.04 | +2.60 |
| 1 | 4 | 0.00 | 0.30 | 25.34 | 0.00 | 0.00 | 15.81 | 0.00 | 12.79 | -3.55 |
| 1 | 5 | 25.77 | 0.00 | 0.00 | 4.23 | 0.00 | 12.91 | 0.07 | 7.45 | +1.25 |
| 1 | 6 | 20.62 | 0.00 | 1.49 | 0.81 | 0.00 | 25.77 | 6.51 | 0.00 | +2.05 |
| 1 | 7 | 7.19 | 0.00 | 15.04 | 0.00 | 0.00 | 20.62 | 0.06 | 4.12 | -2.46 |
| 1 | 8 | 0.87 | 0.06 | 12.79 | 0.00 | 0.00 | 7.19 | 0.00 | 4.64 | +1.76 |
| 1 | 9 | 6.62 | 2.77 | 7.44 | 0.07 | 0.00 | 7.79 | 0.00 | 1.86 | +1.56 |
| 1 | 10 | 9.73 | 0.00 | 0.00 | 6.51 | 2.77 | 6.62 | 1.08 | 1.22 | -0.77 |
| 1 | 11 | 4.25 | 0.00 | 4.12 | 0.06 | 0.00 | 9.73 | 1.80 | 0.00 | +0.37 |
| 1 | 12 | 0.44 | 0.04 | 4.64 | 0.00 | 0.00 | 4.25 | 0.00 | 0.96 | -0.17 |
| 1 | 13 | 0.00 | 2.27 | 1.86 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.40 |
| 1 | 14 | 0.08 | 1.29 | 1.22 | 1.08 | 2.27 | 0.00 | 0.00 | 0.00 | +1.18 |
| 1 | 15 | 0.94 | 0.00 | 0.00 | 1.80 | 1.29 | 0.08 | 0.00 | 0.00 | +0.35 |
| 1 | 16 | 0.00 | 0.00 | 0.96 | 0.00 | 0.00 | 0.94 | 0.00 | 0.00 | +0.02 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1 | 0.00 | 1.01 | 0.00 | 0.00 | 2.87 | 0.00 | 8.62 | 0.00 | +10.48 |
| 2 | 2 | 0.00 | 27.16 | 0.00 | 0.00 | 1.01 | 0.00 | 21.61 | 0.00 | -4.55 |
| 2 | 3 | 0.00 | 28.35 | 0.00 | 6.53 | 27.16 | 0.00 | 9.32 | 0.00 | +1.60 |
| 2 | 4 | 0.00 | 17.37 | 0.06 | 4.49 | 28.35 | 0.00 | 0.00 | 8.07 | -1.52 |
| 2 | 5 | 0.00 | 27.84 | 0.00 | 8.62 | 19.96 | 0.00 | 16.87 | 0.00 | +0.37 |
| 2 | 6 | 0.00 | 41.65 | 0.00 | 21.61 | 27.84 | 0.00 | 23.42 | 0.00 | -12.00 |
| 2 | 7 | 0.00 | 22.01 | 0.00 | 9.32 | 41.65 | 0.00 | 0.80 | 11.98 | -0.86 |
| 2 | 8 | 1.69 | 3.33 | 8.07 | 0.00 | 22.01 | 0.00 | 0.00 | 26.12 | +2.32 |
| 2 | 9 | 0.00 | 11.98 | 0.00 | 16.87 | 10.34 | 0.00 | 17.49 | 0.00 | -1.02 |
| 2 | 10 | 9.20 | 0.71 | 0.00 | 23.42 | 11.99 | 0.00 | 10.36 | 0.15 | +7.27 |
| 2 | 11 | 16.31 | 0.00 | 11.97 | 0.80 | 0.71 | 9.20 | 0.00 | 18.62 | +0.38 |
| 2 | 12 | 18.53 | 0.00 | 26.12 | 0.00 | 0.00 | 16.32 | 0.00 | 26.81 | +1.52 |
| 2 | 13 | 1.34 | 2.59 | 0.00 | 17.49 | 1.00 | 1.53 | 14.69 | 0.00 | -4.57 |
| 2 | 14 | 7.72 | 0.00 | 0.15 | 10.36 | 2.50 | 1.34 | 3.68 | 1.87 | +0.47 |
| 2 | 15 | 14.56 | 0.00 | 18.62 | 0.00 | 0.00 | 7.71 | 0.00 | 26.15 | -0.68 |
| 2 | 16 | 10.32 | 0.00 | 26.81 | 0.00 | 0.00 | 14.56 | 0.00 | 22.83 | -0.27 |

APPENDIX FLOWSENF

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 1 | 0.00 | 1.14 | 0.00 | 0.00 | 0.00 | 0.00 | 1.22 | 0.00 | +0.07 |
| 3 | 2 | 0.00 | 2.71 | 0.00 | 0.00 | 1.14 | 0.00 | 1.37 | 0.10 | -0.30 |
| 3 | 3 | 0.00 | 0.00 | 0.00 | 0.00 | 2.71 | 0.00 | 0.00 | 1.46 | +1.26 |
| 3 | 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | +0.00 |
| 3 | 5 | 0.00 | 8.38 | 0.00 | 1.22 | 0.00 | 0.00 | 6.53 | 0.00 | -3.07 |
| 3 | 6 | 0.00 | 12.31 | 0.10 | 1.37 | 8.38 | 0.00 | 4.48 | 0.06 | -0.78 |
| 3 | 7 | 0.00 | 7.11 | 1.46 | 0.00 | 12.31 | 0.00 | 0.00 | 5.64 | +1.02 |
| 3 | 8 | 0.00 | 1.94 | 0.00 | 0.00 | 7.11 | 0.00 | 0.00 | 5.59 | -0.43 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 1 | 0.00 | 7.31 | 5.64 | 0.00 | 17.36 | 0.00 | 0.00 | 15.34 | +0.35 |
| 4 | 2 | 0.81 | 1.76 | 5.58 | 0.00 | 7.31 | 0.00 | 0.00 | 11.24 | +0.71 |
| 4 | 3 | 4.11 | 0.00 | 15.34 | 0.00 | 3.33 | 1.69 | 0.00 | 20.35 | +0.74 |
| 4 | 4 | 1.25 | 0.00 | 11.24 | 0.00 | 0.00 | 4.11 | 0.00 | 10.45 | -2.07 |
| 4 | 5 | 8.37 | 0.00 | 20.35 | 0.00 | 0.00 | 18.58 | 0.00 | 10.45 | -0.30 |
| 4 | 6 | 1.34 | 0.00 | 10.45 | 0.00 | 0.00 | 8.37 | 0.00 | 1.30 | +2.13 |
| 4 | 7 | 1.09 | 0.00 | 10.45 | 0.00 | 0.00 | 10.32 | 0.00 | 0.46 | +0.77 |
| 4 | 8 | 0.00 | 0.00 | 1.30 | 0.00 | 0.00 | 1.09 | 0.00 | 0.00 | +0.21 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 1.61 | 0.00 | 0.00 | 2.51 | -0.89 |
| 5 | 2 | 0.00 | 0.00 | 2.80 | 0.00 | 1.76 | 0.81 | 0.00 | 3.37 | +0.37 |
| 5 | 3 | 0.00 | 0.00 | 3.37 | 0.00 | 0.00 | 1.25 | 0.00 | 0.13 | +1.99 |

APPENDIX FLOWSENF

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 1 | 0.00 | 1.65 | 0.00 | 0.00 | 0.28 | 0.09 | 0.00 | 8.05 | -9.52 |
| 6 | 2 | 0.00 | 3.50 | 0.00 | 0.00 | 1.65 | 0.00 | 0.00 | 8.02 | -9.87 |
| 6 | 3 | 0.00 | 5.71 | 0.00 | 0.00 | 3.50 | 0.00 | 0.00 | 6.74 | -8.95 |
| 6 | 4 | 0.00 | 2.87 | 0.00 | 0.00 | 5.71 | 0.00 | 1.26 | 2.24 | +1.87 |
| 6 | 5 | 0.00 | 1.55 | 8.05 | 0.00 | 0.00 | 0.78 | 0.00 | 5.73 | -0.00 |
| 6 | 6 | 0.00 | 5.17 | 8.02 | 0.00 | 1.55 | 0.00 | 0.00 | 4.71 | -0.31 |
| 6 | 7 | 0.00 | 11.06 | 6.74 | 0.00 | 5.17 | 0.00 | 0.00 | 2.56 | -1.72 |
| 6 | 8 | 0.00 | 19.96 | 2.24 | 1.26 | 11.06 | 0.00 | 2.24 | 0.04 | -5.72 |
| 6 | 9 | 0.00 | 0.57 | 5.74 | 0.00 | 0.00 | 1.17 | 0.00 | 4.03 | -0.03 |
| 6 | 10 | 0.00 | 3.01 | 4.71 | 0.00 | 0.57 | 0.00 | 0.00 | 2.46 | -0.19 |
| 6 | 11 | 0.00 | 6.04 | 2.56 | 0.00 | 3.01 | 0.00 | 0.84 | 0.23 | +0.15 |
| 6 | 12 | 0.00 | 10.34 | 0.04 | 2.24 | 6.04 | 0.00 | 6.90 | 0.00 | +0.39 |
| 6 | 13 | 0.81 | 0.00 | 4.03 | 0.00 | 0.00 | 1.67 | 0.00 | 3.28 | -0.11 |
| 6 | 14 | 0.37 | 0.36 | 2.47 | 0.00 | 0.00 | 0.81 | 0.00 | 1.76 | -0.10 |
| 6 | 15 | 0.56 | 0.99 | 0.23 | 0.84 | 0.36 | 0.37 | 1.09 | 0.05 | -0.02 |
| 6 | 16 | 1.53 | 1.00 | 0.00 | 6.90 | 0.99 | 0.56 | 6.14 | 0.00 | +0.20 |
| 6 | 17 | 2.21 | 0.00 | 3.28 | 0.00 | 0.00 | 2.40 | 0.00 | 2.87 | +0.23 |
| 6 | 18 | 2.27 | 0.00 | 1.76 | 0.00 | 0.00 | 2.21 | 0.00 | 1.63 | +0.19 |
| 6 | 19 | 4.01 | 0.00 | 0.05 | 1.08 | 0.00 | 2.27 | 0.01 | 0.45 | +0.27 |
| 6 | 20 | 8.55 | 0.00 | 0.00 | 6.14 | 0.00 | 4.01 | 1.58 | 0.00 | -0.02 |
| 6 | 21 | 3.72 | 0.00 | 2.87 | 0.00 | 0.00 | 3.33 | 0.00 | 3.25 | +0.00 |
| 6 | 22 | 4.02 | 0.00 | 1.63 | 0.00 | 0.00 | 3.72 | 0.00 | 2.01 | -0.08 |
| 6 | 23 | 4.31 | 0.00 | 0.44 | 0.02 | 0.00 | 4.01 | 0.00 | 0.60 | +0.11 |
| 6 | 24 | 13.51 | 0.00 | 0.00 | 1.57 | 0.00 | 4.32 | 0.00 | 8.90 | -1.28 |
| 6 | 25 | 5.33 | 0.00 | 3.25 | 0.00 | 0.00 | 4.07 | 0.00 | 4.47 | +0.05 |
| 6 | 26 | 6.73 | 0.00 | 1.99 | 0.00 | 0.00 | 5.33 | 0.00 | 3.71 | -0.33 |
| 6 | 27 | 10.54 | 0.00 | 0.57 | 0.01 | 0.00 | 6.73 | 0.00 | 2.66 | +1.71 |
| 6 | 28 | 7.79 | 0.00 | 8.89 | 0.00 | 0.00 | 10.54 | 0.00 | 8.12 | -1.97 |
| 6 | 29 | 4.61 | 0.00 | 4.47 | 0.00 | 0.00 | 3.13 | 0.00 | 0.00 | +5.94 |
| 6 | 30 | 5.76 | 0.00 | 3.71 | 0.00 | 0.00 | 3.76 | 0.00 | 0.00 | +5.72 |
| 6 | 31 | 9.51 | 0.00 | 2.66 | 0.00 | 0.00 | 5.76 | 0.00 | 0.00 | +6.41 |
| 6 | 32 | 0.00 | 0.00 | 9.61 | 0.00 | 0.00 | 9.51 | 0.00 | 0.00 | +0.11 |

This the first
data set I sent
to you
JW



APPENDIX FLOWSW

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 2.56 | 0.40 | 0.00 | 10.10 | 0.97 | 0.08 | 7.76 | 0.00 | +0.71 |
| 1 | 2 | 2.80 | 0.00 | 0.61 | 3.27 | 0.40 | 2.56 | 4.18 | 0.00 | +2.15 |
| 1 | 3 | 1.70 | 3.47 | 15.77 | 0.00 | 0.00 | 2.80 | 0.00 | 14.49 | -3.29 |
| 1 | 4 | 0.00 | 0.30 | 17.23 | 0.00 | 3.47 | 1.70 | 0.00 | 16.87 | +1.83 |
| 1 | 5 | 12.32 | 0.00 | 0.00 | 7.76 | 0.00 | 5.12 | 0.88 | 0.33 | -0.00 |
| 1 | 6 | 16.11 | 0.00 | 0.00 | 4.18 | 0.00 | 12.32 | 2.58 | 0.97 | +1.23 |
| 1 | 7 | 9.82 | 0.00 | 14.49 | 0.00 | 0.00 | 16.11 | 0.00 | 9.35 | -1.15 |
| 1 | 8 | 0.62 | 0.07 | 16.87 | 0.00 | 0.00 | 9.82 | 0.00 | 6.47 | +1.15 |
| 1 | 9 | 12.72 | 0.00 | 0.32 | 0.88 | 0.00 | 12.80 | 0.85 | 0.00 | +0.22 |
| 1 | 10 | 13.70 | 0.00 | 0.97 | 2.58 | 0.00 | 12.72 | 1.02 | 0.30 | +0.08 |
| 1 | 11 | 5.47 | 0.00 | 9.35 | 0.00 | 0.00 | 13.70 | 0.11 | 1.14 | +0.09 |
| 1 | 12 | 0.48 | 0.03 | 6.47 | 0.00 | 0.00 | 5.47 | 0.00 | 1.88 | -0.44 |
| 1 | 13 | 1.12 | 0.00 | 0.00 | 0.85 | 0.00 | 0.00 | 0.00 | 0.00 | +0.27 |
| 1 | 14 | 2.99 | 0.00 | 0.30 | 1.02 | 0.00 | 1.12 | 0.00 | 0.00 | +1.15 |
| 1 | 15 | 1.94 | 0.00 | 1.14 | 0.11 | 0.00 | 2.99 | 0.00 | 0.00 | -0.01 |
| 1 | 16 | 0.00 | 0.00 | 1.88 | 0.00 | 0.00 | 1.94 | 0.00 | 0.00 | -0.06 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1 | 0.00 | 0.09 | 0.00 | 0.00 | 0.73 | 0.00 | 0.00 | 1.25 | -0.62 |
| 2 | 2 | 0.00 | 3.51 | 0.00 | 0.00 | 0.09 | 0.00 | 4.87 | 0.00 | +1.45 |
| 2 | 3 | 0.00 | 9.08 | 0.13 | 0.70 | 3.51 | 0.00 | 6.59 | 0.00 | +0.45 |
| 2 | 4 | 0.00 | 8.69 | 0.00 | 2.46 | 9.08 | 0.00 | 1.82 | 0.57 | -0.81 |
| 2 | 5 | 0.00 | 9.14 | 1.25 | 0.00 | 6.20 | 0.00 | 0.78 | 0.00 | -0.90 |
| 2 | 6 | 0.00 | 13.27 | 0.00 | 4.87 | 9.14 | 0.00 | 8.65 | 0.00 | -0.36 |
| 2 | 7 | 0.00 | 14.88 | 0.00 | 6.59 | 13.27 | 0.00 | 5.74 | 0.35 | -2.80 |
| 2 | 8 | 0.00 | 3.96 | 0.57 | 1.82 | 14.88 | 0.00 | 0.00 | 8.71 | +0.96 |
| 2 | 9 | 0.00 | 12.04 | 0.00 | 0.78 | 6.36 | 0.00 | 5.50 | 0.00 | -0.96 |
| 2 | 10 | 0.00 | 10.34 | 0.00 | 8.65 | 12.04 | 0.00 | 8.10 | 0.00 | +1.15 |
| 2 | 11 | 1.86 | 1.99 | 0.35 | 5.74 | 10.34 | 0.00 | 0.24 | 7.04 | -1.98 |
| 2 | 12 | 6.83 | 0.00 | 8.71 | 0.00 | 1.99 | 1.86 | 0.00 | 14.08 | +1.58 |
| 2 | 13 | 0.00 | 9.21 | 0.00 | 5.50 | 4.51 | 0.00 | 10.10 | 0.00 | -0.10 |
| 2 | 14 | 0.00 | 4.31 | 0.00 | 8.10 | 9.12 | 0.00 | 3.27 | 0.61 | -0.62 |
| 2 | 15 | 5.37 | 0.00 | 7.04 | 0.24 | 4.32 | 0.00 | 0.00 | 15.77 | +0.71 |
| 2 | 16 | 7.16 | 0.00 | 14.08 | 0.00 | 0.00 | 5.37 | 0.00 | 15.14 | +0.73 |

APPENDIX FLOWSW

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 1 | 0.26 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.33 | -0.07 |
| 3 | 2 | 0.00 | 0.22 | 0.00 | 0.00 | 0.00 | 0.26 | 0.22 | 0.05 | -0.31 |
| 3 | 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.22 | 0.00 | 0.08 | 0.04 | +0.26 |
| 3 | 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | +0.00 |
| 3 | 5 | 0.33 | 0.92 | 0.33 | 0.00 | 0.00 | 0.00 | 0.70 | 0.13 | +0.30 |
| 3 | 6 | 0.00 | 3.10 | 0.05 | 0.22 | 0.92 | 0.33 | 2.45 | 0.00 | -0.22 |
| 3 | 7 | 0.00 | 2.13 | 0.04 | 0.08 | 3.10 | 0.00 | 0.12 | 0.82 | +0.22 |
| 3 | 8 | 0.00 | 0.71 | 0.00 | 0.00 | 2.13 | 0.00 | 0.00 | 1.41 | +0.02 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 1 | 0.00 | 4.65 | 0.82 | 0.12 | 8.69 | 0.00 | 0.00 | 4.66 | +0.07 |
| 4 | 2 | 0.27 | 1.18 | 1.40 | 0.00 | 4.65 | 0.00 | 0.00 | 5.25 | -0.11 |
| 4 | 3 | 0.76 | 0.32 | 4.66 | 0.00 | 3.96 | 0.00 | 0.00 | 8.88 | +0.19 |
| 4 | 4 | 0.67 | 0.00 | 5.25 | 0.00 | 0.32 | 0.76 | 0.00 | 6.53 | -1.05 |
| 4 | 5 | 4.95 | 0.00 | 8.88 | 0.00 | 0.00 | 6.85 | 0.00 | 6.71 | +0.26 |
| 4 | 6 | 0.93 | 0.00 | 6.53 | 0.00 | 0.00 | 4.95 | 0.00 | 1.20 | +1.32 |
| 4 | 7 | 1.04 | 0.00 | 6.71 | 0.00 | 0.00 | 7.16 | 0.00 | 0.53 | +0.06 |
| 4 | 8 | 0.00 | 0.00 | 1.20 | 0.00 | 0.00 | 1.04 | 0.00 | 0.00 | +0.16 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.61 | 0.00 | 0.00 | 0.90 | -0.29 |
| 5 | 2 | 0.00 | 0.00 | 1.04 | 0.00 | 1.18 | 0.27 | 0.00 | 1.96 | -0.01 |
| 5 | 3 | 0.00 | 0.00 | 1.96 | 0.00 | 0.00 | 0.67 | 0.00 | 0.09 | +1.20 |

APPENDIX FLOWSW

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 1 | 0.00 | 0.52 | 0.00 | 0.00 | 0.31 | 0.00 | 1.54 | 0.00 | +1.34 |
| 6 | 2 | 0.00 | 0.91 | 0.00 | 0.00 | 0.52 | 0.00 | 0.76 | 0.00 | +0.37 |
| 6 | 3 | 0.00 | 1.78 | 0.00 | 0.00 | 0.91 | 0.00 | 0.01 | 0.36 | -1.21 |
| 6 | 4 | 0.00 | 0.73 | 0.00 | 0.00 | 1.78 | 0.00 | 0.00 | 1.08 | -0.04 |
| 6 | 5 | 0.00 | 1.03 | 0.00 | 1.54 | 0.78 | 0.00 | 1.85 | 0.00 | +0.06 |
| 6 | 6 | 0.00 | 1.89 | 0.00 | 0.76 | 1.03 | 0.00 | 1.59 | 0.00 | -0.03 |
| 6 | 7 | 0.00 | 3.95 | 0.36 | 0.01 | 1.89 | 0.00 | 1.21 | 0.00 | -0.50 |
| 6 | 8 | 0.00 | 6.20 | 1.08 | 0.00 | 3.95 | 0.00 | 1.04 | 0.00 | -0.13 |
| 6 | 9 | 0.00 | 1.26 | 0.00 | 1.87 | 0.94 | 0.00 | 2.15 | 0.00 | -0.03 |
| 6 | 10 | 0.00 | 2.10 | 0.00 | 1.59 | 1.26 | 0.00 | 2.36 | 0.00 | -0.07 |
| 6 | 11 | 0.00 | 3.68 | 0.00 | 1.21 | 2.10 | 0.00 | 2.84 | 0.00 | +0.04 |
| 6 | 12 | 0.00 | 6.36 | 0.00 | 1.04 | 3.68 | 0.00 | 4.02 | 0.00 | +0.29 |
| 6 | 13 | 0.00 | 1.10 | 0.00 | 2.15 | 0.91 | 0.00 | 2.31 | 0.00 | -0.04 |
| 6 | 14 | 0.00 | 1.61 | 0.00 | 2.35 | 1.10 | 0.00 | 2.82 | 0.00 | -0.04 |
| 6 | 15 | 0.00 | 2.59 | 0.00 | 2.84 | 1.61 | 0.00 | 3.83 | 0.00 | +0.01 |
| 6 | 16 | 0.00 | 4.51 | 0.00 | 4.02 | 2.59 | 0.00 | 5.80 | 0.00 | -0.14 |
| 6 | 17 | 0.00 | 0.66 | 0.00 | 2.31 | 0.63 | 0.00 | 2.40 | 0.00 | +0.06 |
| 6 | 18 | 0.00 | 0.85 | 0.00 | 2.82 | 0.67 | 0.00 | 3.07 | 0.00 | +0.07 |
| 6 | 19 | 0.00 | 1.07 | 0.00 | 3.82 | 0.85 | 0.00 | 4.00 | 0.00 | -0.05 |
| 6 | 20 | 0.08 | 0.97 | 0.00 | 5.80 | 1.07 | 0.00 | 5.73 | 0.00 | +0.10 |
| 6 | 21 | 0.08 | 0.08 | 0.00 | 2.40 | 0.27 | 0.00 | 2.12 | 0.00 | -0.01 |
| 6 | 22 | 0.38 | 0.03 | 0.00 | 3.07 | 0.08 | 0.08 | 2.78 | 0.00 | +0.06 |
| 6 | 23 | 0.76 | 0.04 | 0.00 | 4.03 | 0.03 | 0.38 | 3.92 | 0.00 | +0.26 |
| 6 | 24 | 5.22 | 0.00 | 0.00 | 5.73 | 0.04 | 0.76 | 1.21 | 0.17 | -0.19 |
| 6 | 25 | 0.49 | 0.00 | 0.00 | 2.12 | 0.02 | 0.01 | 1.67 | 0.00 | +0.04 |
| 6 | 26 | 1.81 | 0.00 | 0.00 | 2.72 | 0.00 | 0.49 | 1.07 | 0.00 | -0.33 |
| 6 | 27 | 8.05 | 0.00 | 0.00 | 3.90 | 0.00 | 1.81 | 0.02 | 1.24 | +1.11 |
| 6 | 28 | 12.80 | 0.00 | 0.16 | 1.21 | 0.00 | 8.05 | 0.00 | 4.92 | -1.23 |
| 6 | 29 | 0.26 | 0.00 | 0.00 | 1.67 | 0.00 | 0.01 | 0.00 | 0.00 | -1.41 |
| 6 | 30 | 1.23 | 0.00 | 0.00 | 1.07 | 0.00 | 0.22 | 0.00 | 0.00 | -0.06 |
| 6 | 31 | 5.26 | 0.00 | 1.24 | 0.02 | 0.00 | 1.22 | 0.00 | 0.00 | +5.26 |
| 6 | 32 | 0.00 | 0.00 | 5.72 | 0.00 | 0.00 | 5.26 | 0.00 | 0.00 | +0.46 |

First Data Set

SE



APPENDIX FLOWSS

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 22.37 | 0.00 | 0.00 | 29.83 | 0.00 | 6.57 | 15.57 | 0.00 | +1.55 |
| 1 | 2 | 28.42 | 0.00 | 2.35 | 8.79 | 0.00 | 22.37 | 5.74 | 0.42 | +4.92 |
| 1 | 3 | 14.26 | 0.00 | 45.69 | 0.00 | 0.00 | 28.41 | 0.00 | 32.86 | -1.32 |
| 1 | 4 | 0.00 | 0.68 | 47.09 | 0.00 | 0.00 | 14.26 | 0.00 | 33.60 | -1.44 |
| 1 | 5 | 40.58 | 0.00 | 0.00 | 15.57 | 0.00 | 17.53 | 0.65 | 7.00 | +1.13 |
| 1 | 6 | 40.64 | 0.00 | 0.42 | 5.74 | 0.00 | 40.58 | 9.18 | 0.35 | +3.57 |
| 1 | 7 | 19.29 | 0.00 | 32.85 | 0.00 | 0.00 | 40.64 | 0.00 | 15.47 | -3.97 |
| 1 | 8 | 1.65 | 0.14 | 33.60 | 0.00 | 0.00 | 19.29 | 0.00 | 12.61 | +3.21 |
| 1 | 9 | 19.16 | 0.06 | 6.98 | 0.65 | 0.00 | 22.78 | 0.00 | 0.92 | +1.73 |
| 1 | 10 | 26.60 | 0.00 | 0.35 | 9.18 | 0.06 | 19.16 | 2.20 | 1.48 | -0.59 |
| 1 | 11 | 11.00 | 0.00 | 15.47 | 0.00 | 0.00 | 26.60 | 1.31 | 0.68 | +0.50 |
| 1 | 12 | 1.03 | 0.08 | 12.61 | 0.00 | 0.00 | 11.00 | 0.00 | 3.27 | -0.70 |
| 1 | 13 | 0.00 | 1.01 | 0.92 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.09 |
| 1 | 14 | 2.40 | 0.07 | 1.48 | 2.20 | 1.01 | 0.00 | 0.00 | 0.00 | +2.62 |
| 1 | 15 | 3.31 | 0.00 | 0.68 | 1.31 | 0.07 | 2.40 | 0.00 | 0.00 | +0.35 |
| 1 | 16 | 0.00 | 0.00 | 3.27 | 0.00 | 0.00 | 3.31 | 0.00 | 0.00 | -0.04 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1 | 0.00 | 1.14 | 0.00 | 0.00 | 3.50 | 0.00 | 8.66 | 0.00 | +11.02 |
| 2 | 2 | 0.00 | 32.48 | 0.00 | 0.00 | 1.14 | 0.00 | 28.51 | 0.00 | -2.84 |
| 2 | 3 | 0.00 | 40.42 | 0.00 | 7.48 | 32.48 | 0.00 | 17.62 | 0.00 | +2.20 |
| 2 | 4 | 0.00 | 28.52 | 0.00 | 7.56 | 40.42 | 0.00 | 0.81 | 7.71 | -2.56 |
| 2 | 5 | 0.00 | 38.68 | 0.00 | 8.66 | 25.67 | 0.00 | 20.60 | 0.00 | -1.07 |
| 2 | 6 | 0.00 | 59.12 | 0.00 | 28.51 | 38.68 | 0.00 | 35.73 | 0.00 | -13.22 |
| 2 | 7 | 0.00 | 40.79 | 0.00 | 17.62 | 59.12 | 0.00 | 4.39 | 9.35 | -4.26 |
| 2 | 8 | 1.23 | 7.70 | 7.71 | 0.81 | 40.79 | 0.00 | 0.00 | 37.64 | +3.57 |
| 2 | 9 | 0.00 | 26.15 | 0.00 | 20.60 | 16.98 | 0.00 | 27.28 | 0.00 | -2.49 |
| 2 | 10 | 2.07 | 5.33 | 0.00 | 35.73 | 26.16 | 0.00 | 21.67 | 0.00 | +8.84 |
| 2 | 11 | 17.82 | 0.95 | 9.33 | 4.39 | 5.33 | 2.07 | 0.00 | 27.00 | -1.93 |
| 2 | 12 | 27.50 | 0.00 | 37.64 | 0.00 | 0.95 | 17.83 | 0.00 | 44.74 | +3.53 |
| 2 | 13 | 0.17 | 12.60 | 0.00 | 27.28 | 5.16 | 0.15 | 29.83 | 0.00 | -4.88 |
| 2 | 14 | 3.55 | 0.80 | 0.00 | 21.67 | 12.39 | 0.17 | 8.79 | 2.35 | -0.25 |
| 2 | 15 | 21.56 | 0.00 | 27.00 | 0.00 | 0.80 | 3.53 | 0.00 | 45.69 | +0.14 |
| 2 | 16 | 19.35 | 0.00 | 44.74 | 0.00 | 0.00 | 21.56 | 0.00 | 41.94 | +0.59 |

APPENDIX FLOWSS

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 1 | 0.00 | 0.88 | 0.00 | 0.00 | 0.00 | 0.00 | 0.87 | 0.00 | -0.01 |
| 3 | 2 | 0.00 | 3.08 | 0.00 | 0.00 | 0.88 | 0.00 | 1.55 | 0.02 | -0.68 |
| 3 | 3 | 0.00 | 0.00 | 0.00 | 0.00 | 3.08 | 0.00 | 0.00 | 1.47 | +1.62 |
| 3 | 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | +0.00 |
| 3 | 5 | 0.00 | 9.44 | 0.00 | 0.87 | 0.00 | 0.00 | 7.48 | 0.00 | -2.82 |
| 3 | 6 | 0.00 | 16.53 | 0.02 | 1.55 | 9.44 | 0.00 | 7.55 | 0.00 | -1.07 |
| 3 | 7 | 0.00 | 9.96 | 1.47 | 0.00 | 16.53 | 0.00 | 0.00 | 6.71 | +1.33 |
| 3 | 8 | 0.00 | 2.87 | 0.00 | 0.00 | 9.96 | 0.00 | 0.00 | 7.51 | -0.42 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 1 | 0.00 | 13.20 | 6.71 | 0.00 | 28.52 | 0.00 | 0.00 | 21.57 | +0.45 |
| 4 | 2 | 1.17 | 3.25 | 7.50 | 0.00 | 13.20 | 0.00 | 0.00 | 18.01 | +0.61 |
| 4 | 3 | 4.91 | 0.10 | 21.57 | 0.00 | 7.70 | 1.23 | 0.00 | 31.85 | +0.99 |
| 4 | 4 | 2.11 | 0.00 | 18.01 | 0.00 | 0.10 | 4.91 | 0.00 | 18.74 | -3.42 |
| 4 | 5 | 14.66 | 0.00 | 31.85 | 0.00 | 0.00 | 27.57 | 0.00 | 18.94 | -0.00 |
| 4 | 6 | 2.52 | 0.00 | 18.74 | 0.00 | 0.00 | 14.66 | 0.00 | 2.80 | +3.80 |
| 4 | 7 | 2.39 | 0.00 | 18.94 | 0.00 | 0.00 | 19.35 | 0.00 | 1.12 | +0.87 |
| 4 | 8 | 0.00 | 0.00 | 2.80 | 0.00 | 0.00 | 2.38 | 0.00 | 0.00 | +0.42 |

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 2.42 | 0.00 | 0.00 | 3.70 | -1.28 |
| 5 | 2 | 0.00 | 0.00 | 4.17 | 0.00 | 3.25 | 1.17 | 0.00 | 5.87 | +0.38 |
| 5 | 3 | 0.00 | 0.00 | 5.87 | 0.00 | 0.00 | 2.11 | 0.00 | 0.24 | +3.51 |

APPENDIX FLOWSS

| R# | C# | F1+ | F1- | F2+ | F2- | F3+ | F3- | F4+ | F4- | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 1 | 0.00 | 1.55 | 0.00 | 0.00 | 0.89 | 0.00 | 4.84 | 0.00 | +4.18 |
| 6 | 2 | 0.00 | 2.96 | 0.00 | 0.00 | 1.55 | 0.00 | 2.73 | 0.00 | +1.31 |
| 6 | 3 | 0.00 | 6.43 | 0.00 | 0.00 | 2.96 | 0.00 | 0.19 | 0.45 | -3.73 |
| 6 | 4 | 0.00 | 3.50 | 0.00 | 0.00 | 6.43 | 0.00 | 1.87 | 0.61 | +4.19 |
| 6 | 5 | 0.00 | 2.82 | 0.00 | 4.84 | 2.17 | 0.00 | 5.66 | 0.00 | +0.17 |
| 6 | 6 | 0.00 | 5.54 | 0.00 | 2.73 | 2.82 | 0.00 | 5.35 | 0.00 | -0.10 |
| 6 | 7 | 0.00 | 13.04 | 0.45 | 0.19 | 5.54 | 0.00 | 5.21 | 0.00 | -2.03 |
| 6 | 8 | 0.00 | 25.67 | 0.61 | 1.87 | 13.04 | 0.00 | 7.49 | 0.00 | -6.41 |
| 6 | 9 | 0.00 | 3.17 | 0.00 | 5.69 | 2.51 | 0.00 | 6.26 | 0.00 | -0.09 |
| 6 | 10 | 0.00 | 5.31 | 0.00 | 5.35 | 3.17 | 0.00 | 7.20 | 0.00 | -0.29 |
| 6 | 11 | 0.00 | 9.44 | 0.00 | 5.21 | 5.31 | 0.00 | 9.57 | 0.00 | +0.24 |
| 6 | 12 | 0.00 | 16.98 | 0.00 | 7.49 | 9.44 | 0.00 | 15.88 | 0.00 | +0.86 |
| 6 | 13 | 0.00 | 2.46 | 0.00 | 6.26 | 2.32 | 0.00 | 6.34 | 0.00 | -0.07 |
| 6 | 14 | 0.00 | 3.04 | 0.00 | 7.19 | 2.46 | 0.00 | 7.70 | 0.00 | -0.07 |
| 6 | 15 | 0.00 | 4.04 | 0.00 | 9.57 | 3.04 | 0.00 | 10.56 | 0.00 | -0.00 |
| 6 | 16 | 0.15 | 5.15 | 0.00 | 15.88 | 4.04 | 0.00 | 16.90 | 0.00 | +0.06 |
| 6 | 17 | 0.00 | 1.33 | 0.00 | 6.34 | 1.52 | 0.00 | 6.27 | 0.00 | +0.12 |
| 6 | 18 | 0.02 | 1.00 | 0.00 | 7.70 | 1.33 | 0.00 | 7.52 | 0.00 | +0.17 |
| 6 | 19 | 1.08 | 0.05 | 0.00 | 10.55 | 1.00 | 0.02 | 8.84 | 0.00 | +0.30 |
| 6 | 20 | 6.57 | 0.00 | 0.00 | 16.91 | 0.05 | 1.08 | 11.64 | 0.00 | +0.27 |
| 6 | 21 | 0.18 | 0.10 | 0.00 | 6.27 | 0.66 | 0.00 | 5.50 | 0.00 | -0.03 |
| 6 | 22 | 1.01 | 0.00 | 0.00 | 7.52 | 0.10 | 0.18 | 6.58 | 0.00 | -0.02 |
| 6 | 23 | 2.22 | 0.00 | 0.00 | 8.88 | 0.00 | 1.00 | 7.99 | 0.00 | +0.34 |
| 6 | 24 | 18.26 | 0.00 | 0.00 | 11.63 | 0.00 | 2.24 | 0.58 | 6.37 | -1.41 |
| 6 | 25 | 1.12 | 0.00 | 0.00 | 5.50 | 0.06 | 0.02 | 4.43 | 0.00 | +0.09 |
| 6 | 26 | 3.71 | 0.00 | 0.00 | 6.50 | 0.00 | 1.13 | 3.00 | 0.00 | -0.91 |
| 6 | 27 | 17.62 | 0.00 | 0.00 | 8.00 | 0.00 | 3.72 | 0.12 | 2.85 | +3.16 |
| 6 | 28 | 22.78 | 0.00 | 6.35 | 0.58 | 0.00 | 17.62 | 0.00 | 14.38 | -3.45 |
| 6 | 29 | 0.63 | 0.00 | 0.00 | 4.43 | 0.01 | 0.03 | 0.00 | 0.00 | -3.82 |
| 6 | 30 | 3.28 | 0.00 | 0.00 | 3.01 | 0.00 | 0.52 | 0.00 | 0.00 | -0.25 |
| 6 | 31 | 14.98 | 0.00 | 2.85 | 0.12 | 0.00 | 3.27 | 0.00 | 0.00 | +14.44 |
| 6 | 32 | 0.00 | 0.00 | 16.91 | 0.00 | 0.00 | 14.98 | 0.00 | 0.00 | +1.93 |

| Symbol | Definition | Units | Value |
|---|---|---|---|
| $l$ | Length of Lake | $ft$ | 132000.0000 |
| $h_1$ | Thickness of Epilimnion | $ft$ | 30.0000 |
| $h_2$ | Thickness of Hypolimnion | $ft$ | 200.0000 |
| $\rho$ | Density | $\frac{lb}{ft^3}$ | 62.4000 |
| $\Delta\rho$ | Density Difference | $\frac{lb}{ft^3}$ | .1248 |
| $h_t$ | Depth of Thermocline | $ft$ | 40.0000 |
| $W$ | Wind Velocity | $mph$ | 5 |
| $g$ | Gravity | $\frac{ft}{\sec^2}$ | 32.2000 |
| $C_0$ | Constant $1.0 < C_0 < 1.5$ | $nd$ | 1.2500 |
| $S$ | Slope Eq. 5.2 | $\frac{ft}{\sec}$ | .0000837 |
| $C$ | Celerity (Wave Speed) Eq. 5.3 | $\frac{ft}{\sec}$ | 1.2961 |
| $U_{1max}$ | Velocity, Epilimnion Eq. 5.1 | $\frac{ft}{\sec}$ | .2386 |
| $U_{2max}$ | Velocity, Hypolimnion Eq. 5.2 | $\frac{ft}{\sec}$ | -.0358 |
| $T$ | Period $= 2\frac{l}{C}$ | sec | 203680.4 |
| $T$ | Period | $hr$ | 56.5779 |
| $T$ | Period | $days$ | 2.3574 |

*Table 5.1 Computation of Lake Champlain Maximum Flow and Fundamental Period - Two Layer System*

| Symbol | Definition | Units | Value |
|---|---|---|---|
| $l$ | Length of Lake | $ft$ | 132000.0000 |
| $h_1$ | Thickness of Epilimnion | $ft$ | 60.0000 |
| $h_2$ | Thickness of Hypolimnion | $ft$ | 200.0000 |
| $\rho'$ | Density | $\frac{lb}{ft^3}$ | 62.4000 |
| $\Delta\rho$ | Density Difference | $\frac{lb}{ft^3}$ | .1248 |
| $h_t$ | Depth of Thermocline | $ft$ | 80.0000 |
| $W$ | Wind Velocity | $mph$ | 5 |
| $g$ | Gravity | $\frac{ft}{\sec^2}$ | 32.2000 |
| $C_0$ | Constant $1.0 < C_0 < 1.5$ | $nd$ | 1.2500 |
| $S$ | Slope Eq. 5.2 | $\frac{ft}{\sec}$ | .0000418 |
| $C$ | Celerity (Wave Speed) Eq. 5.3 | $\frac{ft}{\sec}$ | 1.7240 |
| $U_{1max}$ | Velocity, Epilimnion Eq. 5.1 | $\frac{ft}{\sec}$ | .0793 |
| $U_{2max}$ | Velocity, Hypolimnion Eq. 5.2 | $\frac{ft}{\sec}$ | -.0238 |
| $T$ | Period $= 2\frac{l}{C}$ | sec | 153128.9 |
| $T$ | Period | $hr$ | 42.5358 |
| $T$ | Period | $days$ | 1.7723 |

*Table 5.1 Computation of Lake Champlain Maximum Flow and Fundamental Period - Two Layer System*

| Symbol | Definition | Units | Value |
|---|---|---|---|
| $l$ | Length of Lake | $ft$ | 132000.0000 |
| $h_1$ | Thickness of Epilimnion | $ft$ | 40.0000 |
| $h_2$ | Thickness of Hypolimnion | $ft$ | 200.0000 |
| $\rho$ | Density | $\frac{lb}{ft^3}$ | 62.4000 |
| $\Delta\rho$ | Density Difference | $\frac{lb}{ft^3}$ | .1248 |
| $h_t$ | Depth of Thermocline | $ft$ | 50.0000 |
| $W$ | Wind Velocity | $mph$ | 5 |
| $g$ | Gravity | $\frac{ft}{\sec^2}$ | 32.2000 |
| $C_0$ | Constant $1.0 < C_0 < 1.5$ | $nd$ | 1.2500 |
| $S$ | Slope Eq. 5.2 | $\frac{ft}{\sec}$ | .0000669 |
| $C$ | Celerity (Wave Speed) Eq. 5.3 | $\frac{ft}{\sec}$ | 1.4650 |
| $U_{1max}$ | Velocity, Epilimnion Eq. 5.1 | $\frac{ft}{\sec}$ | .1618 |
| $U_{2max}$ | Velocity, Hypolimnion Eq. 5.2 | $\frac{ft}{\sec}$ | -.0324 |
| $T$ | Period $= 2\frac{l}{C}$ | sec | 180186.0000 |
| $T$ | Period | $hr$ | 50.0500 |
| $T$ | Period | $days$ | 2.0850 |

*Table 5.1 Computation of Lake Champlain Maximum Flow and Fundamental Period - Two Layer System*