TRANSPORT MODELING FOR THE VERMONT STATE FISH HATCHERY AT GRAND ISLE

prepared for

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by

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1.0 INTRODUCTION

This report evaluates water quality impacts associated with phosphorus discharged from the proposed Vermont State Fish Hatchery on Grand Isle, Lake Champlain. Existing conditions is this region of the Lake are described, based upon historical data collected under the Vermont Lay Monitoring Program and baseline surveys conducted by Aquatec, Inc. (1987) during August of 1987. A mass-transport model is used to project the spatial distribution of phosphorus concentrations resulting from the hatchery discharge under various wind and flow conditions. The transport model is driven by current fields developed by Laible (1988) using finite-element hydrodynamic models. Model predictions are tested against dye release data collected by Aquatec, Inc. (1987). The analysis is focused on phosphorus, a component of the hatchery discharge which is of concern because of the potential for stimulation of nuisance algal growths.

2.0 LAY MONITORING DATA

The proposed hatchery site is shown in relation to the network of 30 Lay Monitoring Stations operated by the State of Vermont since 1979 in Figure 1. Three stations (13-Cumberland Bay, 14-Treadwell Bay, and 15-The Gut) are located within 8 km of Gordon Landing. Longterm-average phosphorus, chlorophyll-a, and transparency values for all Lay Monitoring Stations are shown in Figure 2. Time series for Stations 13, 14, and 15 are shown in Figures 3, 4, and 5, respectively. Figure 6 shows monthly runoff and lake elevation for water years 1977-1987.

In general, eutrophication-related water quality in the Grand Isle region is similar to that measured in the Main Lake from Thompsons Point to Rouses Point. Of the three monitoring stations closest to Grand Isle, Treadwell Bay (14) is probably most representative of conditions in the hatchery discharge zone. Longterm-average values at this station (total phosphorus 15 ppb, chlorophyll-a 4 ppb, and transparency 5.3 meters) are representative of other stations in the Main Lake (Figure 2). August means for Main Lake stations computed from the entire period of record (1979-1987) are total phosphorus 13.7 ppb (standard error = .45 ppb), chlorophyll-a 4.6 ppb (s.e. = .16 ppb), and transparency 5.3 meters (s.e. = .08 m).

The Cumberland Bay station (13) is apparently influenced by discharges from the Saranac River/Plattsburg area. As shown in Figure 2, the average phosphorus concentration at this station (23 ppb) is above the averages for most of the other Main Lake stations, although average chlorophyll-a (3.8 ppb) and transparency (4.9 m) are similar to averages for other Main Lake stations. The above-average phosphorus concentration at Station 13 reflects measurements made in 1982 and 1984, relatively high-runoff years (Figure 6). As shown in Figure 3, phosphorus measurements in Cumberland Bay were lower in drier years 1980, 1985, 1986, and 1987.

Station 14 time series (Figure 4) also indicate that year-to-year variations in phosphorus, chlorophyll-a, and transparency are partially associated with hydrologic variations. Low transparencies (< 3 meters) measured in early June of 1984 corresponded to a high-runoff period. Seasonal patterns are evident in the chlorophyll-a data, with higher levels in June and August and lower levels in July of most years.

The average phosphorus level in the Gut (Station 13, 23 ppb) is also above the Main-Lake average, although the average chlorophyll-a concentration (3.2 ppb) is relatively low. This station is influenced by discharges from the Northeast Arm and it is possible that phytoplankton responses to phosphorus are limited by residence time or other factors in this region.

3.0 AUGUST 1987 WATER QUALITY SURVEYS

On August 13 and 18, 1987, intensive mapping of phosphorus, chlorophyll-a, and transparency levels in the Grand Isle Region was conducted by Aquatec, Inc. using the network of 21 monitoring stations shown in Figure 7. Observations are displayed by station and date in

Figure 8 (total and ortho phosphorus) and Figure 9 (chlorophyll-a and transparency). Stations are grouped by transect in these figures.

In general, the August 1987 surveys indicate relatively uniform water quality in this lake region, with observations in ranges which are similar to those reported at Lay Monitoring Stations. The lack of pronounced water quality gradients is consistent with high transport rates. The only detectable spatial pattern is associated with discharges from the Saranac River/Plattsburg area, which apparently cause higher total and ortho phosphorus concentrations and lower transparencies in the northern portion of Cumberland Bay.

At stations in the immediate vicinity of Gordon Landing (32 and 33), total phosphorus ranged from 10 to 16 ppb and ortho phosphorus ranged from < 5 to 10 ppb. Ortho phosphorus was present at detectable levels (> 5 ppb) in three out of four samples at these stations. Ortho phosphorus is of particular significance with respect to the potential for shoreline periphyton growth. Other factors, such as season, temperature, light, and substrate also regulate periphyton abundance (Auer, 1987). The presence of ortho phosphorus at detectable levels in this region provides a frame of reference for evaluating the relative impacts of localized increases in ortho phosphorus concentration attributed to the hatchery discharge on the potential for periphyton growth.

Additional data collection underway in 1988 will provide broader perspectives on seasonal and year-to-year variations in phosphorus and other water quality factors in this lake region. Both Lay Monitoring and August 1987 surveys indicate, however, that water quality in the hatchery discharge region is representative of conditions in the open waters of the Main Lake.

4.0 PHOSPHORUS/CHLOROPHYLL-A/TRANSPARENCY RELATIONSHIPS

Scatter plots of paired phosphorus, chlorophyll-a, and transparency observations derived from the Lay Monitoring Program and the Aquatec 1987 Surveys are shown in Figures 10 and 11. Individual data points are shown in relation to the predictions of the following equations:

Chl-a = .33 P (1)

1/Secchi = a + .013 Chl-a (2)

1/Secchi = a + .0043 P (3)

a = non-algal turbidity = .1 to .2 m^{-1}

These response models provide a frame of reference for interpreting the observed data. Relationships of this type are generally applied to seasonally-averaged measurements and considerable data scatter is expected when they are shown in relation to individual measurements.

The chlorophyll-a/phosphorus ratio (.33) is derived from longterm August means for Lay Monitoring Stations in the Main Lake (Total P = 13.7 ppb, chlorophyll-a = 4.6 ppb). The slope of the inverse Secchi/chlorophyll-a relationship (.013 m^2/mg) has been estimated by Effler (1987), based upon studies of optical characteristics in the Grand Isle region (mean estimate = .013 m^2/mg, probable range = .009-.019 m^2/mg). The intercept of the Secchi/chlorophyll-a relationship reflects the impacts of non-algal turbidity on water transparency. Effler(1987) estimated intercepts in the range of .08 to .16 m^{-1}. As shown in Figure 10, Lay Monitoring data for Treadwell Bay suggest a somewhat lower average intercept (.12 m^{-1}), as compared with the August 1987 surveys (.2 m^{-1}). This could be attributed to above-average non-algal turbidity levels during the August 1987 surveys and/or to investigator-related differences in the Secchi disk measurements. The

Secchi/phosphorus equation is derived by combining the Chl-a/phosphorus and Secchi/Chl-a equations.

As shown in Figure 11, stations in the northern end of Cumberland Bay (39, 40, 41, 42) are outliers in relation to the other data points and predictions of the above equations. Relatively high non-algal turbidities (.4-.5 m^{-1}) are indicated for these stations, based upon their locations in the Secchi/chlorophyll and Secchi/phosphorus plots. It is likely that the relatively low transparencies in northern Cumberland Bay (1.8 - 3.5 meters) primarily reflect the influences of inorganic turbidity from the Saranac River, rather than elevated chlorophyll-a concentrations. At other locations, variations in transparency are more closely associated with variations in chlorophyll-a and phosphorus, as represented by the above models.

5.0 HYDRODYNAMIC MODELING

Laible (1988) describes two finite-element hydrodynamic models which are used to support transport modeling of the hatchery discharge. General characteristics of these models are summarized below. Details are given by Laible (1988).

A one-layer model simulates local wind-driven circulation in the epilimnion between Valcour Island and Long Point. The model estimates vertically-averaged total and net current velocities (speeds and directions) within the epilimnion at any latitude and longitude in the model region for a given wind condition. The model assumes a fixed thermocline depth and surface elevation. Predicted current fields generally follow the wind direction in shoreline areas. Flows along the western shore of Grand Isle are parallel to the shoreline and aligned with the north/south component of the wind stress. These flows are balanced by reverse currents in offshore regions. Reverse currents reflect the assumption of fixed thermocline depth (or fixed epilimnetic volume) and the requirement maintain a water balance within the model grid. Alongshore wind-driven currents are likely to be the dominant transport mechanism for the hatchery effluent, particularly during periods of steady winds.

A second model simulates seiche activity in a one-dimensional (north/south), two-layer (epilimnion and hypolimnion) representation of the entire stratified portion of the Main Lake. At any point along the north/south axis of the Lake, the model simulates changes in thermocline level, epilimnetic flow, and hypolimnetic flow in response to time-variable wind conditions. The model is driven by time series of north/south wind loads measured at Burlington Airport and adjusted for spatial variations along the length of the Lake. It has been calibrated to predict thermocline fluctuations observed by Aquatec, Inc (1987) near Grand Isle during August of 1987. The is a relatively limited basis for calibration of a lakewide model. Data from other locations and times would permit further testing and possible refinements to this model.

Predicted thermocline fluctuations and epilimnetic flow at Grand Isle for a four-month simulation period (July-September 1986, August 1987) are shown in Figure 12. The simulations have been run separately for each month (restarted from a level thermocline). Predicted flows are averaged vertically and horizontally within the epilimnion at a given latitude and time. A positive flow is towards the North. Because of thermocline fluctuations, the general magnitudes of the flows predicted by two-layer model at a given latitude are greater than those predicted by the one-layer model.

Neither model in itself is a complete representation of circulation in the Grand Isle region. Because of the fixed thermocline assumption, the one-layer model may over-estimate offshore reverse currents under certain conditions. It also does not account for flows driven by thermocline fluctuations. The two-layer model does not provide resolution of flows within the epilimnion at a given latitude. Such resolution would be important for simulating nearshore discharges.

Simulations using the one-layer model indicate that throughflows driven by seiche activity tend to be focused in deep, offshore regions because of shoreline frictional effects (Laible, 1988). Currents driven by local winds are expected to dominate flows near the shore and in the upper portion of the epilimnion. Currents driven by seiche activity may modify those driven by local winds, however, particularly under light or changing winds. Despite limitations, results of both models are useful for interpreting dye study results and for projecting hatchery impacts, as demonstrated below.

6.0 DYE STUDY

To provide data for evaluating hydrodynamic characteristics in the Grand Isle region, a dye release experiment was conducted at Gordon Landing in August 1987 by Aquatec, Inc. (1987). Rhodamine WT dye was released at a constant rate of 4.58 kg/day (as pure dye) between August 10 and August 21. The release point was approximately 100 meters offshore from the tip of the breakwater at Gordon Landing at a depth of approximately 9 meters. Dilution factors can be inferred from the measured spatial distributions of dye concentrations in the lake (Aquatec, Inc. 1987).

Since the dye release rate was similar to the projected phosphorus loading for the hatchery (3.94 kg/day for September, 3.18-3.75 kg/day for other summer months), measured dye concentrations approximate the increases in phosphorus concentrations above background levels which would have been measured if the hatchery had been discharging at full capacity during the August 10-21 period. While direct interpretation of the dye data provides useful insights into mixing characteristics at the site, the results apply only to the period of the experiment and do not reflect the effects of longterm accumulation.

Model testing is another important use of the dye release and drogue data collected at the site. Hydrodynamic modeling by Laible (1988) and transport modeling described below help to characterize and quantify the dilution mechanisms operating in the Grand Isle region. Modeling also provides a basis for projecting hatchery impacts under a range of environmental conditions (such as wind speed, direction, thermocline depth, and flow). Given the complexities of the lake flow system and numerous controlling factors, modeling requires many simplifying assumptions. Comparisons of dye release data with model predictions help to insure that modeling assumptions are reasonable and that model coefficients are appropriate for simulating plume behavior in this lake region.

Wind velocity is a major factor driving lake circulation on local and lakewide scales (Laible, 1988). Wind conditions must be considered in interpreting dye data and in projecting hatchery impacts. The effects of wind speed on surface shear stress and resulting water movement can be expressed in relative terms using the "wind load factor", which is defined as the ratio of shear stress at a given wind speed to the shear stress at 8.7 mph. The wind load factor is approximately a quadratic function of wind speed. Analysis of Burlington Airport wind records for May-September 1986 and August-September 1987 indicate mean and median load factors of 1.5 and 1.1, respectively. Three-day moving-average load factors range from 0.4 to 4.6.

3-hour observations of wind speed and direction at Burlington Airport during the dye study period are shown in Figure 13. One-day and three-day moving-average wind load factors at Burlington Airport and Grand Isle during August and September of 1987 are plotted in Figure 14. Directional load factors (N/S and E/W) at Burlington Airport are shown in Figure 15; (a corresponding display of directional load factors from the Grand Isle gauge is not possible because the directional sensor was damaged sometime during August). In Figure 15, a positive value for the N/S load factor indicates a stress towards the North. During the dye study, predominant wind directions were from the Southeast (August 13-17, 19) and Northwest (August 11-12, 18, 20).

Dye plumes measured by Aquatec, Inc. (1987) on individual days between August 11 and 20 are shown in Figure 16 (plan view) and Figure 17 (profile view) . These displays are intended to show the general size and orientation of the plume. They emphasize the .25 ppb contour, which was most consistently defined from the field data. Generally, plume orientation was towards the South on August 11 and 20 and towards the North on the remaining days. The largest plumes were observed on August 12 and 19 and the smallest on August 13. Vertical cross-sections (Figure 17) show that the .25 ppb contour extended approximately 4 km North or 2.5 km South of the dye release point. The dye was mixed vertically, except on August 12, when the leading edge of the plume was located between 4 and 10 meters depth, approximately 3-5 km north of the release point.

Drogue data collected during the dye study indicate relatively high flow velocities (typically, 20 cm/sec) in the vicinity of the dye release point on various days (Aquatec, 1987, Figures 24, 26, 27). As discussed by Laible (1988), these velocities generally reflect mid-afternoon conditions and significantly lower velocities (possibly reversing direction) may have occurred as wind velocities decreased during the night and early morning. Drogue data indicate travel times on the order of a few hours from the dye release point to the Grand Isle water intake, approximately 3.5 km to the North. With these velocities, the dye plume would respond relatively rapidly to changes in wind speeds and directions.

Figure 18 compares north/south load factors at Grand Isle and Burlington Airport with dye plume orientations shown in Figure 16. A good correlation between dye plume orientation north/south wind load is evident. On August 13-17 and 19, winds were from the Southeast and the plume extended to the North. On August 11 and 20, winds were from the Northwest and the plume extended to the South. On August 12 and 18, however, winds were relatively light and from the Northwest and the plume extended to the North. Lack of alignment on these days may reflect changing wind conditions, lack of steady-state conditions, and seiche activity, as described below. The good correlation between plume orientation and wind direction for remaining dates suggests that currents driven by local winds (tending to align with wind direction in shoreline areas) are important in the hatchery discharge region.

Figure 19 compares seiche flows at Grand Isle predicted by the two-layer hydrodynamic model (Laible, 1988) with dye plume orientations and north/south wind loads. Predictions of seiche flow are approximate, since the model has been calibrated to limited data from a single location and time period. The north/south orientations of wind stress, flow, and dye plumes are generally correlated. One exception is August 12, when the wind stress was relatively light and towards the South, but the predicted seiche flow and dye plume orientation were towards the North. The opposing directions of seiche flow and wind stress on this date reflect recovery of the thermocline following strong winds from the Northwest and resulting flows towards the South on August 11. August 12 was the only day in which the seiche flows and wind stresses were in opposite directions at midday. This may explain the vertical stratification of the dye plume on this date (Figure 17, also Aquatec, Inc.(1978), Figure 25). The dye (released at 9 meters depth) was carried north in seiche-driven flows; lower dye concentrations near the surface reflect wind-driven currents in the opposite direction. For the hatchery discharge through a diffuser, greater mixing over depth would be expected under these conditions.

The relatively small surface area of the dye plume on August 13 may be explained by the alignment of wind stress and seiche flows on this date. During the August 13-17 period of wind stress towards the North, seiche flows gradually decreased as the thermocline was depressed in the northern lake. On August 14-17, seiche-related flows were small and oscillated on a diurnal basis in response to diurnal variations in wind load. Dynamic equilibrium during this period is described by Laible (1988). The dye plume was very stable and oriented towards the North, probably in response to currents aligning with the wind load along the western shore of Grand Isle. Diurnal variations in the plume during this period are also likely, but not definable from the midday measurements.

Shifts in wind load and seiche flows towards the South were not reflected in the dye plume measurements on August 18. It is possible that there was insufficient time for the plume to respond, since winds shifted again towards the North on August 19. The relatively large surface area of the dye plume on August 19 is somewhat inconsistent with the relatively strong wind stress and seiche flow on that date. A review of the Grand Isle wind record, however, indicates the southerly wind stress was interrupted by periods of westerly winds in early morning and mid-afternoon on August 19. On August 11 and 20, winds shifted into the Northwest and southern stresses were aligned with southern seiche flows. These conditions promoted relatively rapid dilution of the dye as it moved south on these dates; hence the plumes projecting south were relatively small.

The above discussion indicates that, with the possible exception of August 18, day-to-day variations in the dye plume can be explained qualitatively by consideration of wind stresses, seiche flows, and regional variations in wind conditions. Modeling efforts described below attempt to explain plume behavior in quantitative terms.

7.0 TRANSPORT MODELING

Modeling of dye plumes and the hatchery discharge involves application of hydrodynamic and mass-transport models which have been developed and tested at several other locations on Lake Champlain (Laible and Walker, 1986-1988). The finite-element hydrodynamic models (Laible, 1988) predict current fields resulting from wind and topographic effects on local and lakewide scales (see **HYDRODYNAMIC MODELING**). The mass-transport model (Walker, 1985) predicts changes in concentration resulting from a given current field and discharge scenario in a two-dimensional (latitude x longitude) grid of vertically mixed cells.

The transport grid covers the area east of Cumberland Head from Sawyer Island on the South to Young Island on the North (Figure 20). Most previous model applications have employed a grid cell size of 400 meters. A cell size of 200 meters provides the resolution necessary for representing flow fields in this region, particularly in the dynamic area between Gordon Landing and Cumberland Head. On a 200-meter grid (Figure 21), each cell represents an area of 4 hectares or approximately 10 acres. Current fields predicted by the hydrodynamic model under alternative wind conditions are used to drive the transport model. Flows generated by the lake's water balance and by seiche activity are also considered.

As discussed above (see **HYDRODYNAMIC MODELING**), a single model which predicts currents driven both by local winds and by lakewide seiche activity does not exist. Both transport mechanisms are important in the Grand Isle Region, depending upon season and antecedent wind conditions. Two alternative approaches to modeling the dye plume and hatchery discharge are taken below:

(1) **Wind-Driven:** Transport is modeled using currents driven by local wind conditions. Wind-induced flow is likely to be the dominant transport mechanism along the shoreline, particularly during periods of steady winds.

(2) **Seiche-Driven:** Transport is modeled using currents driven by seiche flows and an empirically calibrated dispersion coefficient. Seiche flows are likely to be more important than wind-induced flows during periods of light and/or shifting winds.

Since each approach ignores one or more mechanisms contributing to currents and dilution potential in the discharge region, resulting impact projections are conservative. The wind-driven simulations have a much broader basis, since the models have been tested and applied in several regions of Lake Champlain (Laible and Walker, 1986-1988). Predictions of seiche flows are very approximate, since the two-layer model has been calibrated to limited data from one location and time period. Conclusions regarding impacts of the hatchery discharge are insensitive to modeling approach, since projected impacts are similar and very small using either method.

All simulations include a throughflow of 6.4 x 10^6 m^3/day to the North to account for the lake water balance. This flow is based upon a runoff rate of .5 cfs/mi^2 (Figure 6) and drainage area of 5243 mi^2 at Grand Isle. Based upon decay rates estimated in studies of Hawkins Bay (Smeltzer, 1985; Laible and Walker, 1987) and the short travel times characteristic of the dye plumes, dye decay is ignored in the simulations.

Observed maximum dye concentrations in each grid cell and day are displayed in Figures 22, 23, and 24. These observations are used for testing the simulations described below. To avoid complex spatial weighting procedures, the displays are based upon cell-maximum concentrations. This fact should be considered in comparing observed cell-maximum values with mean concentrations predicted by the models.

8.0 WIND-DRIVEN SIMULATIONS OF DYE PLUME

Predictions of the wind-driven current models have been tested against two wind loads which were experienced during the dye study:

(1) Southeast, Load Factor = 1.87, August 14-17, Figure 25;
(2) Northwest, Load Factor = 1.37, August 20, Figure 26.

For each wind load, dye transport has been predicted using flow fields corresponding to thermocline depths of 10 and 25 meters. This brackets the range of thermocline depths observed during the dye study (Aquatec, Inc. 1987). Average thermocline depths were closer to 25 meters, particularly between August 14 and 17.

As discussed above (HYDRODYNAMIC MODELING), the one-layer, wind-driven current model maintains a constant thermocline depth and water balance within the model grid. Because of the possibility of thermocline depression in and downwind of the grid, the model may over-predict offshore reverse currents which are required to maintain a water balance within the grid. Additional simulations in Figures 25 and 26 include a net throughflow of 50 x 10^6 m^3/day in offshore regions (columns 5-10 of the grid). This flow (North in Figure 25 and South in Figure 26) approximately balances the reverse currents predicted by the hydrodynamic model under these wind loads. This provides a means of modifying the wind-driven flow fields to diminish the impacts of reverse currents on dye transport.

Because of the relatively small influence of seiche flows and stability of the wind load and dye plume, August 14-17 represents a good period for testing the steady-state transport model based upon wind-driven currents. Dye observations and predictions for August 14-17 are given in Figures 23 and 25, respectively. Consistent with observations, all simulations show the dye plume heading north, with the .5 ppb contour extending around Wilcox Point (1.4 km) and the .2 ppb contour extending north between 3 and 6 km. For a 10-meter thermocline depth, reverse currents cause the predicted .2 ppb dye plume to extend further west than observed. Addition of a northern throughflow offsets the reverse currents and causes more of the simulated dye to move northeast along the shore. The 25-meter thermocline simulations come closest to matching the observed dye plumes during this period. Addition of a throughflow to this simulation causes the .2 ppb contour to move further north by about 1.4 km, but has little impact on the higher concentration contours (e.g., .5 ppb) closer to the release point. This suggests that the wind-driven current model adequately predicts dye transport during this period of relatively steady, southeasterly winds, particularly when concerned with concentration increases of .5 ppb or greater.

Dye observations and predictions for August 20 are given in Figures 24 and 26, respectively. Wind loads on August 11 were similar (Northwest, Load Factor = 1.33, Figure 22). At both thermocline depths, addition of throughflow to offset reverse currents reduces transport of the dye to offshore regions. As for southeasterly winds, throughflow has little influence on maximum dye concentrations immediately south of the release point and along the shoreline. The simulated .5 ppb contour extends just below Rockwell Bay, or approximately 3 km south of the release point. Observed .5 ppb levels extend approximately 1.8 km south on August 11 and 1.4 km south on August 20. Generally, simulated dye concentrations are above those observed for this wind load. This is consistent with the alignment of wind loads and seiche flows (100 - 300 x 10^6 m^3) on these dates, as shown in Figure 19. Enhancement of wind-driven transport by seiche-driven transport may explain the lower observed dye concentrations.

Based upon the above comparisons, the wind-driven current model is adequate for generating conservative projections of transport along the shoreline north and south of Gordon Landing. As indicated in the simulations of the northwest wind loading, the model may under-estimate flows and effluent dilution attributed to seiche activity, particularly on days immediately following a major shift in wind direction (e.g, south to north or vice versa), as observed on August 11, 13, and 20.

9.0 SEICHE-DRIVEN SIMULATIONS OF DYE PLUME

As an alternative model, seiche flows can be used, in combination with an empirically calibrated dispersion coefficient, to simulate dye transport. Figure 27 shows predicted dye plumes for seiche flows of 25, 50, 100, and 200 x 10^6 m^3/day in northern and southern directions. The flow magnitudes are based upon predictions of the two-layer hydrodynamic model for the dye study period, as shown in Figure 19. Seiche flows, generally focused offshore, are routed through the transport grid using flow fields estimated by the one-layer hydrodynamic model for a fixed throughflow (e.g., Laible, 1988, Figure 2.7). Because seiche flows tend to be more important during late summer when stratification is relatively strong and the thermocline is deep, seiche simulations employ a thermocline depth of 25 meters.

Consideration of seiche flows alone under-estimates transport in shoreline areas because currents driven by local winds are not reflected. A calibrated dispersion coefficient (40,000 m^2/day) is applied to the entire grid to represent effects of wind-driven currents, random turbulence, and other transport mechanisms. With this value for the dispersion coefficient, the model simulates the observed northern extents of the .25 and .5 ppb dye contours for northern seiche flows in the range of 25 to 50 x 10^6 m^3/day, typical of predicted midday flows for August 14-16. For southern seiche flows in the range of 100 to 200 x 10^6 m^3/day, as predicted for August 11 and 20, the model places the .5 ppb contour 1.2 to 1.4 km south of the release point and the .25 ppb contour at and below Rockwell Bay (2.6 km).

10.0 PHOSPHORUS IMPACTS

The models described have been used to simulate the impacts of the hatchery discharge on phosphorus concentrations in the lake region. Results for phosphorus can be rescaled based upon loading to estimate the impacts of other constituents in the discharge. Loading, wind, flow, and boundary conditions for these simulations are summarized in Table 1. Simulations are based upon the projected phosphorus loading for September (3.94 kg/day). Projected loadings are somewhat lower for other summer months (Table 2). Modeling results are displayed in the following figures:

Figure	Model	Thermocline	Discharge Location
28	Wind-Driven	25 m	Offshore
29	Wind-Driven	25 m	Onshore
30	Wind-Driven	10 m	Offshore
31	Wind-Driven	10 m	Onshore
32	Seiche-Driven	25 m	Offshore
33	Seiche-Driven	25 m	Onshore

Table 3 lists the surface areas impacted by the discharge for each simulation. All simulations are expressed in terms of an increase in phosphorus concentration above a baseline level of approximately 15 ppb.

Two alternative locations for the hatchery discharge are considered in the simulations: "offshore" (Column 13, Row 30 of the transport grid, outside the breakwater, approximate dye release point) and "onshore" (Column 14, Row 30, east of the breakwater). For the latter, slightly higher concentration increases are predicted in the discharge cells and adjacent cells. The grid and simulations do not provide the resolution required for detailed comparison of an offshore vs. onshore discharge point, however. In particular, the grid is too course to reflect the hydrodynamic effects of the breakwater and embayment adjacent to the ferry landing. Because of this, simulations of the offshore discharge point (as tested via dye release) are more reliable. The onshore simulations are intended primarily to show the low sensitivity of plume size (e.g., area with >1 ppb increase) and plume location to discharge point.

Simulations do not account for dilution of the hatchery effluent induced by an offshore diffuser. Based upon the design for the Kingsland Bay hatchery outfall and the relatively high current velocities near Grand Isle, it is likely that an outfall could be designed to provide a minimum 20-fold dilution of the effluent within 200 feet (62 meters) of the discharge point. With such a design, the concentration increase attributed to the hatchery effluent (53 ppb above background during September, less for other summer months) would be limited to less than 2.7 ppb. Higher dilution ratios may also be feasible at this site. The offshore diffuser would help to reduce local concentration increases during unfavorable wind conditions. It would not influence the general regional patterns shown in Figures 28-33, however.

A boundary concentration increase of .22 ppb has been applied in each simulation to reflect impacts at the edge of the simulation grid. As indicated in Table 1, this is calculated from the phosphorus loading, throughflow, and lakewide phosphorus retention coefficient. This calculation does not account for dilution in flows entering the Main Lake at and north of The Gut. It may over-estimate actual impacts at and beyond the grid boundary. An alternative estimate would be based upon the net annual loading from the hatchery (914 kg) in relation to the annual loading to the whole lake (536,000 - 804,300 kg, Bogden, 1978). Applied to an average existing concentration of 14 ppb for the Main Lake, the ratio of hatchery loading to existing loading would correspond to an increase of .016-.024 ppb.

Wind-driven simulations are presented for each of eight wind directions. Based upon frequency analysis of wind data from Burlington Airport for May-September 1986 (Figure 34), prevailing winds are from the South or Southeast, with secondary winds from the North or Northwest. A wind load factor of 1.0 is used in all simulations. This is below the mean (1.5) and median (1.1) load factors computed from the Burlington Airport record for May-September 1986 and August-September 1987. As shown in Figures 14 and 34, the 3-day moving-average load factor rarely drops below 0.5. Concentration increases over a 3-day period of low winds can be estimated by multiplying the simulated values by 2.0 (corresponding to a change in load factor from 1.0 to 0.5). Depending upon duration, lake concentrations may not reach steady-state during periods of low wind. Seiche-driven flows would tend to reduce sensitivity to low wind speeds and to unfavorable wind directions. Projections of the plume west into offshore waters (as for easterly winds) would be dampened by offshore seiche-driven currents.

Thermocline depths of 10 and 25 meters have been used in the wind-driven simulations. The 25-meter thermocline would be typical of conditions in late summer, particularly during periods of steady southerly winds, which promote depression of the thermocline in northern portions of the lake. The 10-meter thermocline would be more typical of conditions in early summer or in late summer during periods of steady northerly winds, which promote elevation of the thermocline.

Seiche-driven projections (Figures 32 and 33) employ average northern and southern flows of 57 x 10^6 m^3/day predicted by the two-layer hydrodynamic model based upon simulation of four months of wind data (Figure 12). These average flows compare with average and maximum seiche amplitudes of approximately 180 and 400 x 10^6 m^3/day, respectively. Three simulations are shown in each figure. The flows are applied separately to estimate typical responses to northern and southern seiche movements. A third simulation applies northern and southern flows simultaneously. This amounts to modeling seiche activity as a dispersion process which is focused on a north/south axis and is analogous to procedures employed in tidally-averaged models of estuaries.

As shown in Figure 32 and 33, overlaying the north and south seiche flows causes the plume to move further north than predicted for the north or south flows individually. When the seiche flows are overlayed, the net north/south transport attributed to the seiche is canceled and the plume is driven north by the relatively small northern flow (6.4 x 10^6 m^3/day) attributed to the lake water balance. Although physical interpretation of the results for overlayed flows is difficult (since the northern and southern flows do not actually occur simultaneously), conclusions based upon these results are not qualitatively different from conclusions based upon other simulations.

One measure of impact is the number of model cells (or surface area) with a phosphorus increase of 1 ppb or greater. Increases of less than 1 ppb cannot be detected in the laboratory, even in the absence of natural or sampling variability. As illustrated in Figures 4 and 8, phosphorus levels in this region of the lake vary over a range of 5 to 30 ppb. When seasonal and year-to-year variabilities are considered, detection of an average increase of 1 ppb (or 6.7% of the existing mean) would be difficult, as demonstrated in recent statistical analyses of monitoring data from Vermont lakes (Smeltzer et al.,1988).

As summarized in Table 3, the offshore discharge results in phosphorus increases exceeding 1 ppb over surface areas ranging from 60 to 380 acres for the various simulations. The corresponding range for the onshore discharge is 80 to 400 acres. Plume size is generally insensitive to discharge location. The higher projected impact area for the Kingsland Bay hatchery (~ 2,120 acres with a phosphorus increase of 1-2 ppb, Laible and Walker, 1986) reflects more favorable transport in the Grand Isle region. Despite differences in plume area, phosphorus changes of this magnitude would be difficult to detect in either case.

Plume areas are highest (270 to 400 acres) for easterly and westerly winds. As shown in Figure 34, these conditions are relatively infrequent. Consideration of seiche flows in the model would reduce the concentration increases predicted for these wind loadings. As discussed above, discharge through an offshore diffuser would also avoid increases exceeding 3 ppb in the discharge cell.

Plume areas are smallest (60 to 90 acres) for dominant southerly and southeasterly winds and a 25-meter thermocline depth. As observed during the dye study, the plume travels north along the shoreline under these conditions. The 1-ppb increase extends just beyond Wilcox Point. For northerly and northwesterly winds, the 1-ppb increase extends south just beyond Rockwell Bay.

11.0 EUTROPHICATION IMPACTS

Phosphorus is of concern because of the potential for stimulation of nuisance algal growths. Biological responses to localized increases in phosphorus concentrations in this relatively turbulent region of Lake Champlain would not necessarily be the same as if those increases were experienced in a stagnant pond or bathtub. In particular, low residence times (reflecting high transport rates) may impede phytoplankton responses. Algal cells may be transported into and out of the hatchery plume before responding to localized increases in phosphorus concentration.

Modeling of phytoplankton responses in rapidly-flushed impoundments indicates that time scales on the order of two weeks are required for full algal responses to nutrients (Walker,1985a). For a thermocline depth of 25 meters, the epilimnetic volume within the entire transport grid (Figure 21) is on the order of 600 x 10^6 m^3. Hydraulic residence times corresponding to average and maximum seiche flows of 57 and 400 m^3/day (Figure 12) are on the order of 11 and 1.5 days, respectively. Wind-driven currents would further reduce residence times, particularly in shoreline areas adjacent to the hatchery discharge. Based upon drogue studies and modeled flows, residence times in the narrow region between Gordon Landing and Cumberland Head are less than 1 day.

Figure 36 shows that there is no spatial correlation between phosphorus and chlorophyll-a, based upon longterm averages at Lay Monitoring stations in the Main Lake from Thompson's Point to Rouses Point. Although average phosphorus concentrations range from 12 to 23 ppb in this region, chlorophyll-a remains within the relatively narrow range of 3.2 to 4.6 ppb. This may reflect transport rates in the Main Lake which are too high to permit phytoplankton responses to localized changes in phosphorus. Increases in phytoplankton are more feasible in embayments with are more isolated from the Main Lake (e.g., Mississquoi, St. Albans). Although a relationship would be expected between average phosphorus and average chlorophyll-a for the Main Lake as a whole, it is unlikely that localized increases in algal densities (or decreases in transparency) would occur in direct proportion to localized increases in phosphorus.

Worst-case impacts on transparency can be evaluated by ignoring effects of residence time. Based upon equation (3) and an average non-algal turbidity .12 m^{-1}, phosphorus concentrations of 15, 16, and 17 ppb correspond to transparencies of 5.42, 5.30, and 5.17 meters. Phosphorus increases of 1 to 2 ppb above an existing average of 15 ppb could result in transparency decreases on the order of .12 to .25 meters, or 2.2 to 4.6 %. This provides an approximate basis for expressing regional impacts of the hatchery discharge in terms of transparency. Detecting such a change in the presence of natural variability in transparency (3 to 8 meters, Figure 4) would be difficult. The average transparency would remain above 5 meters, which is considered oligotrophic by most limnologists (Maloney, 1979).

The potential for stimulation of periphyton growth along the shoreline is related to ortho phosphorus concentrations (Auer, 1987). Increases in ortho phosphorus attributed to the hatchery discharge would be lower than those projected for total phosphorus because portions of the phosphorus in the effluent would be in particulate, organic, or otherwise non-ortho forms. As compared with the onshore discharge, the offshore discharge results in lower projected concentration increases along the shoreline in the immediate vicinity of Gordon Landing, but has little influence on the plume size or total shoreline length with projected increases exceeding 1 ppb.

The presence of detectable levels of ortho phosphorus in the vicinity of Gordon Landing (<5-13 ppb, Figure 8) suggests that any ortho phosphorus contributed by the hatchery, particularly in the range of 1-2 ppb, would not have a qualitative impact on the nutrient climate or on the potential for periphyton growth. The presence of ortho phosphorus during August of 1987 may reflect growth regulation by factors other than phosphorus. Monitoring data from other seasons (particularly, late spring and early summer) will provide broader perspectives on nutrient regimes and existing periphyton populations in the Gordon Landing area.

Lakewide impacts of the hatchery discharge would not be perceptible. The net annual phosphorus loading (914 kg) amounts to .11 to .17% of the total loadings to Lake Champlain estimated by Bogden (1978). The small increase in loading does not necessarily mean that lake phosphorus levels will increase in proportion. For example, planned implementation of phosphorus removal at Vermont sewage treatment plants over the next few years will decrease the total loading to the lake by at least 50,000 kg/yr. This will offset the additional loading contributed by the hatchery by more than 50-fold. If the average phosphorus concentration in the Main Lake (~ 14 ppb) responds in proportion to the change in load, a reduction in the range of .9 to 1.3 ppb would be expected. While this suggests some improvement in the immediate future, longterm increases in land development and population in the basin would also have to be considered in projecting conditions and in developing effective longterm management strategies for the Lake.

12.0 CONCLUSIONS

(1) Because of hydrodynamic characteristics, Grand Isle is a favorable location for the hatchery from a water quality perspective.

(2) Existing phosphorus, chlorophyll-a, and transparency levels in the Grand Isle region are typical of values found in the Main Lake between Thompson's Point and Rouses Point. Based upon Lay Monitoring data from Treadwell Bay, longterm average values are 15 ppb, 4 ppb, and 5.3 meters, respectively.

(3) Transport in the hatchery discharge zone is driven by local winds and seiche activity. Wind-induced currents are dominant along the western shore of Grand Isle. Seiche-induced flows tend to focus in offshore regions, but may enhance dilution of the hatchery effluent, especially on days immediately following a major shift in wind direction (e.g., south to north or vice versa) or during periods of light winds.

(4) Hatchery impacts on phosphorus concentrations have been projected using wind-driven and seiche-driven transport models which have been tested against a dye release experiment conducted by Aquatec, Inc. (1987) in August 1987. Sensitivities of the impact projections to model form (wind-driven vs. seiche-driven), thermocline depth, discharge location, and wind direction have been evaluated.

(5) Simulations indicate that phosphorus increases in the immediate vicinity of the discharge would tend to be higher for an onshore vs. offshore discharge point. The size and location of the 1 ppb impact zone are insensitive to discharge location, however. A refined analysis of an onshore discharge would require a finer simulation grid and consideration of the breakwater and shoreline topography. Simulations of the offshore location (as evaluated in the August 1987 dye study) are more reliable.

(6) Wind-driven simulations have been performed for a load factor (related to speed) of 1.0, as compared with mean and median values of 1.5 and 1.1, respectively, computed from Burlington Airport wind records. For this load, an offshore discharge would increase phosphorus concentrations by 1-2 ppb over surface areas ranging from 60 to 380 acres for various wind directions. Projected plume areas are smallest (60 to 90 acres) under dominant southerly and southeasterly winds. The plume would tend to align with the north/south component of the wind stress. Increases of 1-2 ppb would be experienced along the shoreline between Rockwell Bay on the South and Wilcox Point on the North for various wind directions. Although these increases would be theoretically detectable in the laboratory, it is unlikely that they could be detected in the presence of natural variability (approx. 5 to 30 ppb).

(7) Because of short residence times and rapid plume movements in response to wind and seiche activity, it is unlikely that localized increases in algal densities (or decreases in transparency) would occur in direct proportion to localized increases in phosphorus. This is supported by lack of spatial correlation between phosphorus and chlorophyll-a for Lay Monitoring stations on the Main Lake. Although unlikely, a full response to phosphorus increases in the range of 1-2 ppb would result in transparency decreases of .12-.25 meters or 2.2-4.6% of the existing mean.

(8) The presence of detectable levels of ortho phosphorus in the vicinity of Gordon Landing during August 1987 suggests that any ortho phosphorus contributed by the hatchery, particularly in the range of 1-2 ppb, would not have a qualitative impact on the nutrient regime or on the potential for periphyton growth. The ongoing monitoring program will provide data from other seasons to further define existing nutrient regimes and periphyton populations.

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Figure 1
Lake Champlain Lay Monitoring Stations

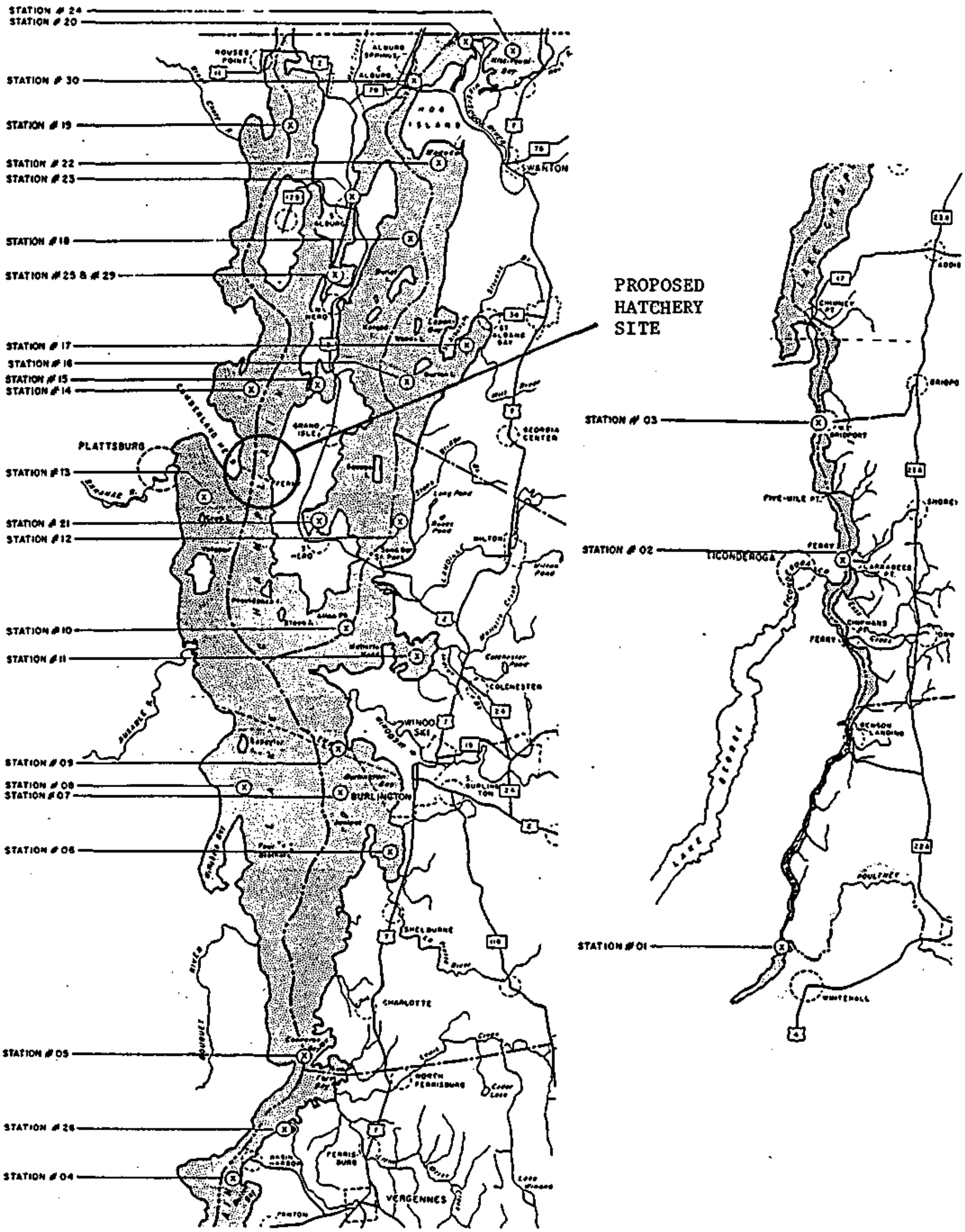


Figure 2.
Longterm Water Quality Means at Lay Monitoring Stations
(Mean +- 1 Standard Error, see Figure 1 for Station Locations)

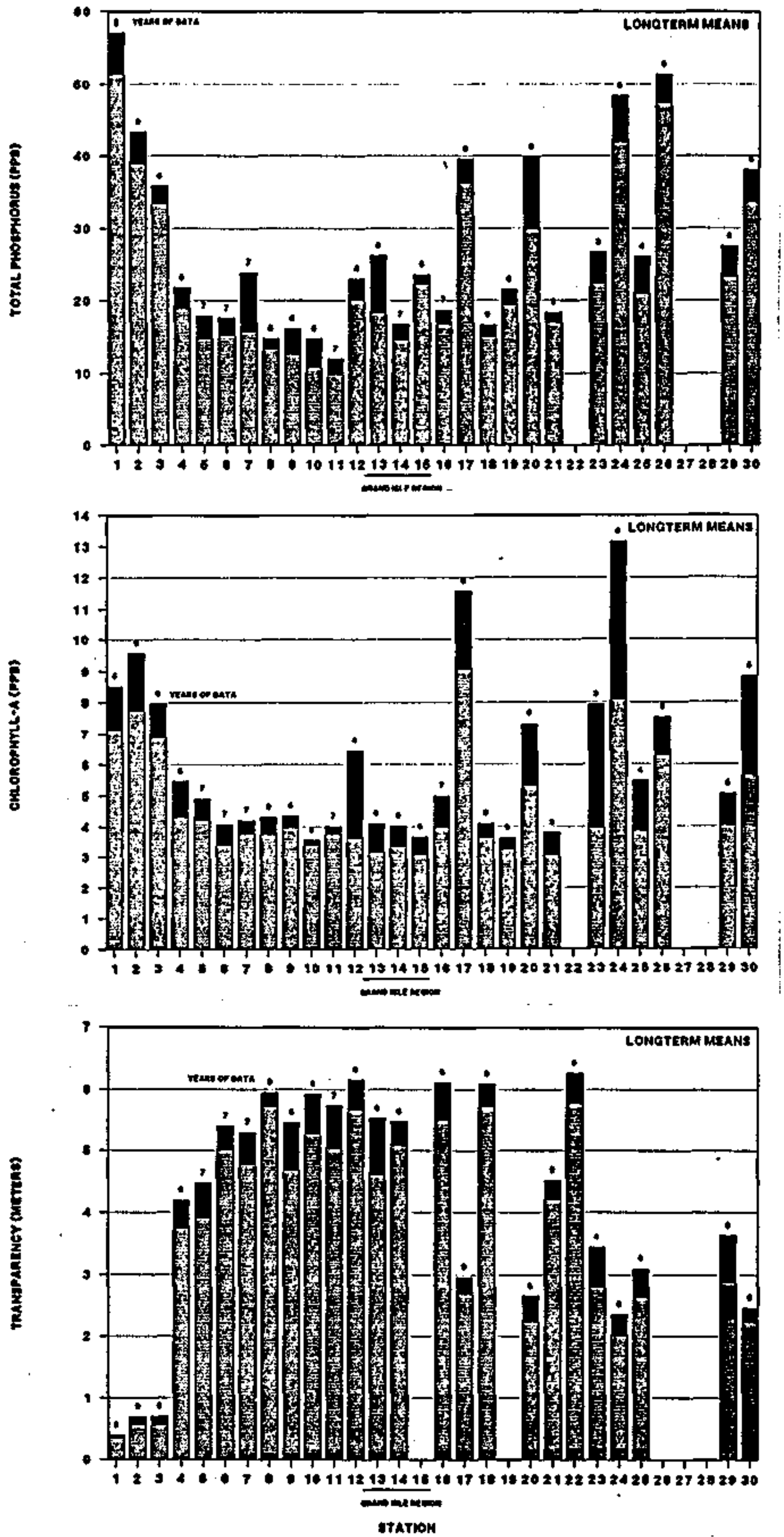


Figure 3
Phosphorus, Chlorophyll-a, and Transparency Time Series
Lay Monitoring Station 13 - Cumberland Bay
(See Figure 1 for Station Location)

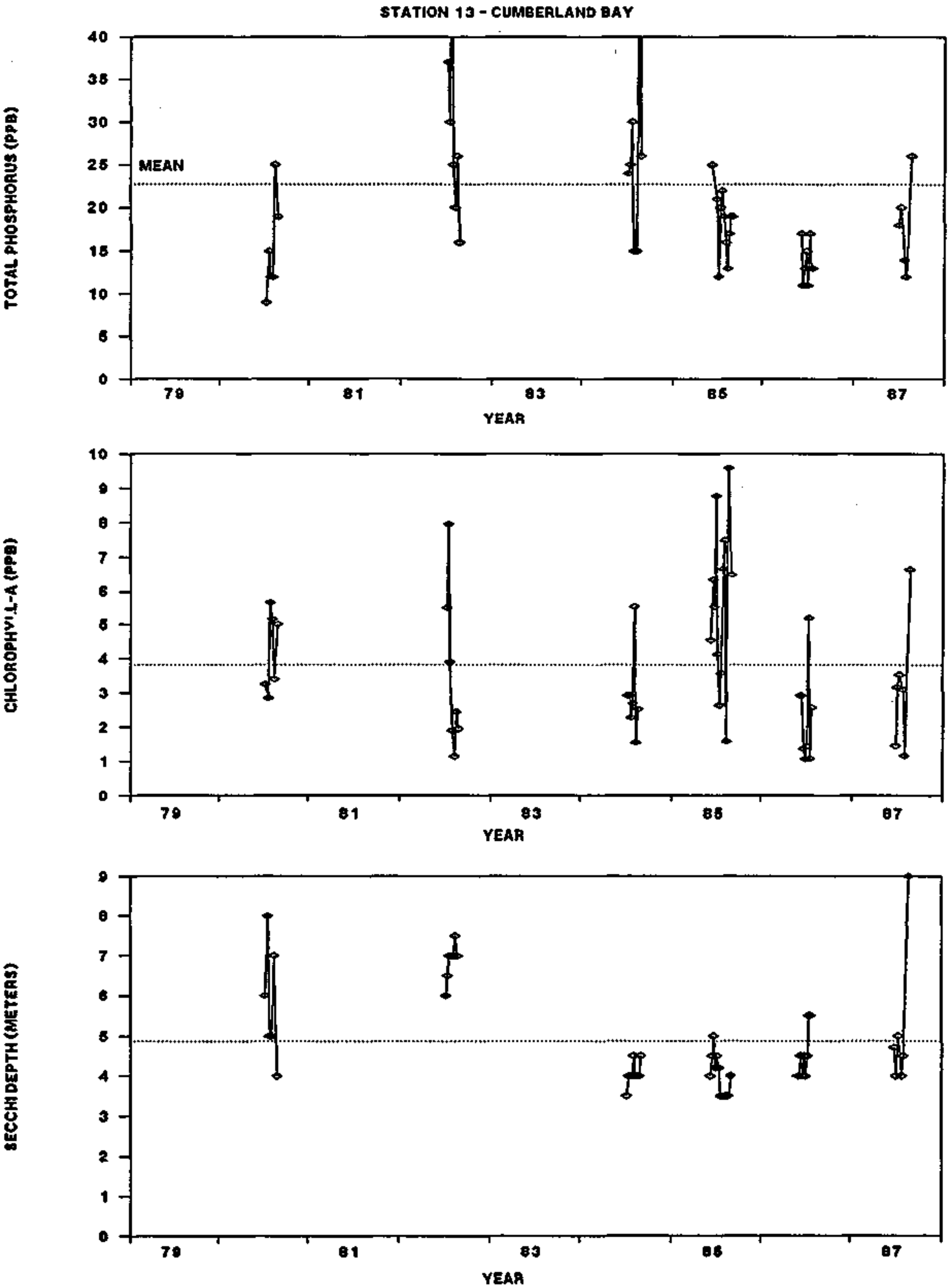


Figure 4
Phosphorus, Chlorophyll-a, and Transparency Time Series
Lay Monitoring Station 14 - Treadwell Bay
(See Figure 1 for Station Location)

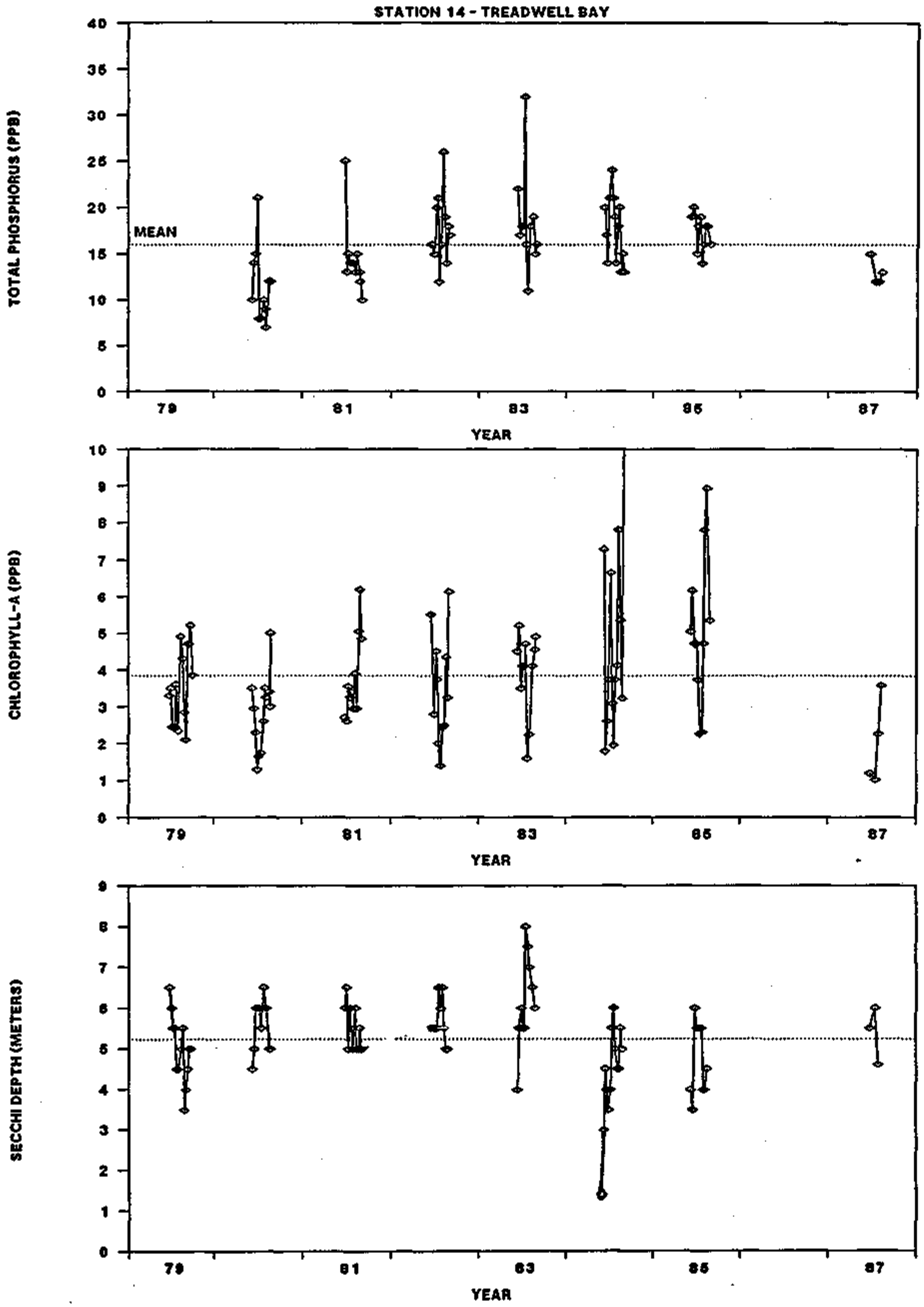


Figure 5
Phosphorus and Chlorophyll-a Time Series
Lay Monitoring Station 15 - The Gut
(See Figure 1 for Station Location)

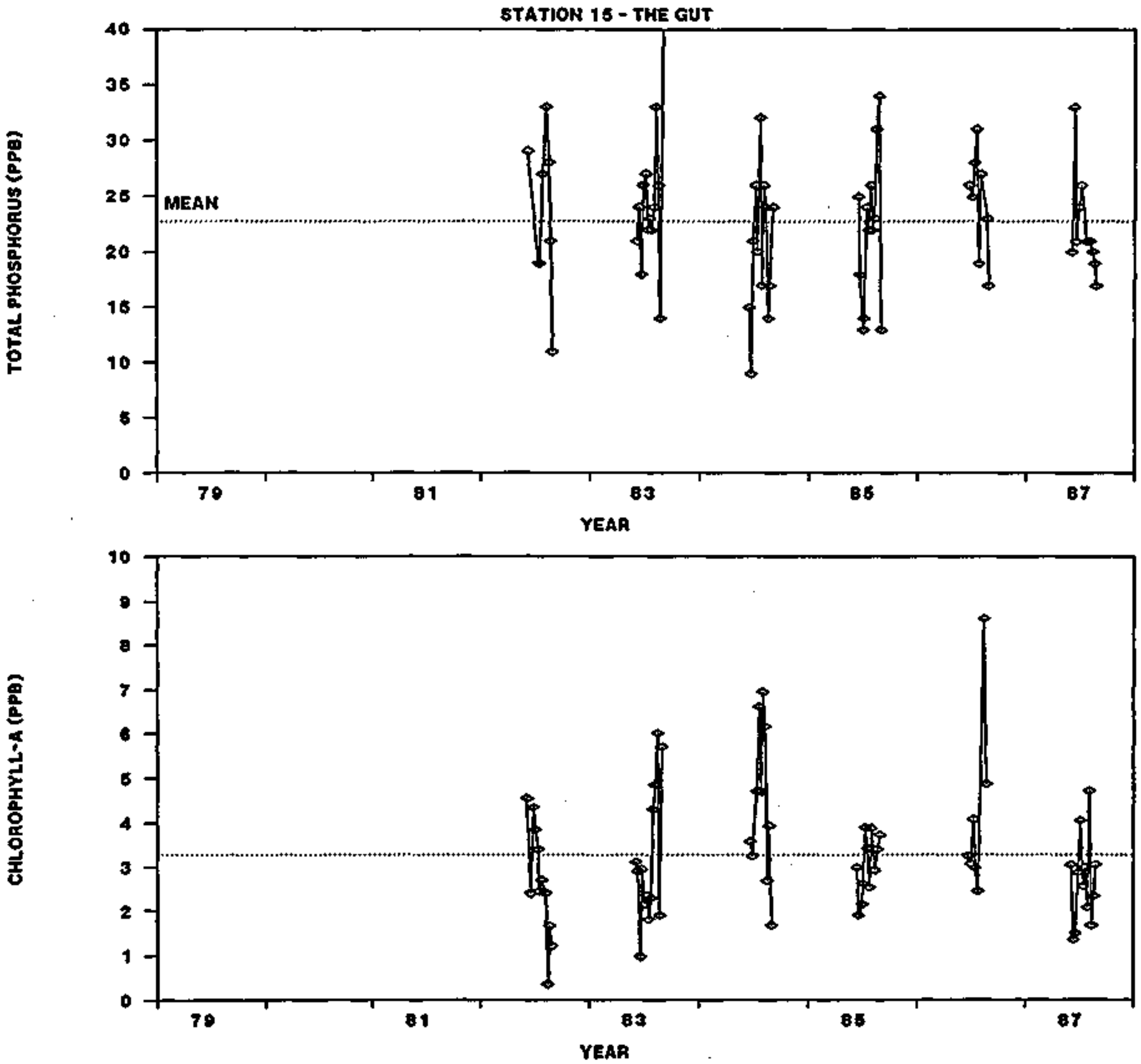


Figure 6
Monthly Unit Runoff and Lake Elevation for Water Years 1976-1987

USGS Monitoring Stations in Lake Champlain Basin
Runoff - Composite of Otter, Winooski, and Lamoille River Gauges

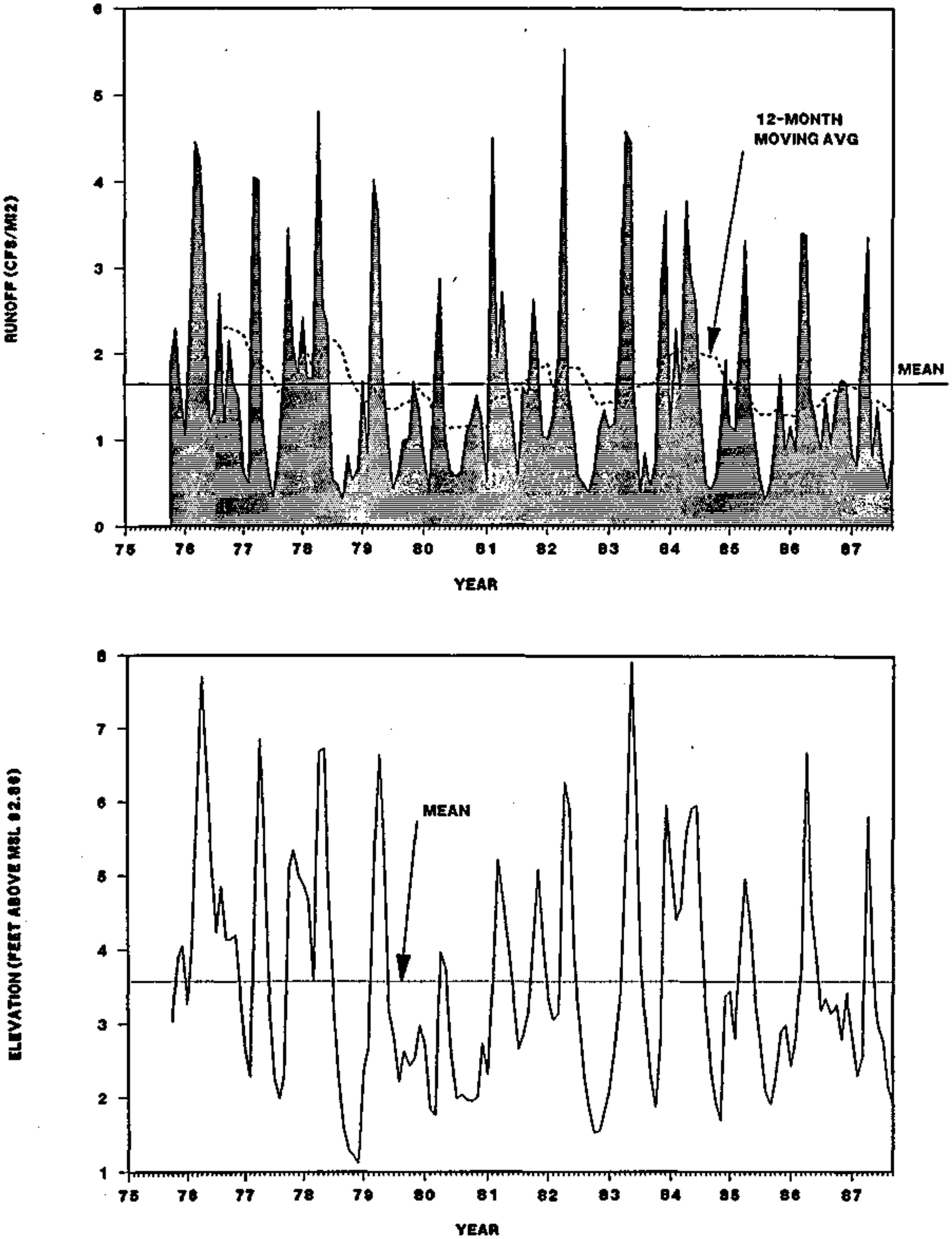


Figure 7
Water Quality Station Map
Aquatec, Inc. (1987)

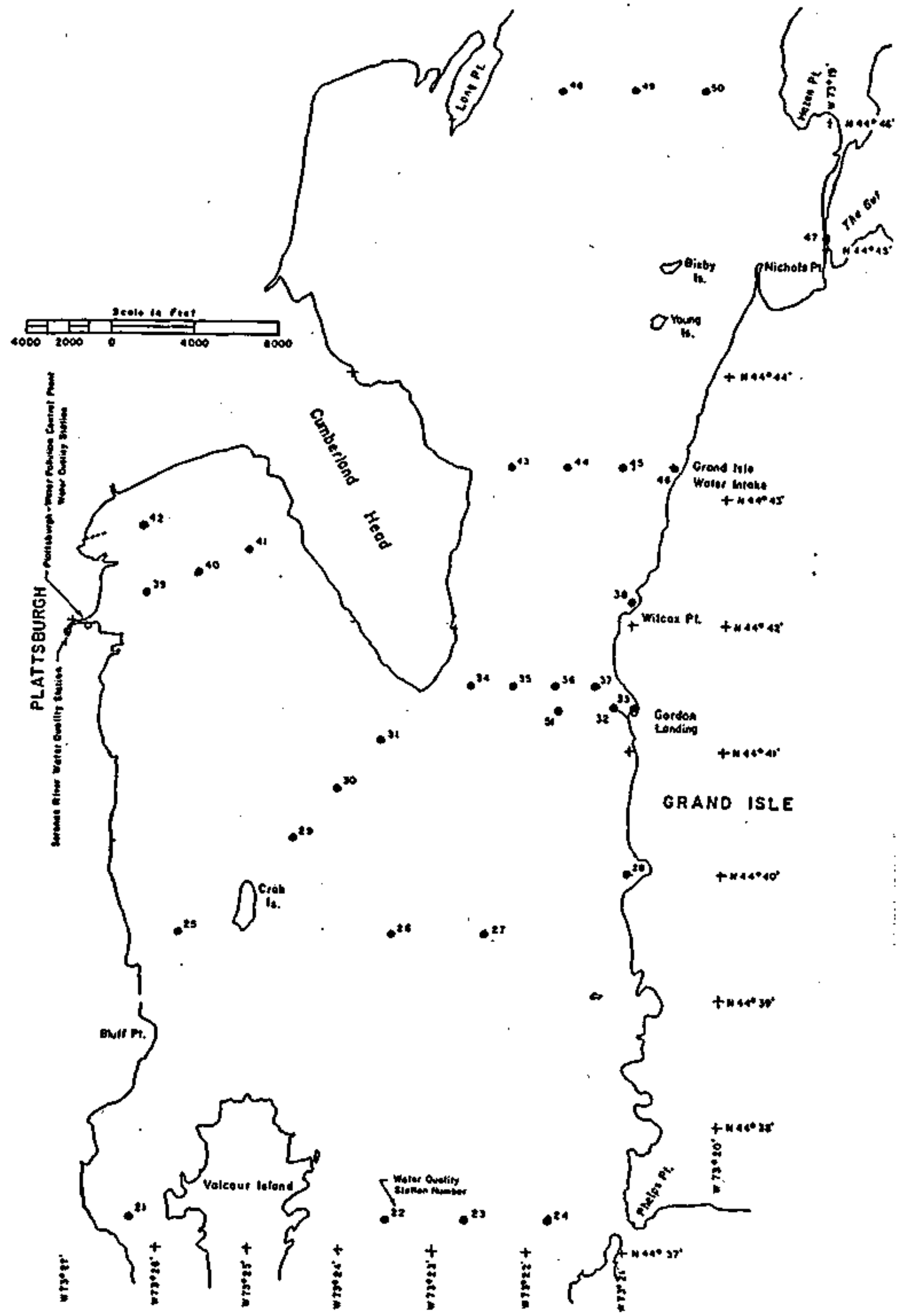


Figure 8
Total Phosphorus and Ortho Phosphorus Measurements in Grand Isle Region
August 1988
(See Figure 7 for Station Locations)

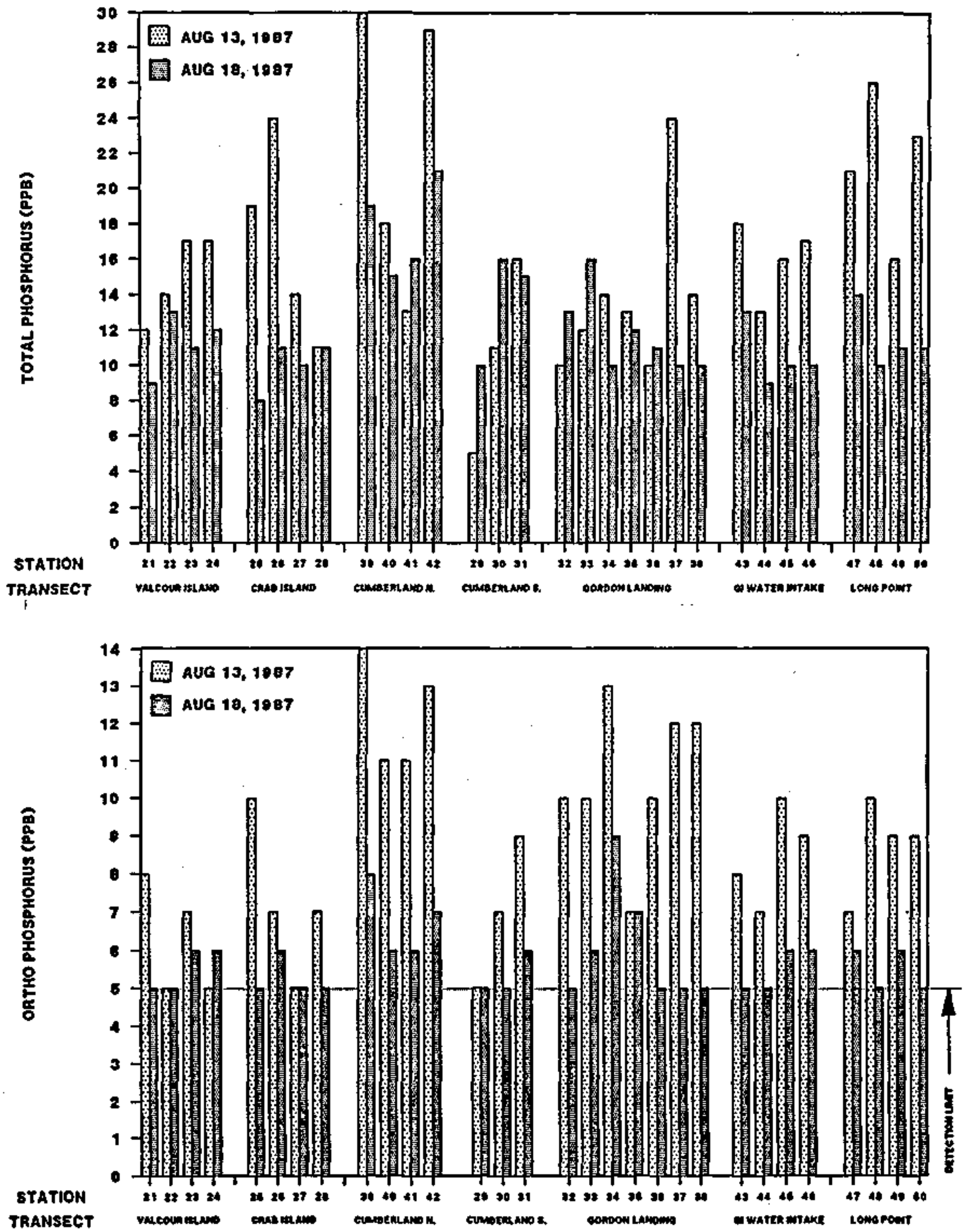


Figure 9
Chlorophyll-a and Transparency Measurements in Grand Isle Region
August 1988
(See Figure 7 for Station Locations)

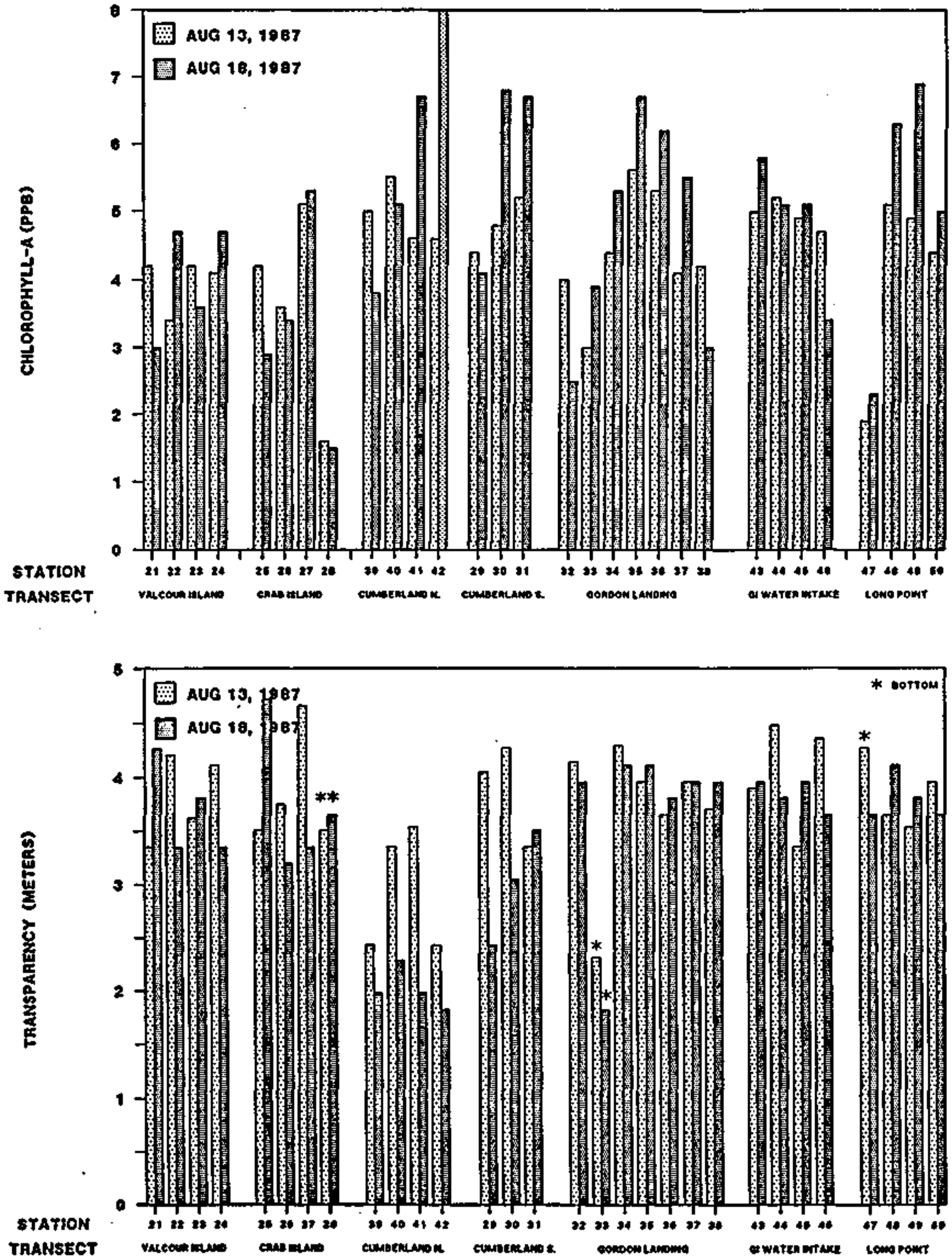


Figure 10
Phosphorus/Chlorophyll-a/Transparency Relationships
Lay Monitoring Station 14 - Treadwell Bay

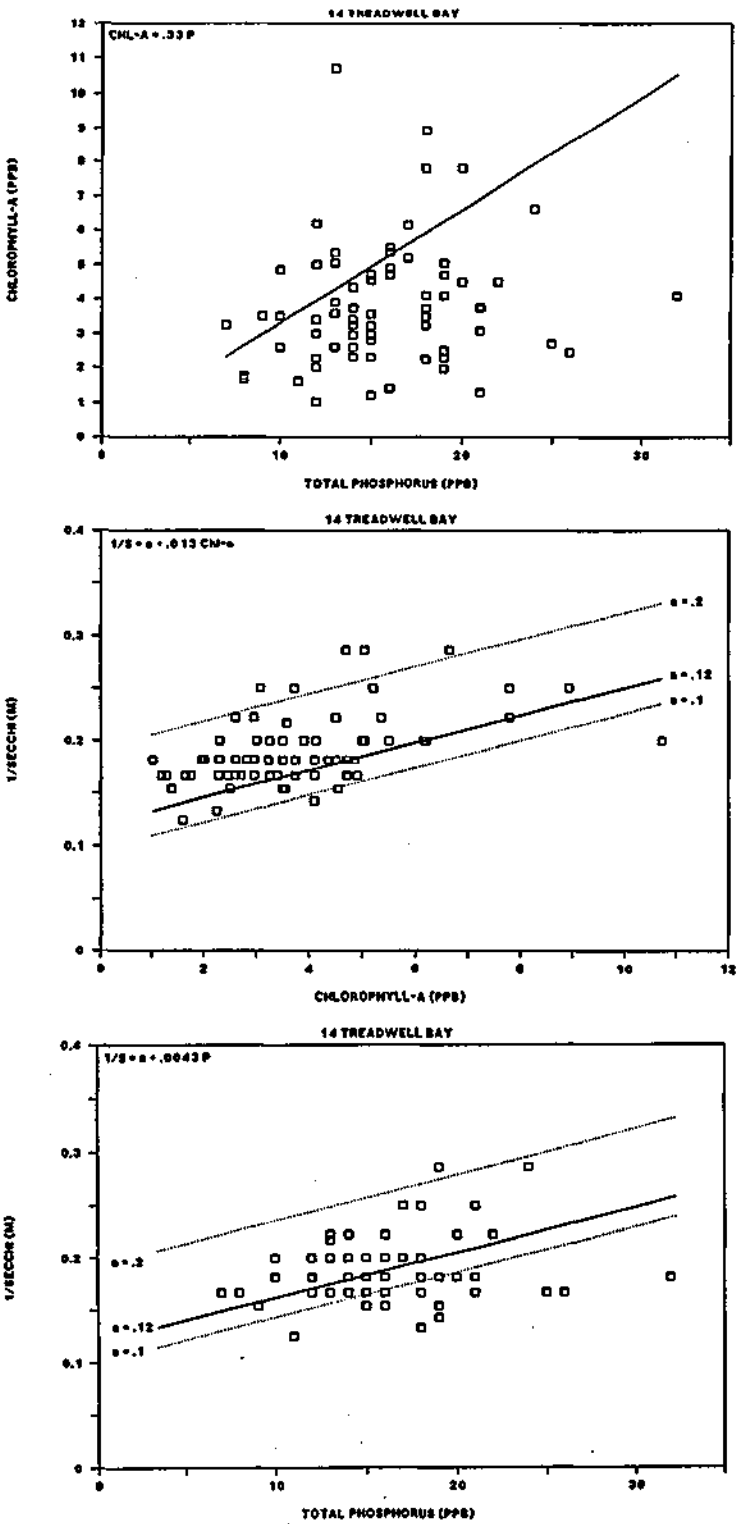


Figure 11
Phosphorus/Chlorophyll-a/Transparency Relationships
August 1987 Surveys (Aquatec Inc., 1987)
Symbol = Station Number (Figure 7)

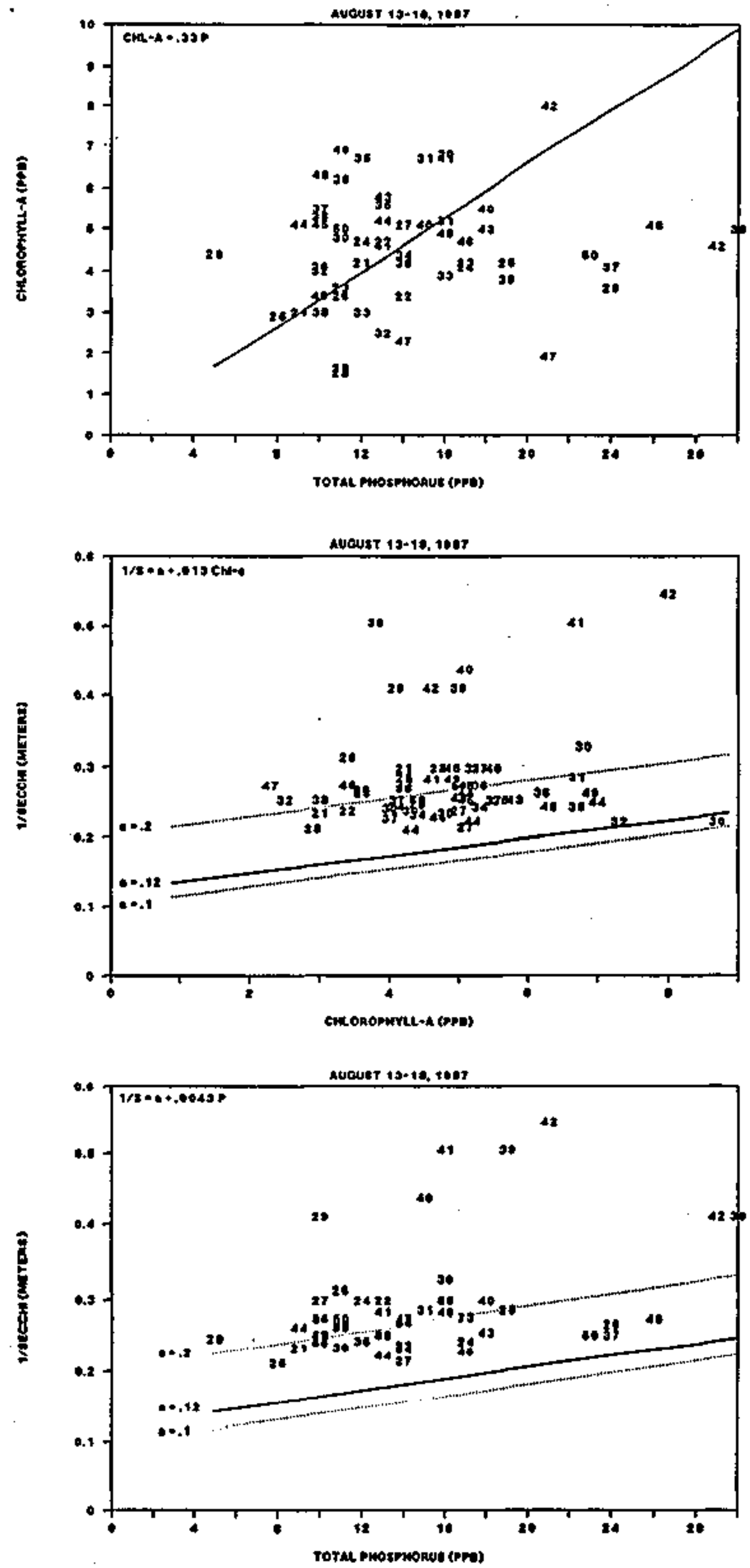
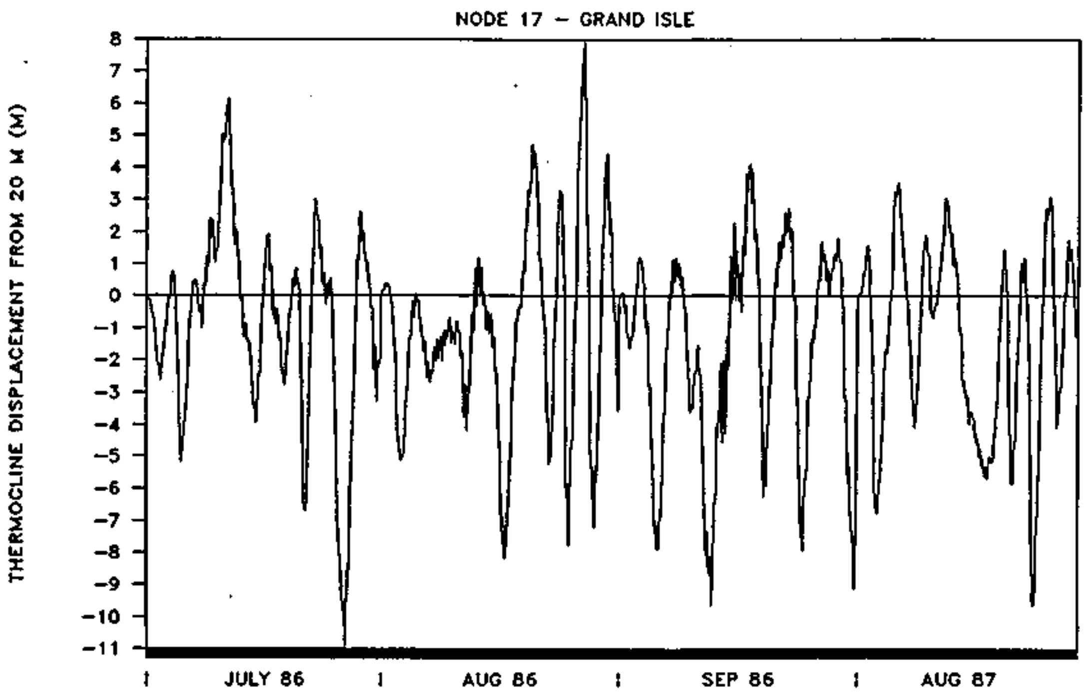


Figure 12
Simulated Thermocline Displacements and Throughflow at Grand Isle
July-September 1986 and August 1987 (Laible, 1988)



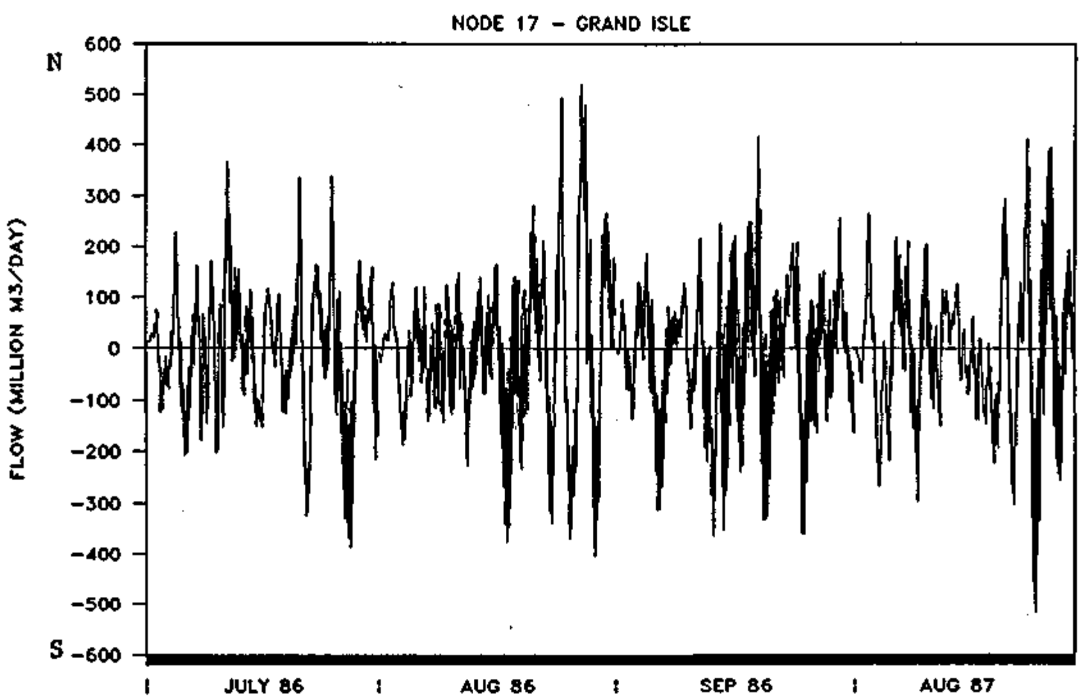


Figure 13
Wind Speed and Direction at Burlington Airport
August 10-21, 1987 Dye Study Period

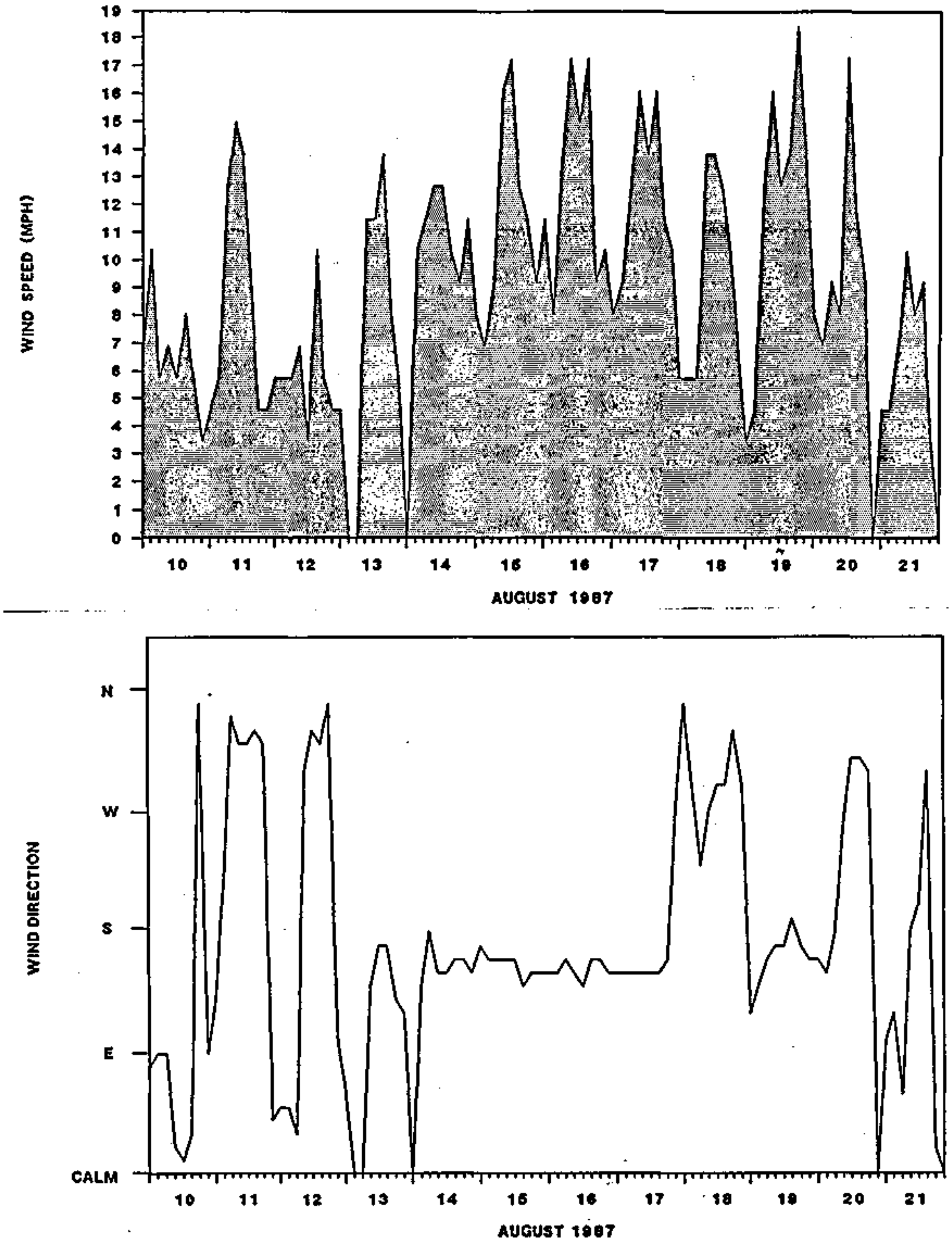


Figure 14
One-Day and Three-Day Moving Average Wind Load Factors
Burlington Airport and Grand Isle
August-September 1987
Wind Load Factor = Stress at Observed Wind Speed / Stress at 8.7 mph

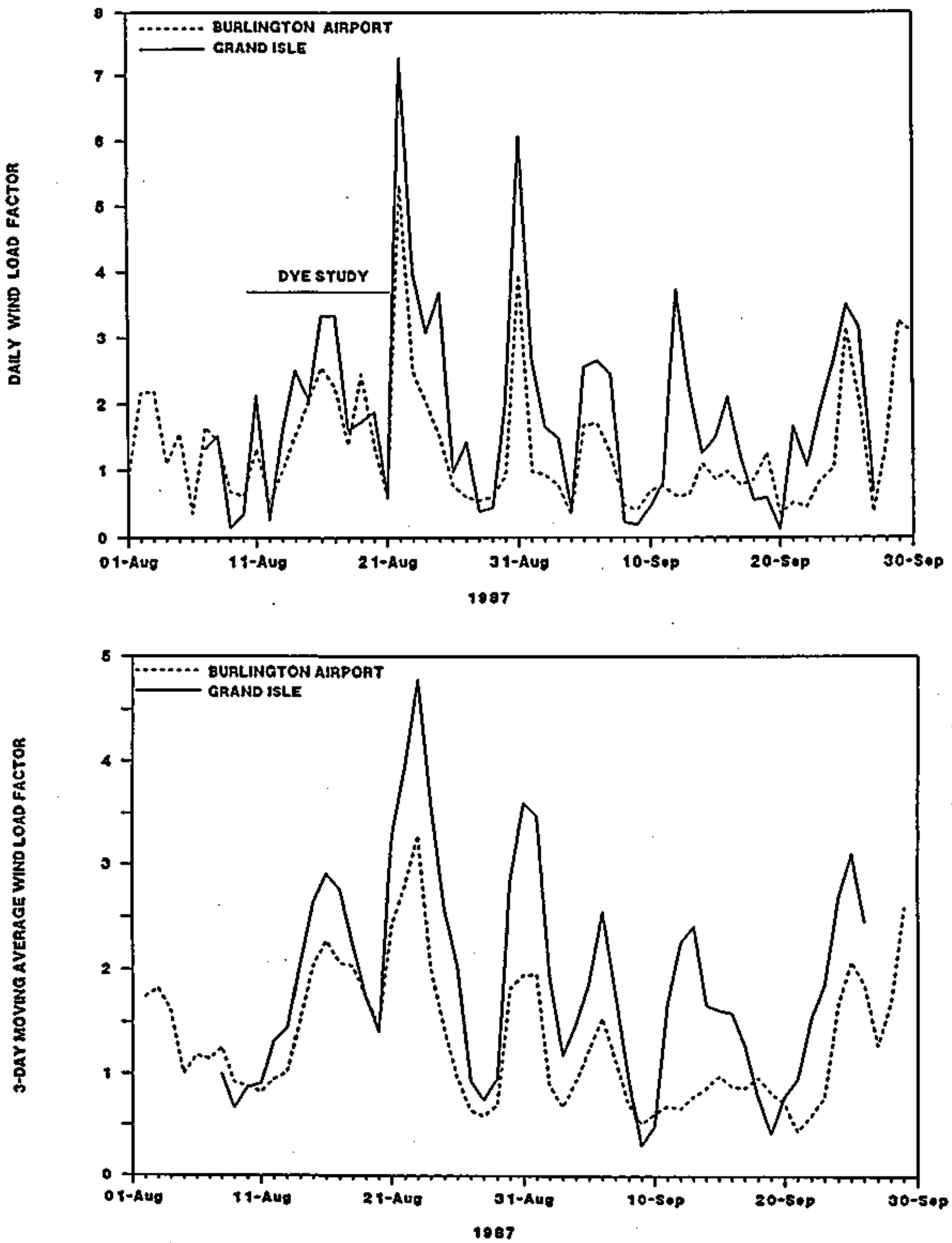


Figure 15
Directional Components of Wind Load
Burlington Airport - 3-hour Observations - August-September 1987

Wind Load Factor = Stress at Observed Wind Speed / Stress at 8.7 mph
"N" = Wind Load Oriented Towards North

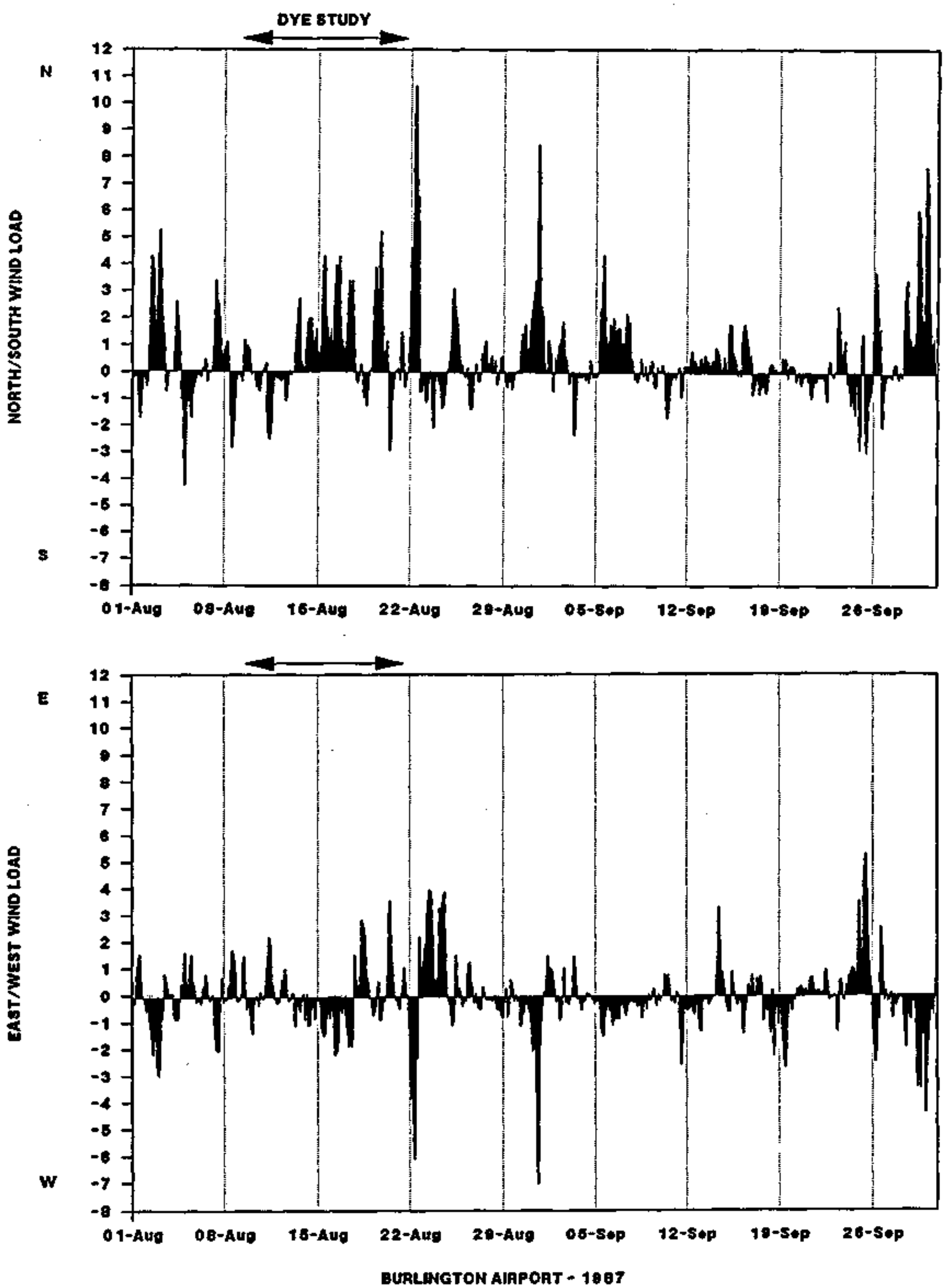


Figure 16
Dye Plumes - August 10-21, 1987

Shaded Area = .25 PPB Dye Contour
Aquatec, Inc. (1987)

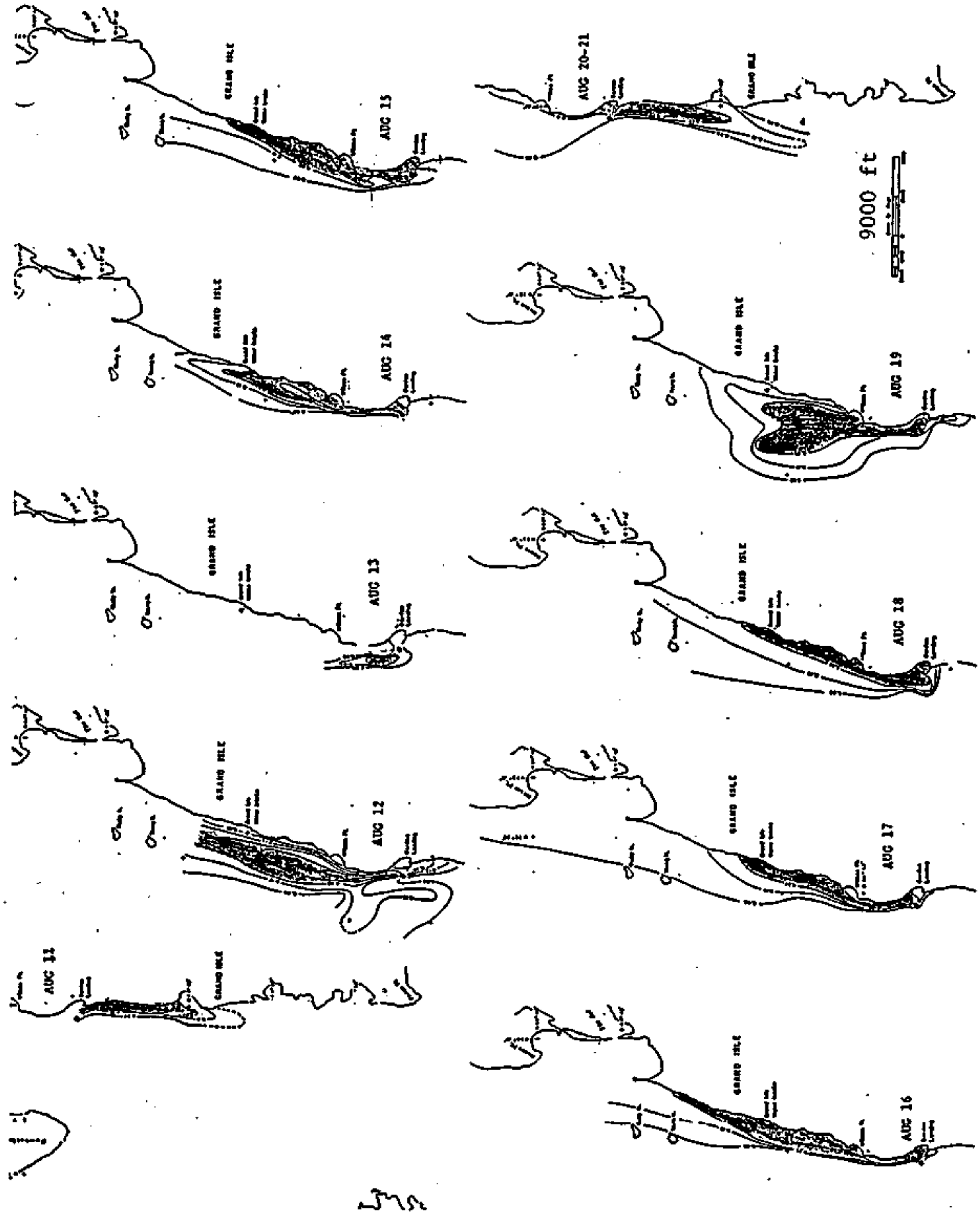
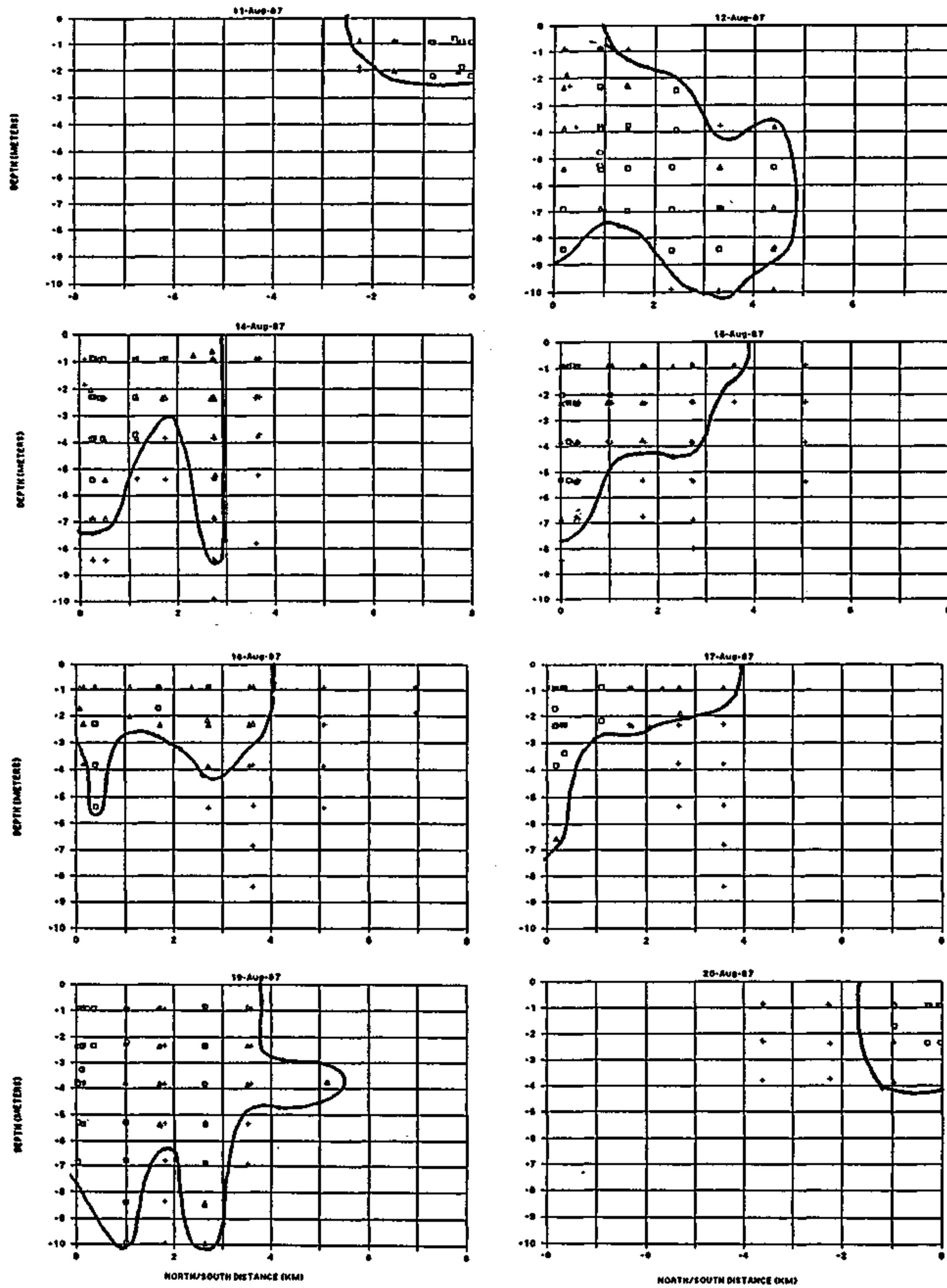


Figure I7
Cross-Sections of Dye Plume on Various Days
Y = Depth (m), X = Distance N or S of Release Point (km)
Contour = .25 ppb



○ 0.5 + 0.1 ▲ 0.25

Figure 18
Dye Plume Orientation vs. North/South Wind Loads at Grand Isle and Burlington Airport

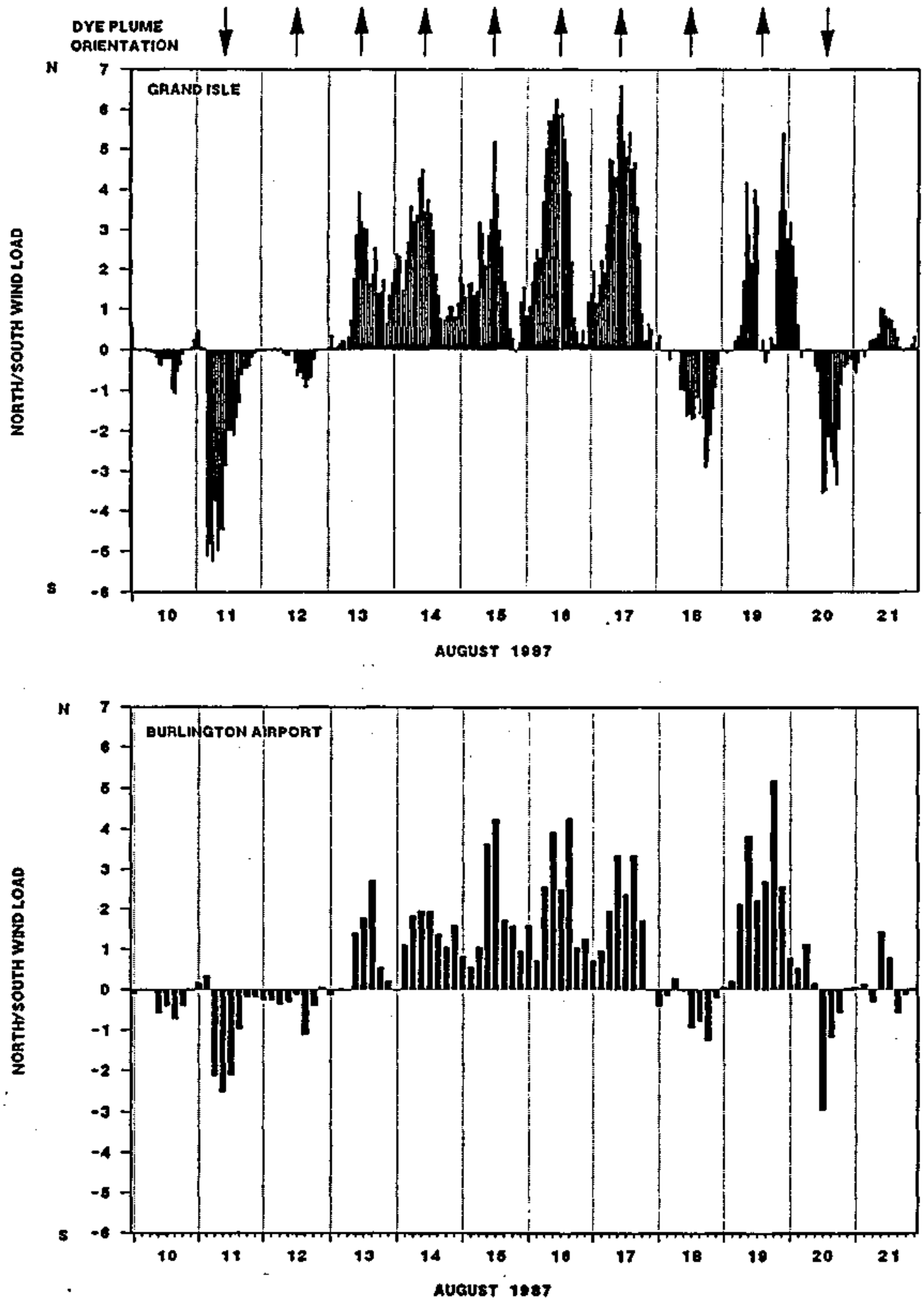


Figure 19
Dye Plume Orientation, Seiche Flows, and North/South Wind Load
During Dye Study Period

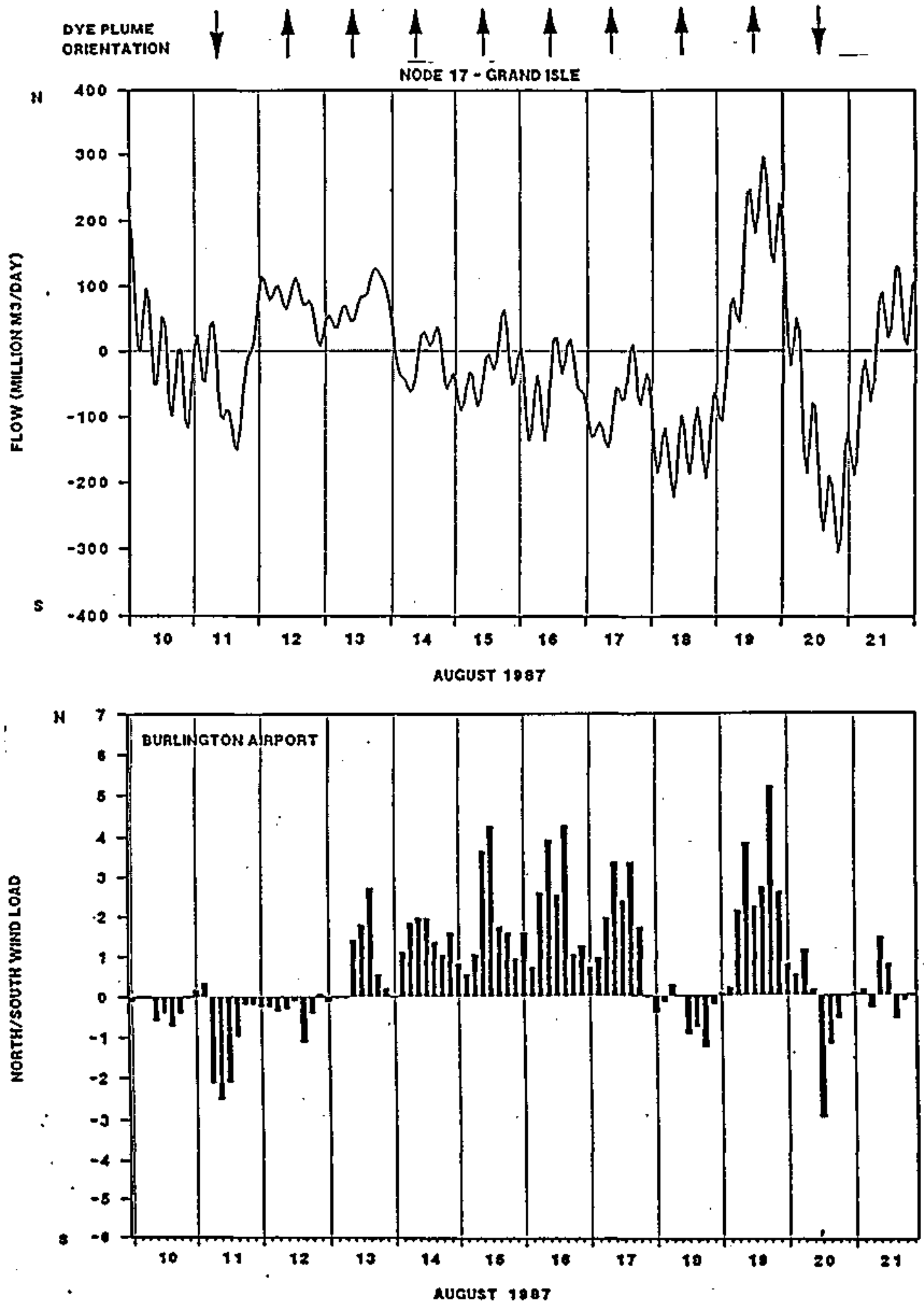


Figure 20
Transport Model Region

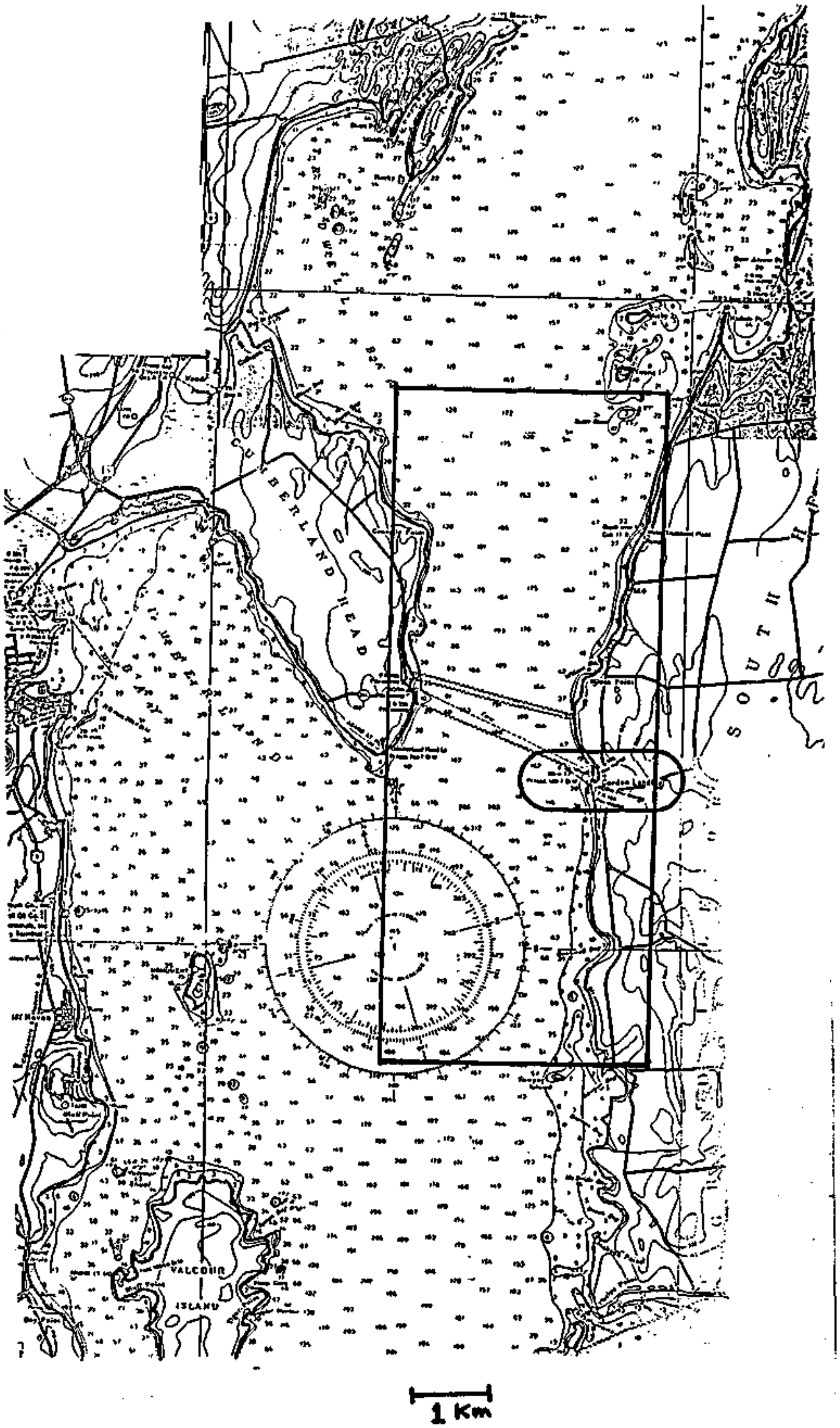


Figure 21
Transport Model Grid

Lake Region Shown In Figure 20
Column Dimension = Row Dimension = 200 meters

```
     1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21
   +---------------------------------------------------------------+
  1| Treadwell Bay                            Young Island         |
  2|                                                               |
  3|                                                               |
  4|                                                               |
  5|                                                            xxx|
  6|                                                         xxxxxx|
  7|                                                         xxxxxx|
  8|                                                         xxxxxx|
  9|                                                      xxxxxxxxx|
 10|                                                      xxxxxxxxx|
 11|                                                      xxxxxxxxx|
 12|xxxxxx Gravelly Point              GI Water Intake xxxxxxxxxxxx|
 13|xxxxxx                                             xxxxxxxxxxxx|
 14|xxxxxx                                             xxxxxxxxxxxx|
 15|xxxxxx                                          xxxxxxxxxxxxxxx|
 16|xxxxxx                                          xxxxxxxxxxxxxxx|
 17|xxxxxx                                          xxxxxxxxxxxxxxx|
 18|xxxxxx                                          xxxxxxxxxxxxxxx|
 19|xxx                                             xxxxxxxxxxxxxxx|
 20|xxx                                          xxxxxxxxxxxxxxxxxx|
 21|xxx                                          xxxxxxxxxxxxxxxxxx|
 22|xxx                                          xxxxxxxxxxxxxxxxxx|
 23|xxx                          Wilcox Pt    xxxxxxxxxxxxxxxxxxxxx|
 24|xxx                                    xxxxxxxxxxxxxxxxxxxxxxxx|
 25|xxxxxx                                 xxxxxxxxx G R A N D xxxx|
 26|xxx                                    xxxxxxxxxx I S L E xxxxx|
 27| Cumberland Head                       xxxxxxxxxxxxxxxxxxxxxxxx|
 28|                                       xxxxxxxxxxxxxxxxxxxxxxxx|
 29|                                          xxxxxxxxxxxxxxxxxxxxx|
 30|              Dye Release Point --->  *   xx Gordon Landing xxx|
 31|                                          xxxxxxxxxxxxxxxxxxxxx|
 32|                                          xxxxxxxxxxxxxxxxxxxxx|
 33|                                          xxxxxxxxxxxxxxxxxxxxx|
 34|                                          xxxxxxxxxxxxxxxxxxxxx|
 35|                                          xxxxxxxxxxxxxxxxxxxxx|
 36|                                          xxxxxxxxxxxxxxxxxxxxx|
 37|                                          xxxxxxxxxxxxxxxxxxxxx|
 38|                                          xxxxxxxxxxxxxxxxxxxxx|
 39|                                          xxxxxxxxxxxxxxxxxxxxx|
 40|                                          xxxxxxxxxxxxxxxxxxxxx|
 41|                                          xxxxxxxxxxxxxxxxxxxxx|
 42|                          Rockwell Bay       xxxxxxxxxxxxxxxxxx|
 43|                                             xxxxxxxxxxxxxxxxxx|
 44|                                          xxxxxxxxxxxxxxxxxxxxx|
 45|                                          xxxxxxxxxxxxxxxxxxxxx|
 46|                                          xxxxxxxxxxxxxxxxxxxxx|
 47|                                          xxxxxxxxxxxxxxxxxxxxx|
 48|                                          xxxxxxxxxxxxxxxxxxxxx|
 49|                                          xxxxxxxxxxxxxxxxxxxxx|
 50|                                          xxxxxxxxxxxxxxxxxxxxx|
   +---------------------------------------------------------------+
```

Figure 22
Cell-Maximum Dye Concentrations by Day
August 10-13
Digit = Dye Concentration (ppb) x 10

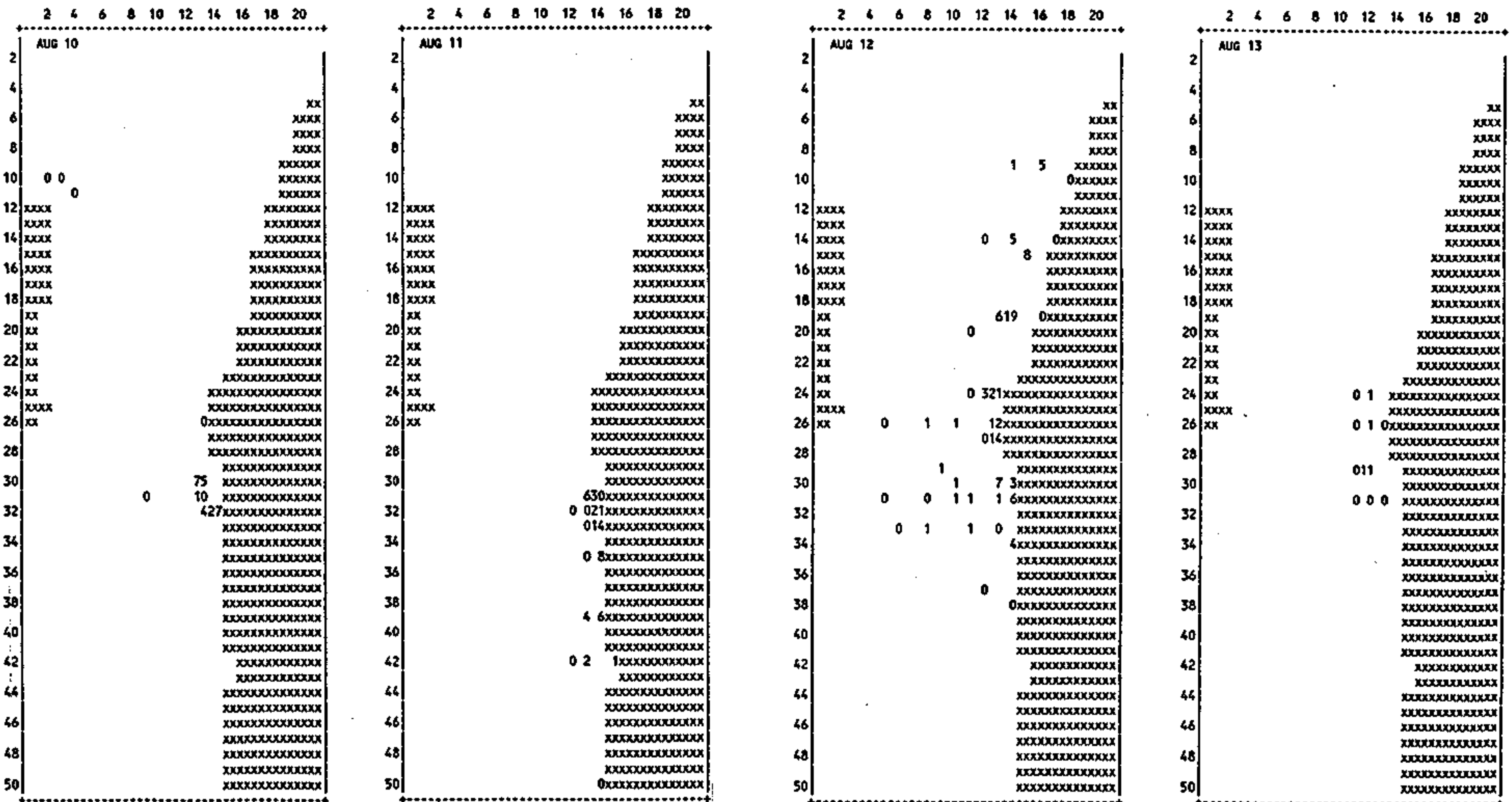


Figure 23
Cell-Maximum Dye Concentrations by Day
August 14-17
Digit = Dye Concentration (ppb) x 10

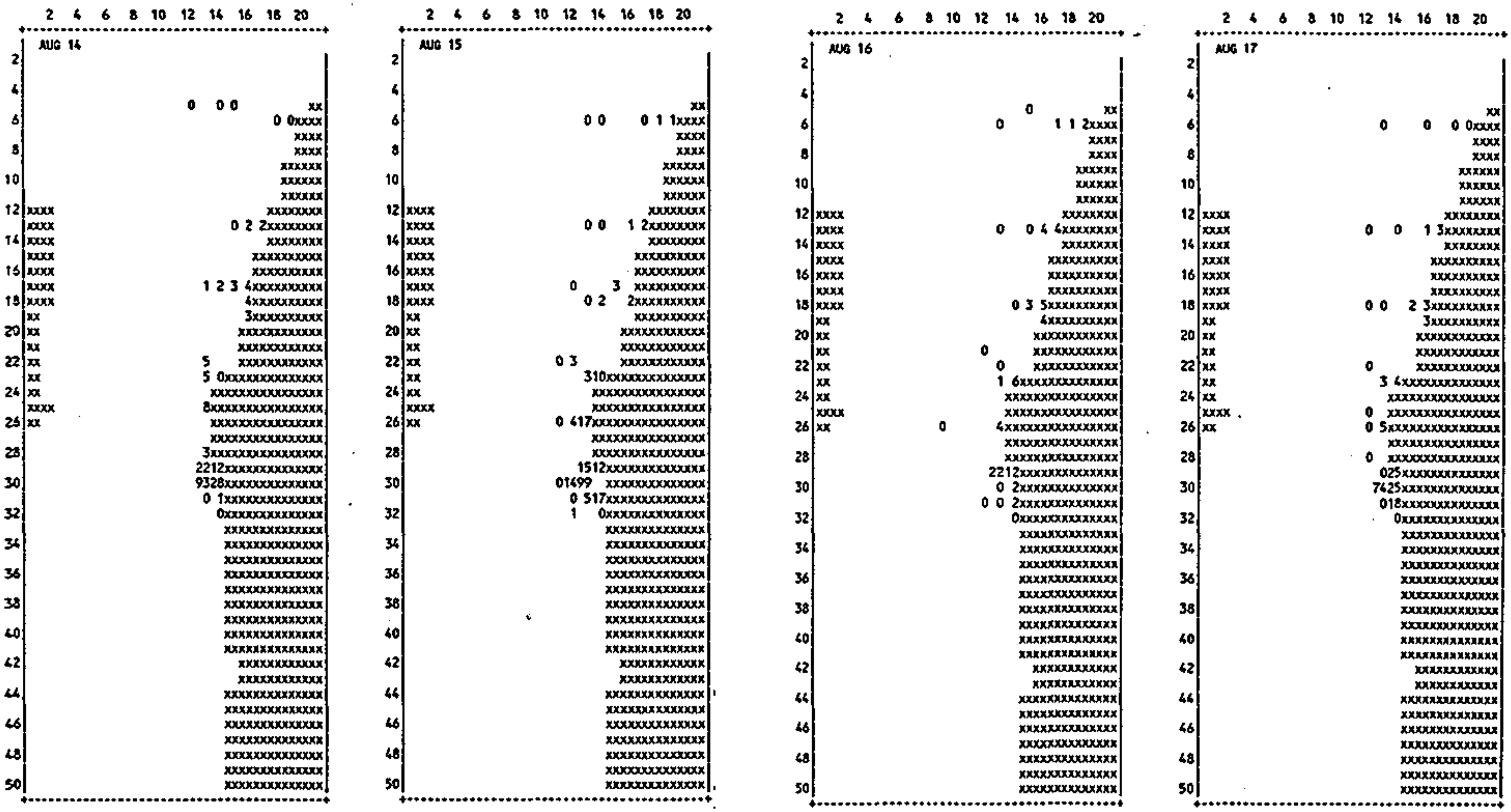


Figure 24
Cell-Maximum Dye Concentrations by Day
August 18-20
Digit = Dye Concentration (ppb) x 10

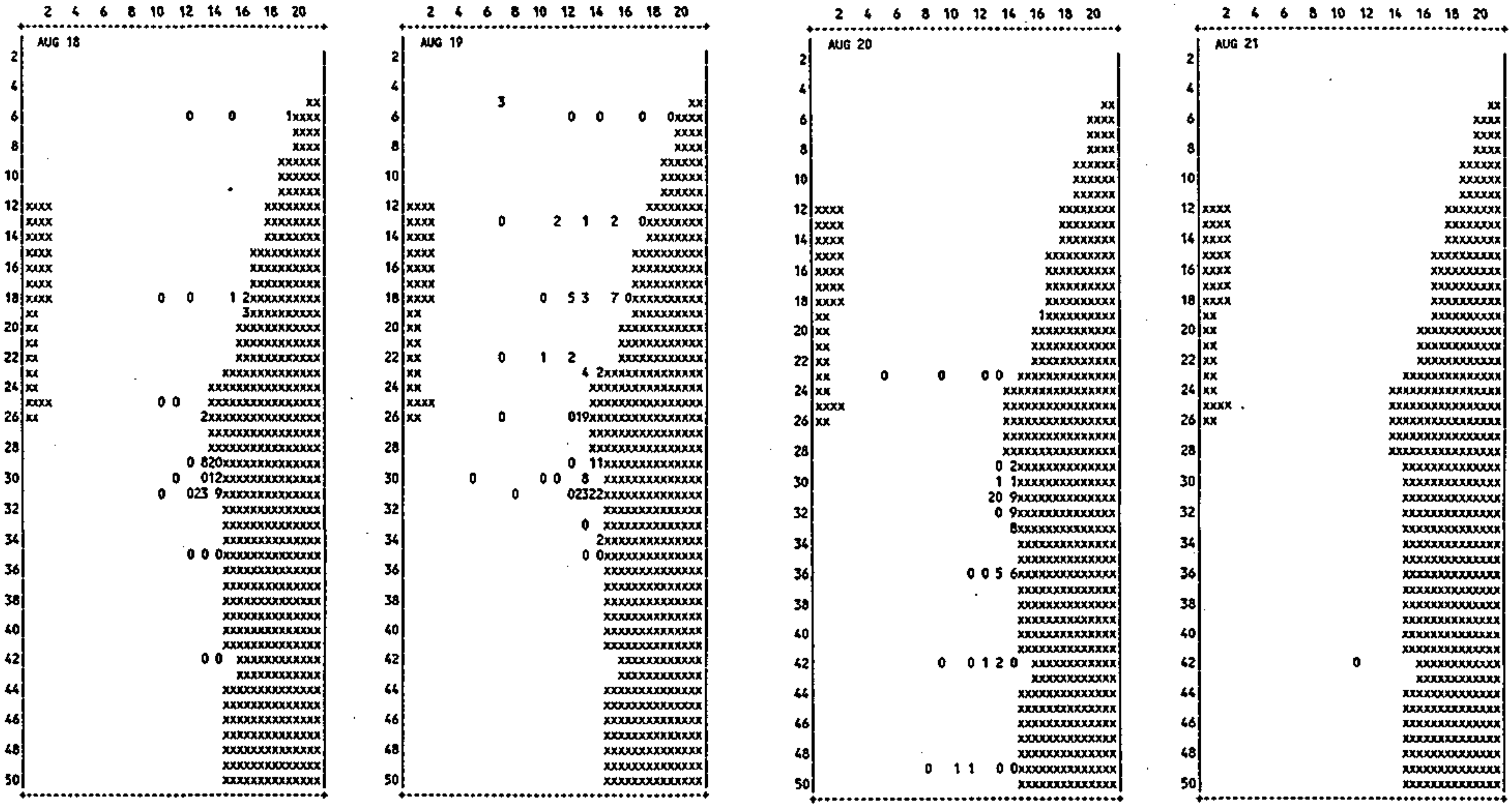


Figure 25
Simulated Dye Concentrations - August 14-17 Conditions
Southeast Wind, Load Factor = 1.87
Z = Thermocline Depth (m), Q = Throughflow (10^6 m^3/day)
Digit = Conc. (ppb x 10), Contours = .2 and .5 ppb

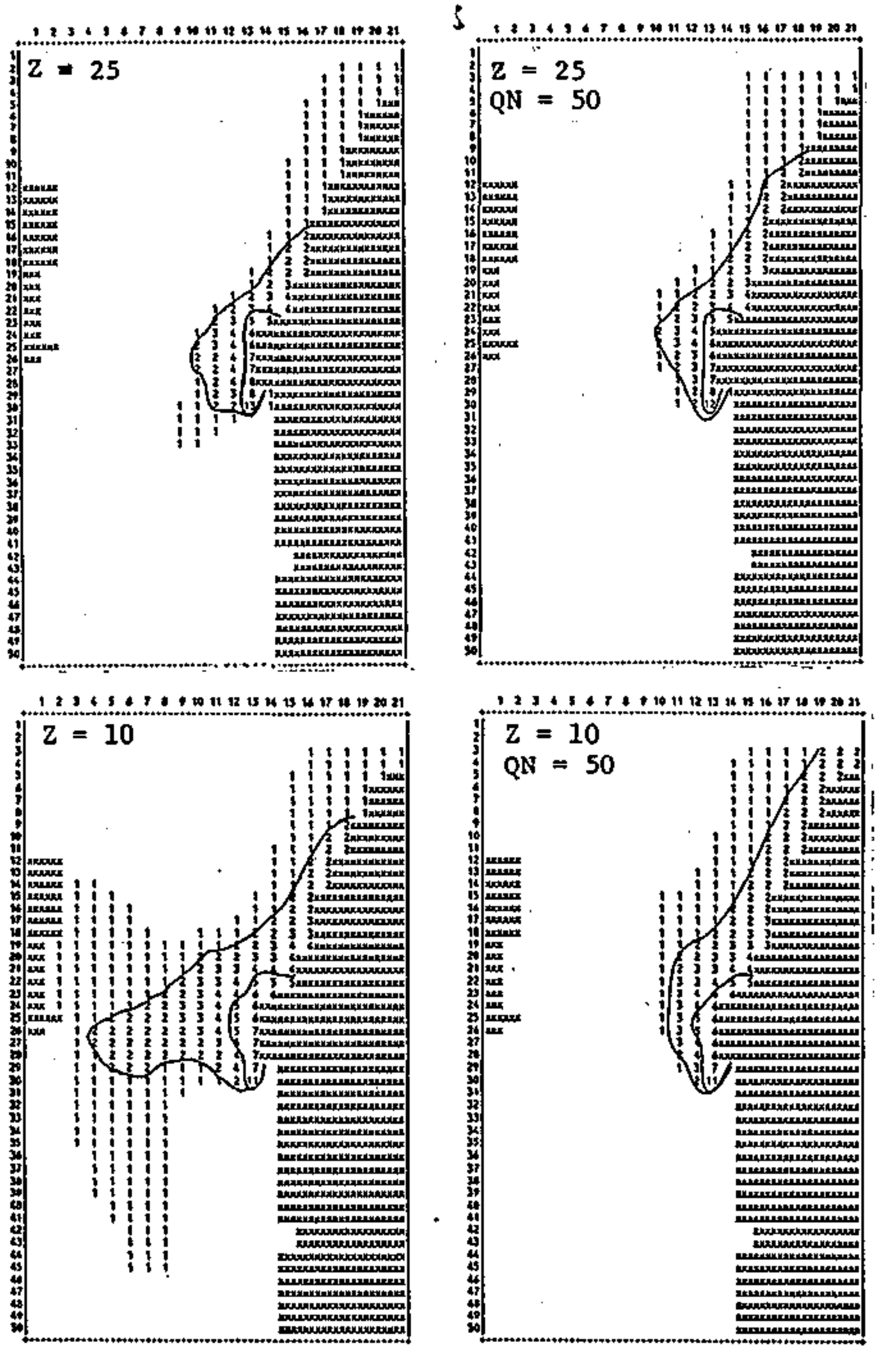


Figure 26
Simulated Dye Concentrations - August 20 Conditions
Northwest Wind, Load Factor = 1.37
Z = Thermocline Depth (m), Q = Throughflow (10^6 m^3/day)
Digit = Conc. (ppb x 10), Contours = .2 and .5 ppb

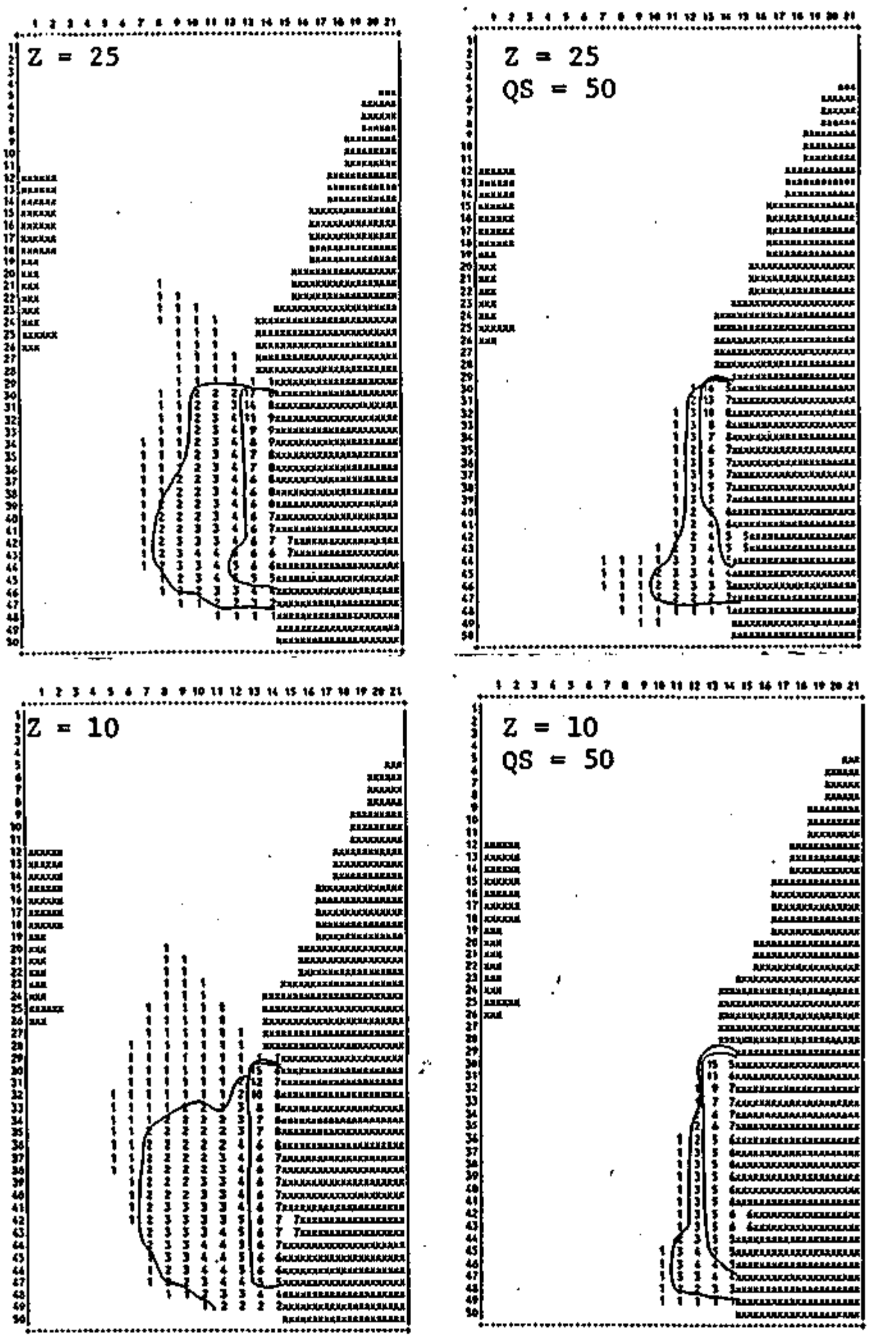
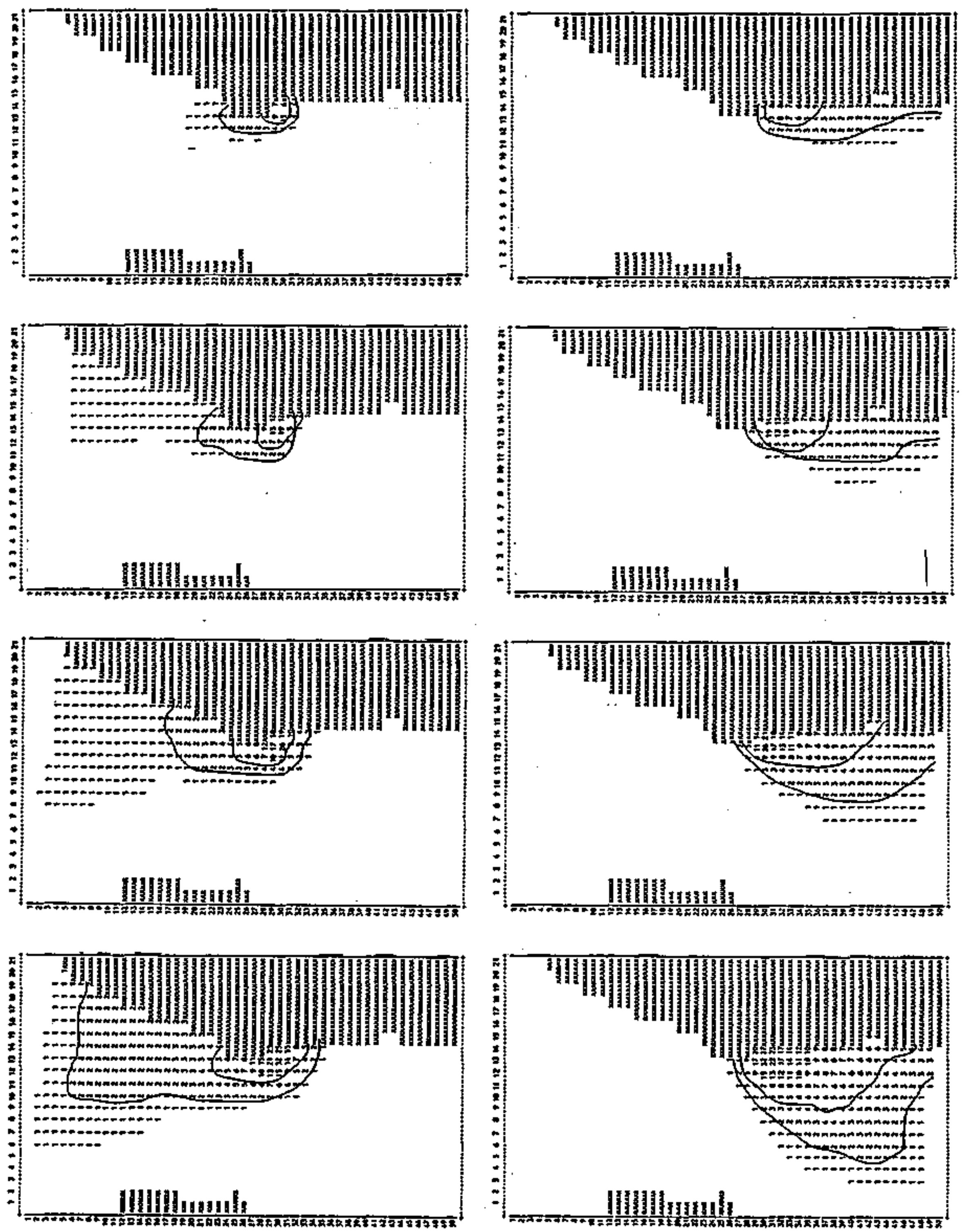


Figure 27
Simulated Dye Plumes Driven by Seiche Flows
Q - Throughflow (10^6 m^3/day), S - South, N - North
Digits - Dye Conc. (ppb x 10), Contours - .2 and .5 ppb



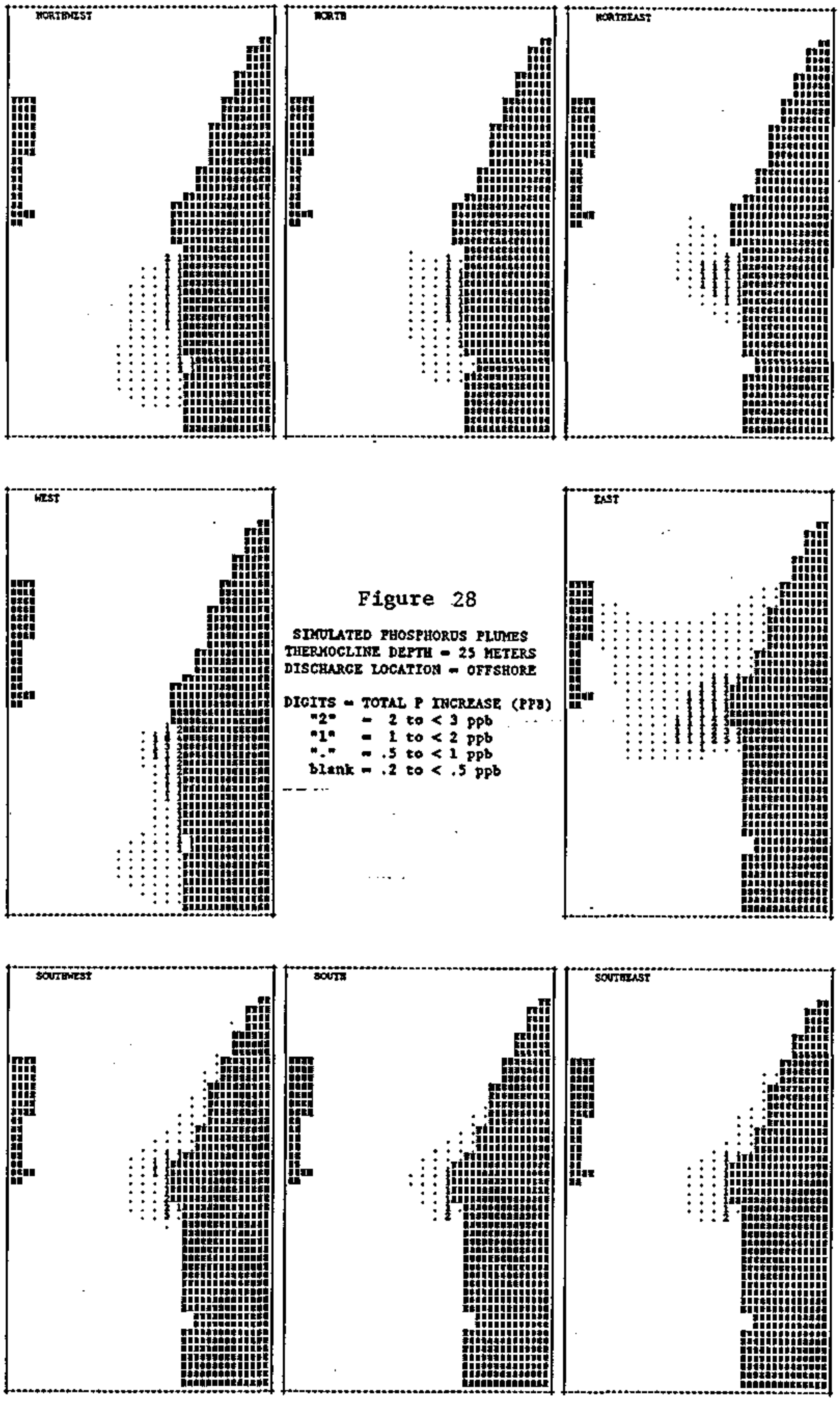


Figure 28

SIMULATED PHOSPHORUS PLUMES
THERMOCLINE DEPTH = 25 METERS
DISCHARGE LOCATION = OFFSHORE

DIGITS = TOTAL P INCREASE (PPB)
"2" = 2 to < 3 ppb
"1" = 1 to < 2 ppb
"." = .5 to < 1 ppb
blank = .2 to < .5 ppb

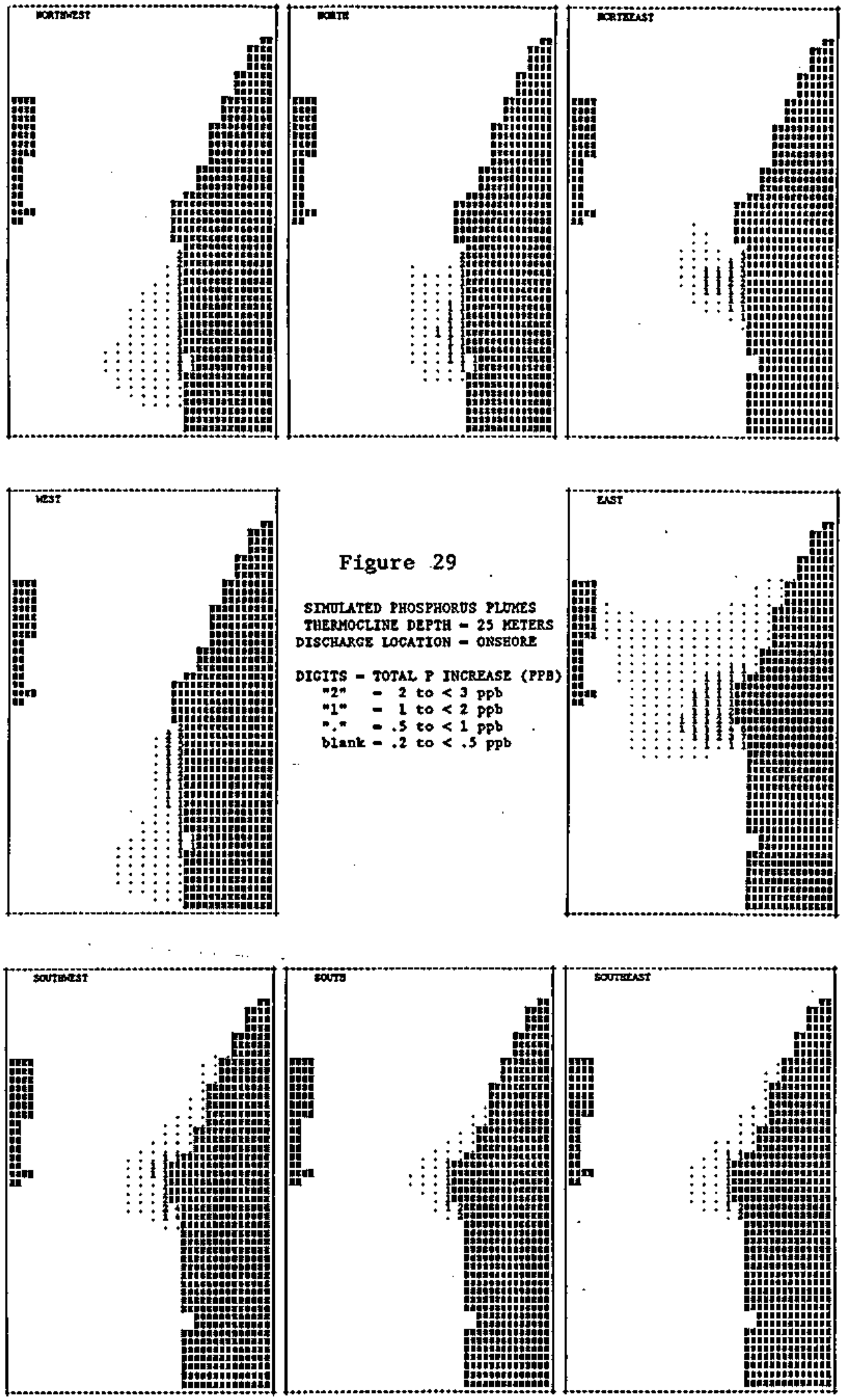


Figure 29

SIMULATED PHOSPHORUS PLUMES
THERMOCLINE DEPTH = 25 METERS
DISCHARGE LOCATION = ONSHORE

DIGITS = TOTAL P INCREASE (PPB)
"2" = 2 to < 3 ppb
"1" = 1 to < 2 ppb
"." = .5 to < 1 ppb
blank = .2 to < .5 ppb

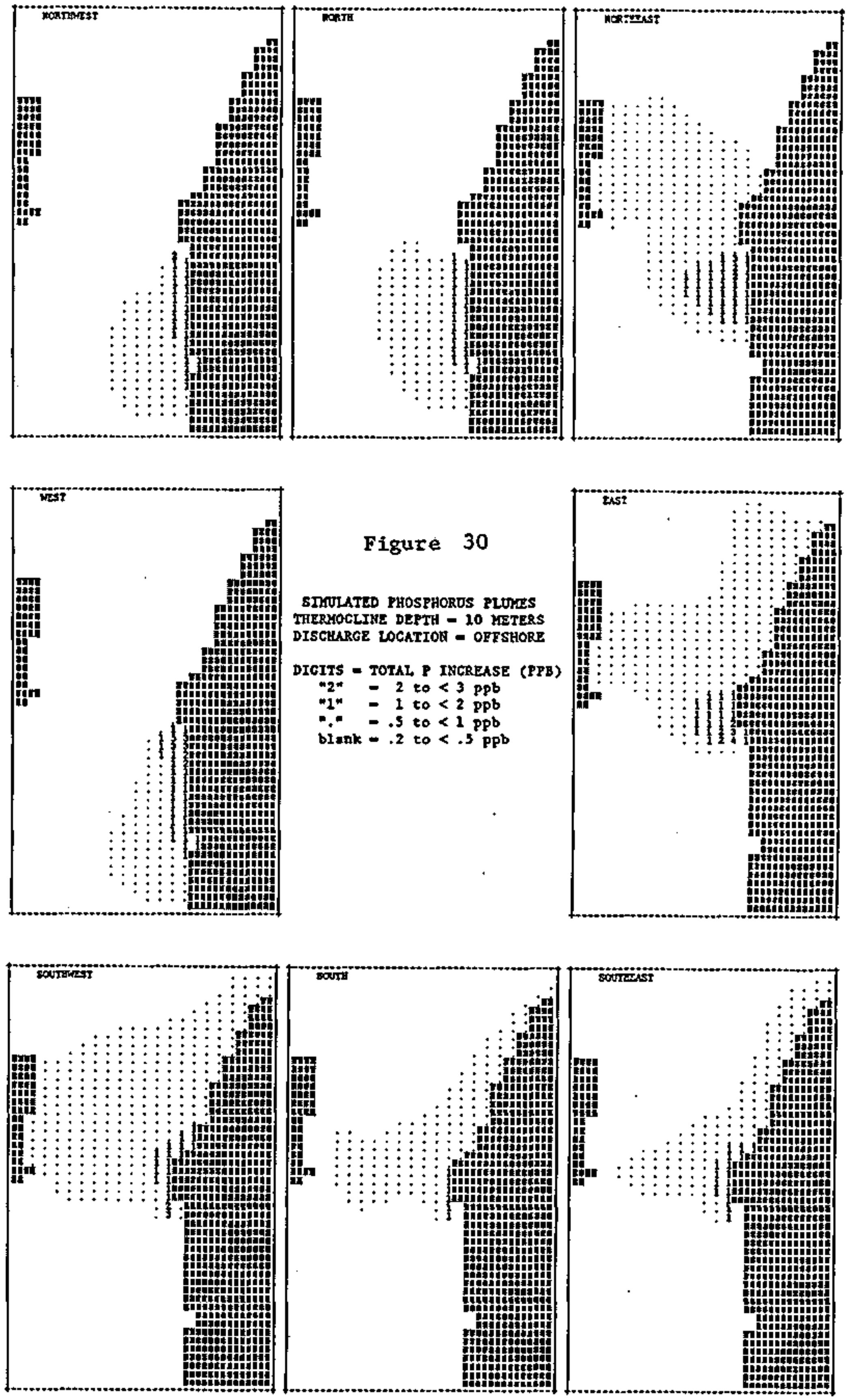


Figure 30

SIMULATED PHOSPHORUS PLUMES
THERMOCLINE DEPTH = 10 METERS
DISCHARGE LOCATION = OFFSHORE

DIGITS = TOTAL P INCREASE (PPB)
"2" = 2 to < 3 ppb
"1" = 1 to < 2 ppb
"." = .5 to < 1 ppb
blank = .2 to < .5 ppb

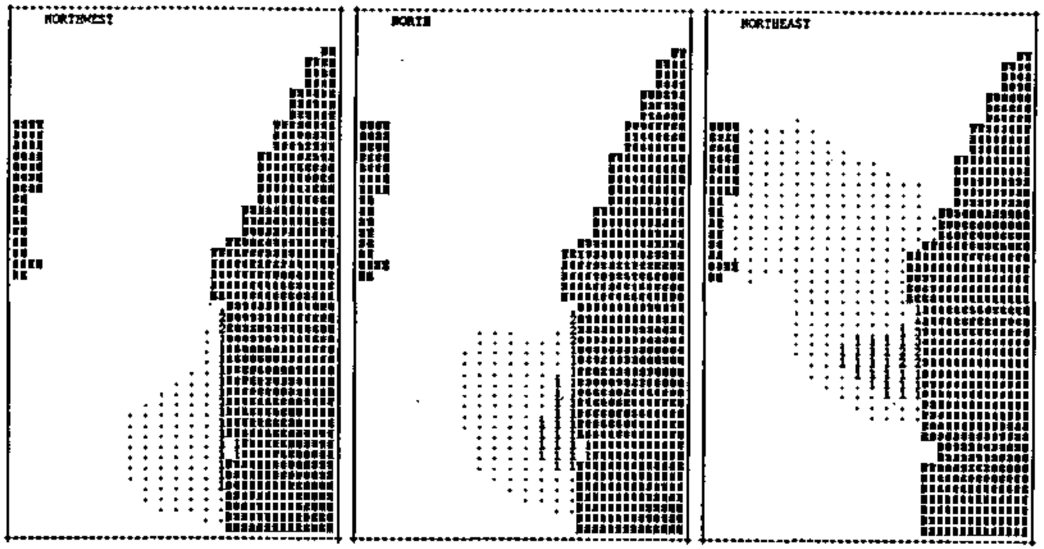
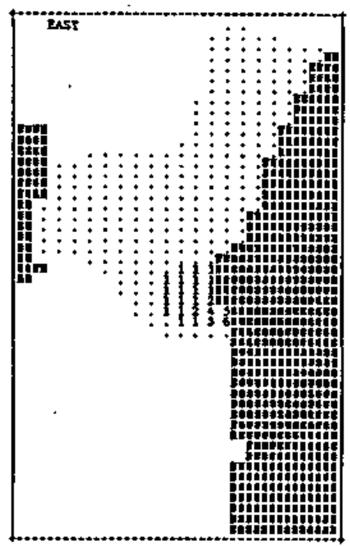


Figure 31

SIMULATED PHOSPHORUS PLUMES
THERMOCLINE DEPTH = 10 METERS
DISCHARGE LOCATION = ONSHORE

DIGITS = TOTAL P INCREASE (PPB)
"2" = 2 to < 3 ppb
"1" = 1 to < 2 ppb
"." = .5 to < 1 ppb
blank = .2 to < .5 ppb



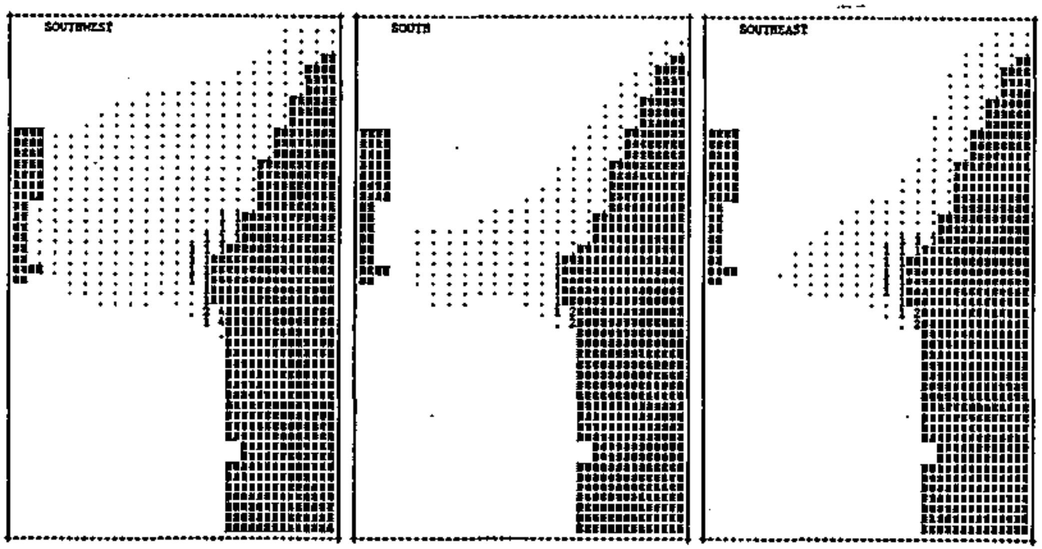


Figure 32
Phosphorus Increases Attributed to Offshore Hatchery Discharge
Based upon Mean Seiche Flows
Digits = Phosphorus Increase (ppb x 10), Contours = .5, 1, 2 ppb
Flow Directions = North, South, Both

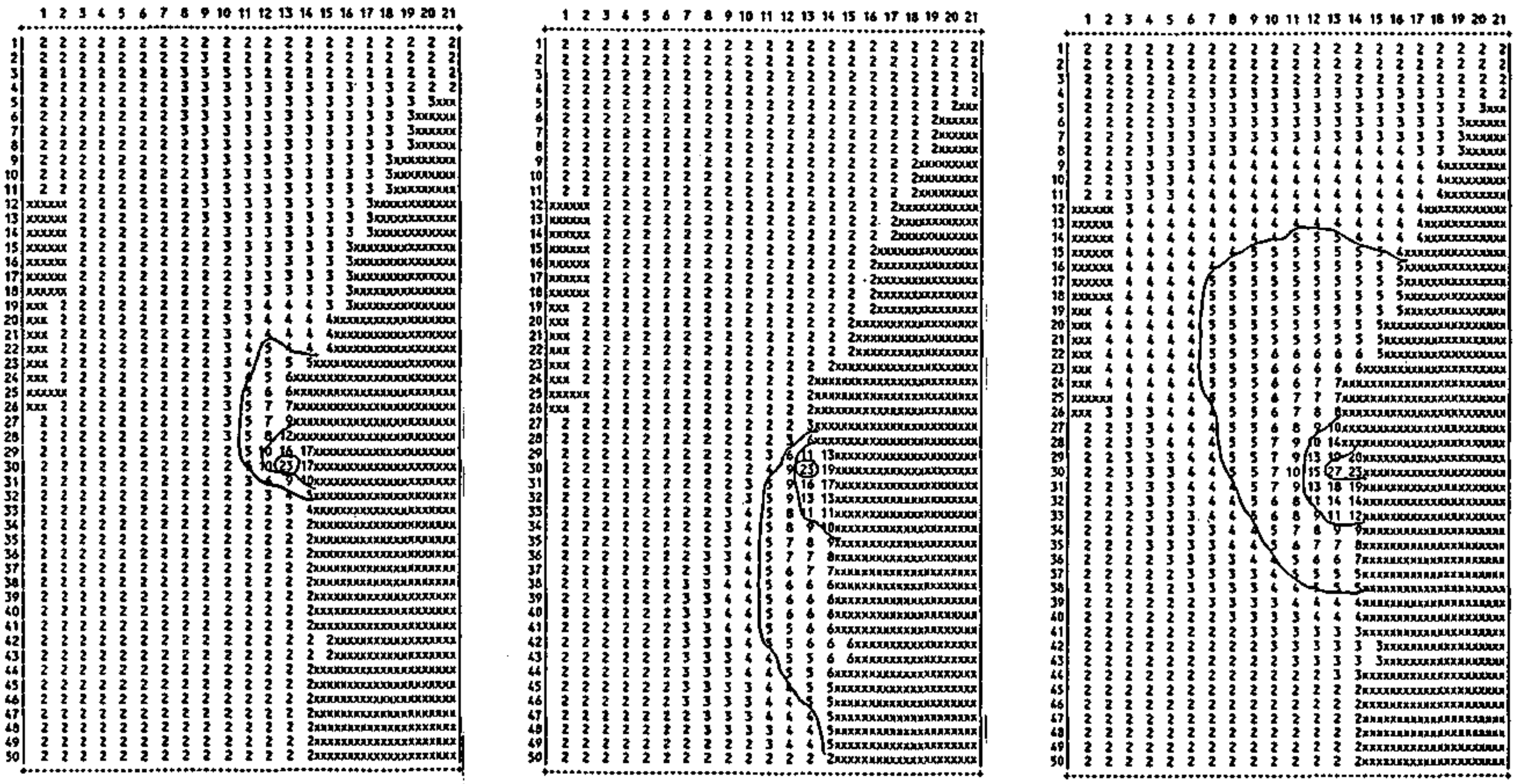


Figure 33
Phosphorus Increases Attributed to Onshore Hatchery Discharge
Based upon Mean Seiche Flows
Digits = Phosphorus Increase (ppb x 10), Contours = .5, 1, 2 ppb
Flow Directions = North, South, Both

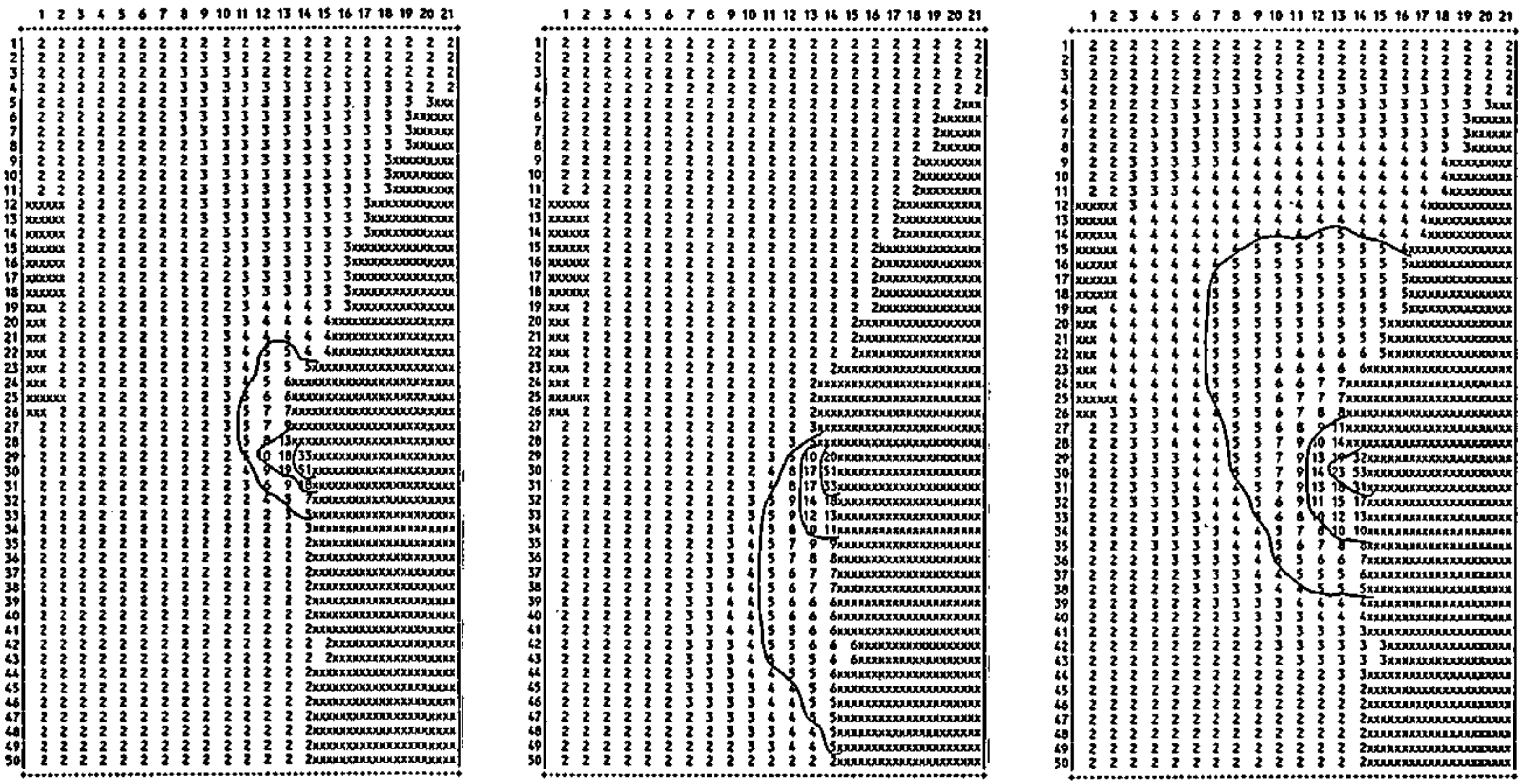
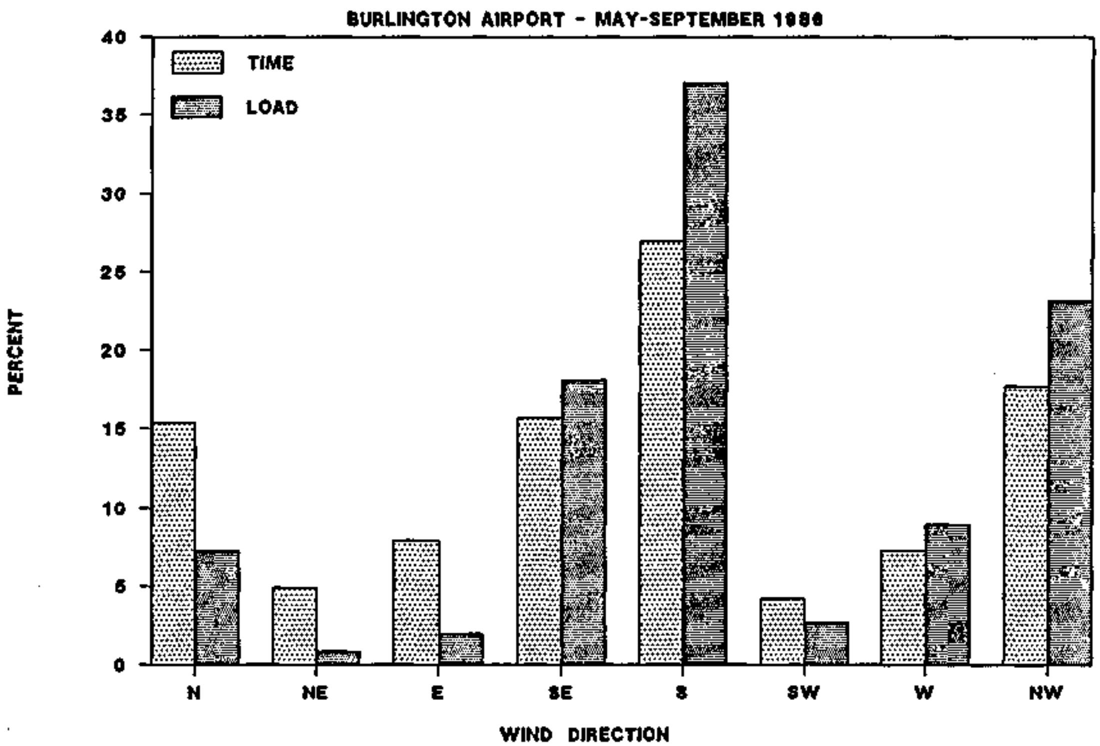


Figure 34
Frequency Distribution of Wind Directions at Burlington Airport



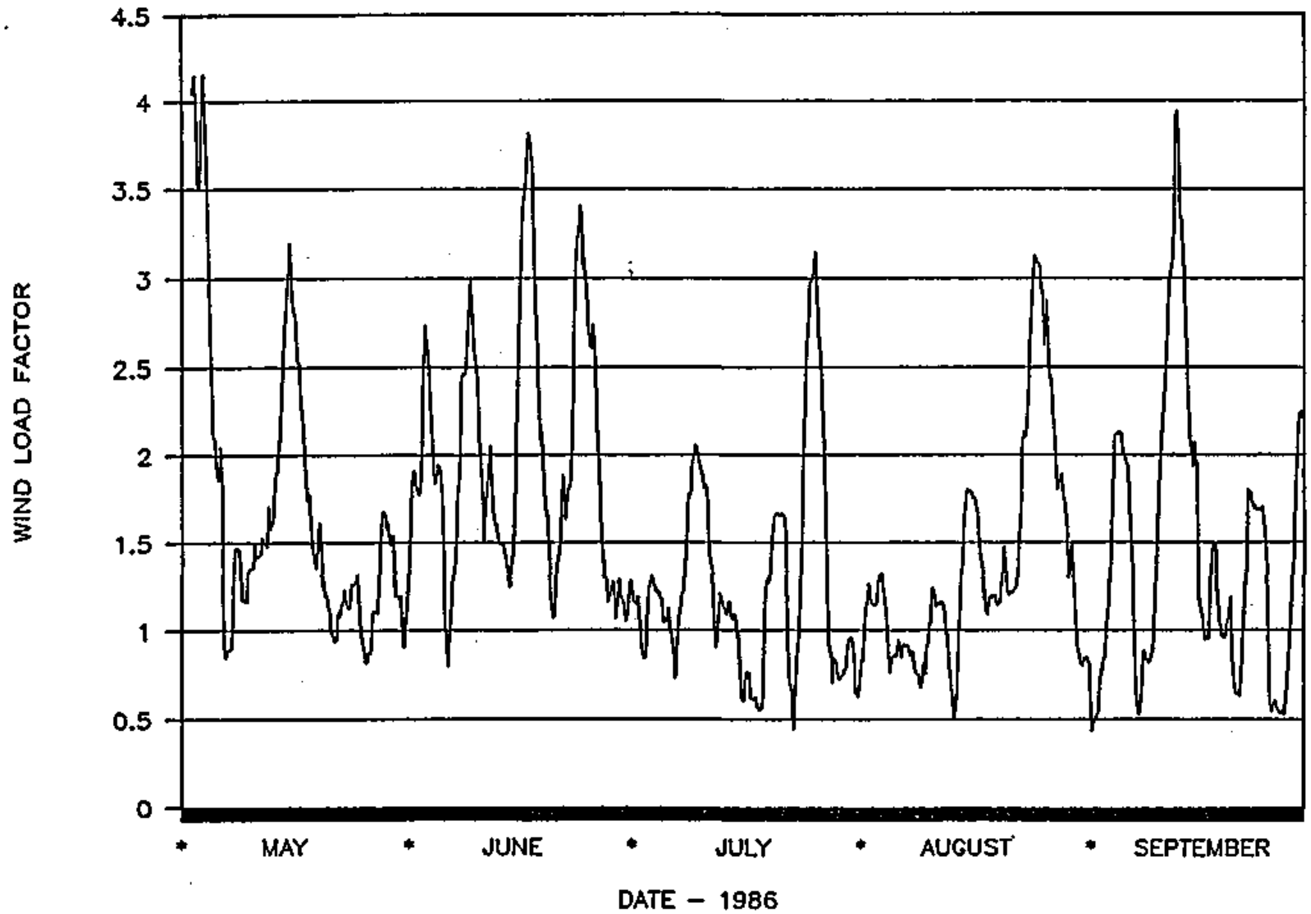
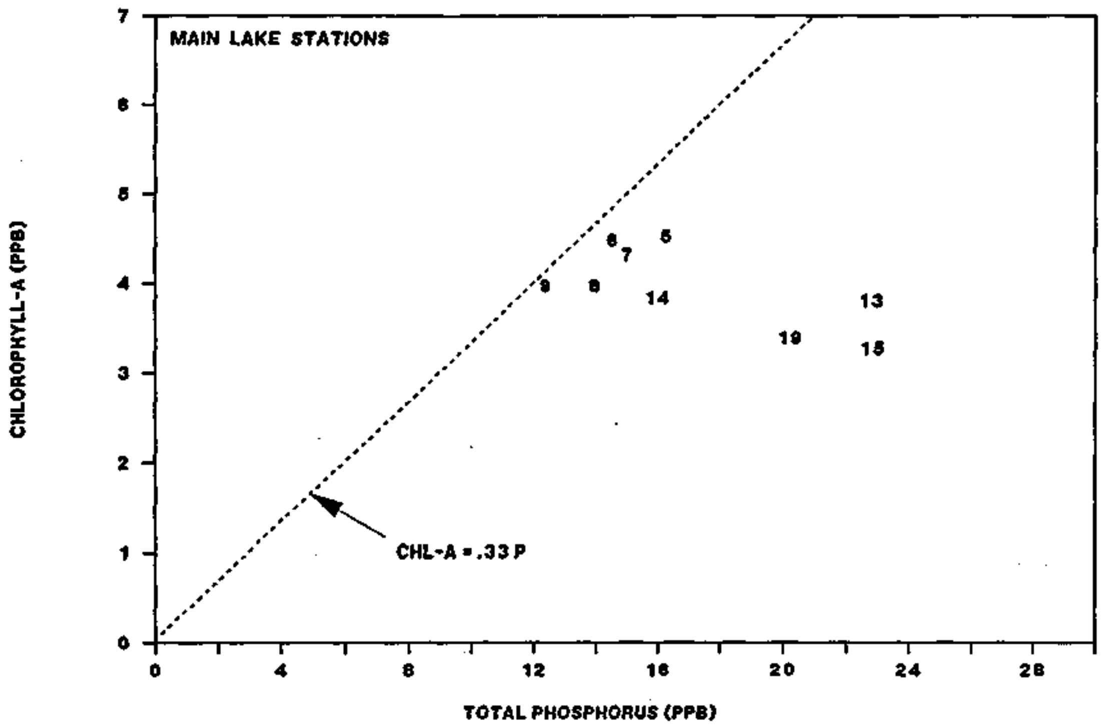


Figure 35
3-Day Moving-Average Wind Load Factor
Burlington Airport, 3-Hr Observations, May-September 1986

Figure 36
Phosphorus-Chlorophyll-a Relationship for Main-Lake Stations
in Vermont Lay Monitoring Program

Station Locations Shown In Figure 1
Lake Region: Thompsons Point to Rouses Point



LIST OF TABLES

1 Specification of Conditions for Hatchery Discharge Simulations

2 Hatchery Phosphorus Budget

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Table 1
Specification of Conditions for Hatchery Discharge Simulations

ALL SIMULATIONS:

Hatchery Discharge (September Conditions, Table 2):

Hatchery Effluent Flow = 10,800 gpm = 15.5 mgd = 58,871 m^3/day
Effluent Phosphorus Conc. = 67 ppb (incl. 15 ppb Background)
Effluent Phosphorus Load = 3.94 kg/day

Phosphorus Decay Rate = 0 day^{-1}

Water Balance Throughflow
Flow North = 2,622 cfs = 6.4×10^6 m^3/day
Drainage Area = 5,243 mi^2 @ Runoff Rate = .5 cfs/mi^2 (Figure 6)
(Mean Runoff Rate for August/September 1976-87 = .9 cfs/mi^2)

C_b = Boundary Cell Concentrations
= (Hatchery Load/Lake Throughflow) x (1 - R_p)
Rp = Phosphorus Retention Coefficient for Lake Champlain
From Vollenweider (1976):

$$1 - Rp = 1/(1 + T^{.5}) = .369$$

T = Hydraulic Residence Time = 2.9 years (Van Benscoten,1979)

$$C_b = (3.94 / 6.4) \times .369 = .22 \text{ ppb}$$

WIND-DRIVEN SIMULATIONS: (Figures 28 - 31)

Thermocline Depths = 10 meters and 25 meters

Dispersion Coefficient = 10,000 m^2/day

Wind Velocities:
8 Directions (N,NE,E,SE,S,SW,W,NW)
Load Factor = 1, Corresponds to Speed of 8.7 mph
Mean Load Factors at Burlington Airport:

August 1987	1.56
September 1987	1.12
May-Sept 1986	1.59

Minimum 3-Day-Moving-Average Load Factor for Above Months ~ .5

SEICHE-DRIVEN SIMULATIONS: (Figures 32 - 33)

Thermocline Depth = 25 meters
Dispersion Coefficient = 40,000 m^2/day
Seiche Flows:
Mean Flows Derived from Seiche Model Simulations (Figure 12)
Mean Flow North = Mean Flow South = 57×10^6 m^3/day
Corresponds to Average Amplitude of 179×10^6 m^3/day

Table 2
Hatchery Phosphorus Budget

PHOSPHORUS MANAGEMENT PLAN

DATE	FLOW (gpm)	TOTAL PHOSPHORUS IN FEED (lb)	PHOSPHORUS ASSIMULATED BY FISH (lb)	PHOSPHORUS REMOVED BY CLARIFER (lb)	PHOSPHORUS IN DISCHARGE FROM HATCHERY OPERATIONS		BACKGROUND PHOSPORUS CONCENTRATIONS		TOTAL PHOSPHORUS IN DISCHARGE	
					WT. (lb)	CONC. (mg/l)	WT. (lb)	CONC. (mg/l)	WT. (lb)	CONC. (mg/l)
JAN	8494	266	53	134	79	0.025	47	0.015	127	0.040
FEB	9165	318	64	167	89	0.029	46	0.015	136	0.044
MAR	9834	365	73	193	99	0.027	55	0.015	154	0.042
APR	10800	838	168	478	193	0.050	58	0.015	252	0.065
MAY	10800	849	170	484	196	0.049	60	0.015	256	0.064
JUN	10412	823	165	469	190	0.051	56	0.015	247	0.066
JUL	8289	725	145	409	171	0.055	46	0.015	217	0.070
AUG	10621	801	160	455	186	0.047	59	0.015	245	0.062
SEP	10800	885	177	506	203	0.052	58	0.015	261	0.067
OCT	10800	1040	208	598	234	0.058	60	0.015	294	0.073
NOV	10800	1010	202	581	228	0.059	60	0.015	288	0.074
DEC	8974	579	116	322	142	0.042	50	0.015	192	0.057
TOTALS	Peak Flow	8499	1700	4795	2010		659		2669	

Source: T. Wiggins, Vermont Dept of Fish and Wildlife, July 11, 1988.

Table 3
Surface Areas Impacted by Hatchery Discharge

DISCHARGE LOCATION	THERMO. DEPTH (M)	WIND DIRECTION	NUMBER OF MODEL CELLS * PHOSPHORUS INCREASE (PPB) >5	>2	>1	>.5
Offshore	25	N	0	0	17	72
Offshore	25	NE	0	2	19	53
Offshore	25	E	1	8	36	204
Offshore	25	SE	0	1	9	55
Offshore	25	S	0	1	6	40
Offshore	25	SW	0	3	12	64
Offshore	25	W	1	8	29	89
Offshore	25	NW	0	1	25	92
Onshore	25	N	0	2	24	69
Onshore	25	NE	0	7	20	51
Onshore	25	E	2	9	40	206
Onshore	25	SE	0	2	10	55
Onshore	25	S	0	2	8	39
Onshore	25	SW	0	4	13	67
Onshore	25	W	2	9	27	85
Onshore	25	NW	0	2	17	87
Offshore	10	N	0	0	28	135
Offshore	10	NE	0	3	38	265
Offshore	10	E	0	5	24	272
Offshore	10	SE	0	0	16	148
Offshore	10	S	0	0	6	156
Offshore	10	SW	0	2	19	309
Offshore	10	W	1	6	35	115
Offshore	10	NW	0	1	27	109
Onshore	10	N	0	3	29	125
Onshore	10	NE	0	7	33	261
Onshore	10	E	2	6	24	272
Onshore	10	SE	0	2	18	146
Onshore	10	S	0	2	8	156
Onshore	10	SW	0	3	22	308
Onshore	10	W	2	6	32	111
Onshore	10	NW	0	2	19	98
Offshore	25	Seiche - N	0	1	8	30
Offshore	25	Seiche - S	0	1	11	70
Offshore	25	Seiche - N&S	0	3	18	169
Onshore	25	Seiche - N	1	2	7	32
Onshore	25	Seiche - S	1	3	12	71
Onshore	25	Seiche - N&S	1	4	20	169

* 1 MODEL CELL = 200 X 200 METERS = 4 HECTARES ~ 10 ACRES