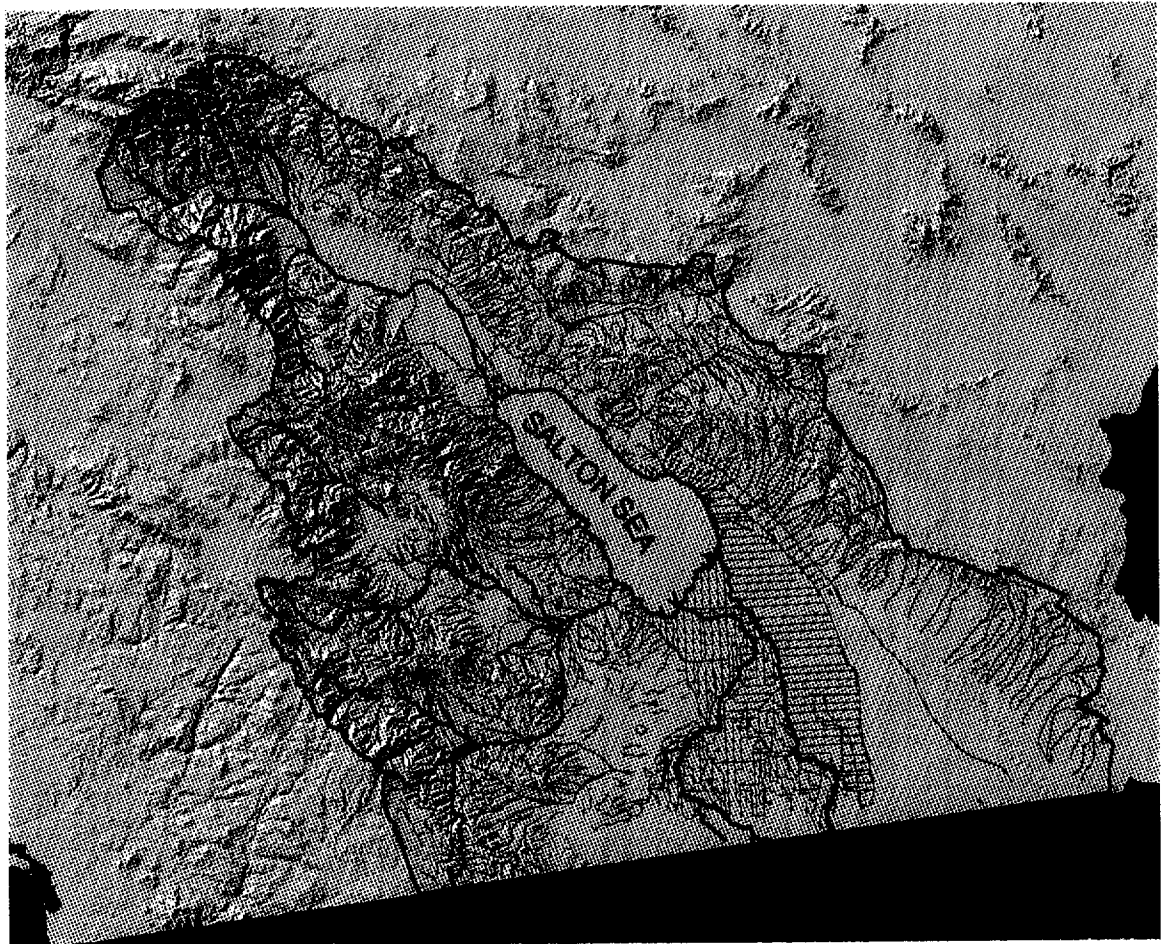


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Salton Sea Project

Phase I Final Report

September 1995



Modeling Group
Center for Water Resources and Environmental Engineering
Department of Civil and Environmental Engineering
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EXECUTIVE SUMMARY

This report summarizes results of Phase I of a study to model circulation in the Salton Sea. To better understand circulation and transport processes within the Sea, both two- and three-dimensional finite element models have been applied. Understanding of these processes is a critical first step to solving issues facing the Sea, such as rapidly changing water levels, rising salinity levels, fish kills, and large algae mats. Because of the large size of the Sea and the relatively small hydrologic fluxes, the hydrodynamics of the system are assumed to be generated solely by wind and Coriolis forces. Wind-induced circulations initially are generated by imposing a steady representational wind derived from analysis of observations at three weather stations located on the north, west, and south-east shores of the Sea. Simulation results indicate the presence of several large gyres within the Sea, located at the north and south ends. These regions are of critical concern for future investigations and for placement of current profilers within the Sea. Recommendations are made for future investigation of alternative management strategies for problems currently facing the Salton Sea.

1. INTRODUCTION

1.1 Background

The modern day Salton Sea, often referred to as the largest "man-made" water body in California, was formed in late 1904 as the result of a break in a temporary levee along the Colorado River. For a period of about 16 months thereafter water flowed through this break into the below-sea level depression, then known as the Salton Sink, filling it to a depth of more than 80 feet above its lowest elevation, approximately 278 feet below mean ocean sea level (msl). Since that time the water level in the Salton Sea has been seeking a balance between the harsh desert forces that extract water by evaporation, the only mechanism for removal of water from this land-locked depression, and inflows of water from surface and subsurface sources. For a time following closure of the break in the levee water levels declined rapidly, as evaporation greatly exceeded inflow. A minimum level was reached in the 1920's, after which the level of the Sea once again began to rise, due in major part to importation of water for agriculture. By the 1990's maximum elevations were recorded, exceeding -227.9 feet msl (McClurg, 1994).

During the course of historical changes in the Sea's water balance its salinity has also changed. Initially the salinity of the Sea was about that of the Colorado River at the time of the levee break, but because of evaporative concentration, the salinity began to rise as water levels fell toward the minimum of the 1920's. Subsequently, with the importation of water for irrigation, salt loads from irrigation drainage and return flows added salt to the water body. As agriculture expanded and water importation increased, not only did the Sea's water level increase, but salinity also rose steadily, surpassing that of the ocean. Today it is at its highest historical level (approximately 45 parts per thousand), about 30 percent greater than that of the ocean.

These two conditions, rising water levels and increasing salinity, have prompted investigation of control measures that could reduce potential threats to land, recreational, and ecological values in the region. This report presents results

of an initial study aimed at providing practical tools for assessing alternatives for managing changes in water levels and water quality in the Sea.

1.2 Scope and Objectives

Historical changes in both water levels and salinity in the Salton Sea have reached a point where they threaten both land and property values, and also the region's ecological and recreational resources. Rising water levels are encroaching onto private property, causing loss of usable land and damage to property by flooding. Increases in salinity have reached the point where sport fisheries, particularly of the orange mouth Corvina, are in danger of destruction. Because the Sea is either a permanent or a temporary home for millions of birds on the Pacific flyway (a fact that attracts avid bird watchers to the area), the stability of the ecosystem (both aquatic and aviatory) is also threatened by these changes.

To address these concerns, the Salton Sea Authority is supporting investigation of alternative measures to control water levels and water quality in the Sea that will preserve its intrinsic values. Among possible alternatives are those that would physically alter the configuration of open water areas in parts of the sea, and thereby alter the natural circulation and water quality characteristics. Before such physical alterations are made in the Sea's configuration and bathymetry, it is necessary to determine the effects these changes may have on circulation patterns and how these may in turn influence water quality and the indigenous ecosystem.

To meet these needs the Center for Water Resources and Environmental Engineering Modeling Group of the University of California at Davis entered into an agreement with the California Department of Water Resources (DWR) to provide a capability to simulate wind-driven circulation in the Salton Sea by means of a three-dimensional mathematical model. The preliminary study defined in the agreement, identified here as Phase I, calls for the execution of a series of specific tasks, as follows:

1. Assemble and Collate Existing Data
2. Analyze Physical, Hydrologic, and Meteorological Data
3. Develop the Model Grid to Represent Bathymetry

4. Select Test Case for Simulation
5. Perform Test Simulation
6. Design Comprehensive Study Program
7. Report on Preliminary (Phase I) Study

This report presents results of the Phase I study, organized according to these tasks, and recommendations for continued development of practical analysis tools.

1.3 Organization

This project was managed by Mr. Christopher Cook, Post Graduate Research Engineer and doctoral candidate at the University of California at Davis. He was assisted in analysis of data, preparation of model runs, and development of graphical presentations and animation by Mr. Stephen Breithaupt, Ms. Jamie Anderson, and Ms. Joanna Fellos. Professor Emeritus Gerald T. Orlob served as Principal Investigator for the project. Mr. David Inouye served as Project manager for the Department of Water Resources.

1.4 Acknowledgments

We are very thankful for the help and guidance received from different agencies represented in the Technical Advisory Committee of the Salton Sea Authority and from the many individuals who generously contributed their time and expertise. In particular, we wish to express our appreciation to Mr. David Inouye of DWR for his assistance in acquainting us with the complexities of the Salton Sea and its problems. We also thank Karen Beardsley of the California Rivers Assessment, a project of the California Resources agency, for her help in constructing the map on the cover of this report. Data for the cover map was provided by Teale Data Center, US Environmental Protection Agency, and CA Dept. of Fish and Game. Lastly, we thank those of our colleagues in the Modeling Group at UC Davis whose prior experience with the models implemented here helped to make this project more productive.

2. STUDY AREA AND ACQUIRED PHYSICAL DATA

Hydrologic and meteorologic data were acquired from many different sources. During Phase I, information discovered was both limited in scope and detail. Hence, direct implementation of data into the model was somewhat restricted. Nevertheless, sufficient information for the purpose of Phase I was developed as described below.

2.1 Bathymetry

An excellent data base containing 133,376 bathymetry points (measurements of underwater topography) of the Salton Sea was obtained through the courtesy of Mr. Hank Kaplan (US Bureau of Reclamation) via Mr. David Inouye (DWR, Southern District). It served as foundation for bathymetric representation of the Sea. Personal communication with Mr. Kaplan revealed that this data set is being updated and revised. Further refinement, especially around the shore of the Sea, will allow for improved representation of the Sea's bathymetry in succeeding phases. As soon as the new data set is received, the models will be updated.

2.2 Wind Information

To date, the Modeling Group has been informed of six California Irrigation Management Information System (CIMIS) meteorologic stations in the Coachella and Imperial Valleys: Station 41 in Calipatria, Station 50 at Thermal, Station 68 in Seeley, Station 87 in Meloland, Station 127 near Salton City, and Station 128 near the Alamo River delta outflow. Station 127 and 128 are very close to the shore of the Sea and as such provide excellent point measurements of wind on the west and southeast shores. Station 50, north of the Sea, offers a unique picture of wind conditions in the Coachella Valley. Therefore, the wind analysis completed by the Modeling Group focused on wind magnitudes and velocities recorded at Stations 50, 127, and 128. These three stations offer a good representation of the wind in the Coachella and Imperial Valleys with respect to the Salton Sea. Stations 41, 68,

and 87 were not included in the wind analysis, due to their geographic displacement from the boundary of the Sea. Additional meteorologic stations will be necessary to provide the data needed for a complete representation of air-sea interactions.

2.3 Hydrologic Fluxes

The US Geological Survey (USGS) maintains gages on numerous surface water bodies throughout the Coachella and Imperial Valleys. Measurements at these gages are reported in the USGS Water Resources Data, California Reports (WRD). Gage records on the Alamo, New, and Whitewater Rivers, Salt Creek, and on the Salton Sea itself are especially pertinent to this report. The gage on the Salton Sea measures water surface elevation and has a period of record back to November 1904. All other gages record flow, and are reported in the WRD as daily mean discharges in cubic feet per second.

To date, no additional hydrologic data from 1990 onward has been discovered, especially concerning flows from agricultural runoff to the sea that would not be recorded by USGS gages listed above. Several reports from the US Geological Survey (Hely, et al., 1966; Schroeder, et al., 1993; Setmire, et al., 1993) give summaries of conditions during previous decades. Additional recent data on agricultural runoff returns will be needed in later studies.

The Modeling Group has not been successful as yet in discovering reliable groundwater flow information about the Coachella and Imperial Valleys. Hely, et al. (1966), state that :

Salton Sea and the surrounding area are underlain by thick deposits of alluvium, which are rather impermeable except in Coachella Valley and locally at the mouth of San Felipe Creek. The relative impermeability in Imperial Valley is indicated by the extremely low yields of wells near the sea and by data from a line of auger holes that extends across the valley just south of the sea. The greater permeability of the alluvium in Coachella Valley is demonstrated by the yields of many artesian and water-table wells.

Additional information about groundwater flows in the Imperial and Coachella Valleys will be very useful in later phases of the investigation.

2.4 Future Data Needs

During Phase I, the limited scope of the existing data base became apparent. To serve the needs of subsequent phases of the investigation, it will be necessary to extend the data collection activity, particularly concerning direct measurement of currents and water quality in the Sea, characteristics of its overlying atmosphere, and groundwater flow in the region.

3. ANALYSIS OF PHYSICAL DATA

3.1 Wind Results

Three CIMIS stations were considered during Phase I of the Salton Sea Project . These were: Station 50 at Thermal, Station 127 near Salton City, and Station 128 near the Alamo River Delta. The maximum length of continuous record for Stations 127 and 128 was for the period December 1994 through July 1995 (current). Wind velocities and magnitudes were reported hourly at these stations and data are accessible through DWR-Sacramento via a computer account.

The first goal of the analysis was to characterize wind velocity throughout a daily cycle at each station for December 1994 through July 1995. Hourly observations for a particular station and month were grouped together and averaged. This resulted in mean hourly velocity values for a particular month (e.g., the mean 9 AM velocity for April at Station 50 is approximately 6 mph) which are summarized in figures shown in Appendix A. Maximum and minimum values are indicated by horizontal lines across the figures. Results of this analysis indicate that wind velocities vary during the day, showing a different pattern for each month. Wind velocities varied about 2 mph, from minimum to maximum, during the day in winter. The variation increased to about 5 mph in the spring and early summer. Between December and March, the general pattern indicates that wind velocity is greatest during the late morning to early afternoon and dies off at night. During April to July, the wind velocity is greatest during the late afternoon to night, with a minimum in the early morning. The mean wind velocity also increased from December to July, from approximately 3.6 mph in December to a maximum mean of 8.5 mph in May.

The second goal of the analysis was to discover if a correlation existed between wind directions recorded at the three stations. For example, when the wind is blowing from the north at station 50, what is its direction at stations 127 and 128, on the west and east sides of the sea? A program was written in FORTRAN to examine such a correlation, and it was run for the months of December 1994 to July 1995. Generally, Stations 127 and 128 were found to correlate well with

Station 50, indicating that when the wind at Station 50 was blowing towards a certain direction, wind directions at Stations 127 and 128 would consistently be oriented in another certain direction. It is important to note here that the dominant directions were not the same at all three stations. Generally, the wind appeared to change direction gradually as it flowed through the Coachella and Imperial Valleys.

To characterize an annual cycle of wind activity, wind directions were grouped by month and analyzed. Results of this analysis showed that at Station 50 the wind was predominately from the North. Station 127 had a weaker pattern, but generally the wind was out of the Northwest. Station 128 had the weakest trend and varied quite dramatically from month to month. A generally consistent trend was found for the months of March, April, and May, when the wind patterns were: Station 50 = North, Station 127 = Northwest, Station 128 = West. A graphical representation of this wind circulation pattern can be found in Figure 1. This analysis suggests that the wind is deflected from north to west as it travels down Coachella Valley into Imperial Valley, a pattern of atmospheric flow that more or less follows the topography of the area.

3.2 Gaged River Flow

The USGS gage information, reported in the Water Supply Papers (WSP) (USGS, 1904-1970 and 1971-1993), was obtained for those gages closest to, or actually on, the Salton Sea. Figures 2 to 6 provide summaries of this data.

The average water surface level of the Sea for September 1993 was 227.9 feet below mean sea level. Hely, et al. (1966), provide a relationship for water surface elevation versus volume of the Sea. For the water level of September 1993, this relationship indicates that the volume of the Sea was approximately 8 million acre-feet. From the WSP reports, the average yearly inflows of water at the several key gages (using a significant period of record for each gage) are: New River at Westmorland (1943-93) = 443,600 ac-ft; Alamo River at Niland (1961-93) = 611,700 ac-ft; Whitewater River near Mecca (1961-92) = 80,380 ac-ft; and Salt Creek (1962-90) = 9,900 ac-ft. Total combined yearly inflow from these four sources is 1,145,580 ac-ft. On a daily basis, only 0.00039 of the volume of the sea enters through these tributaries. Even over an entire year, the tributary/Sea volume

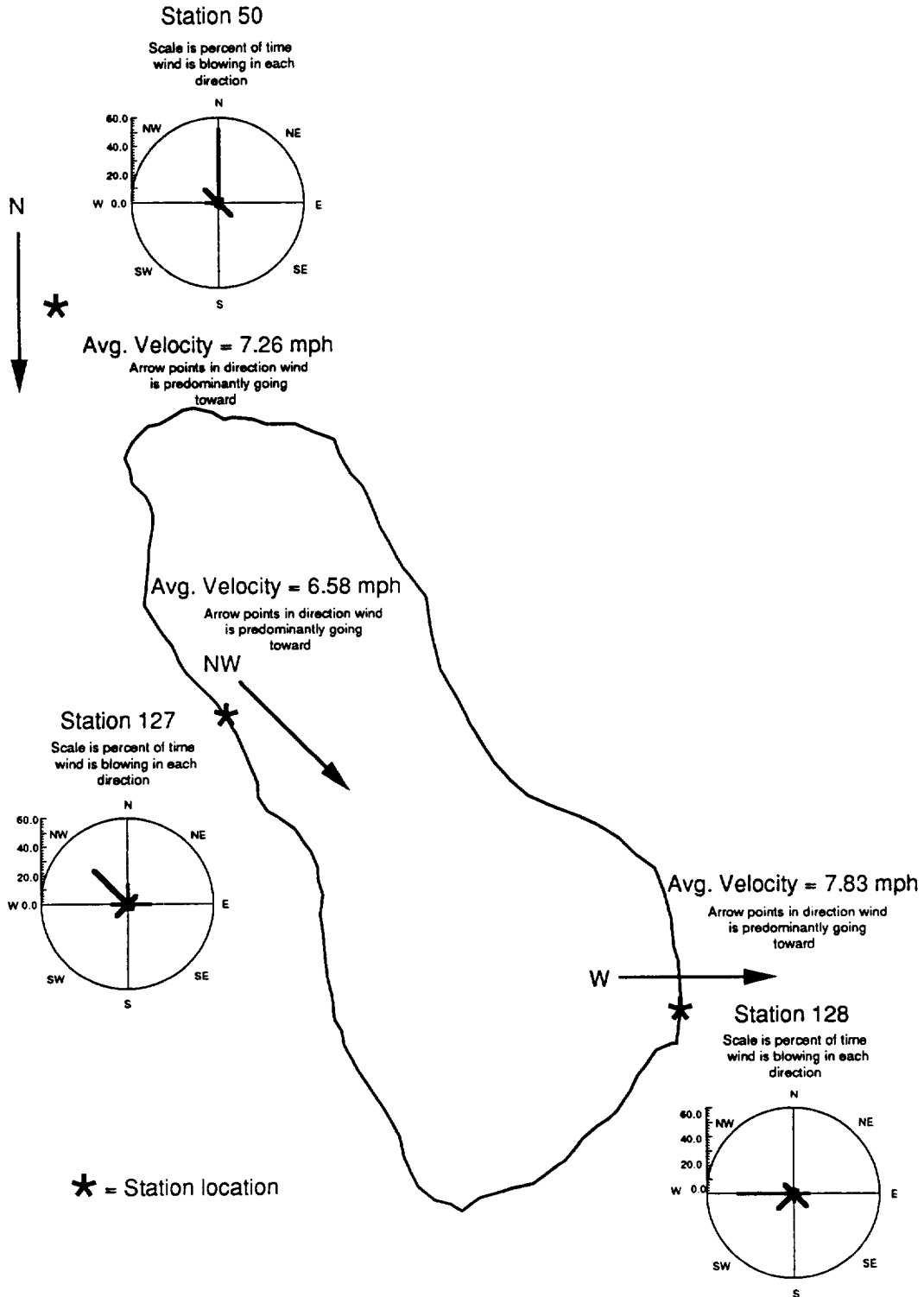


Figure 1. Wind Data Summary. March 1995 through May 1995

Total Flow for the Whitewater River Near Mecca 1961-1994
Hydrodate: USGS Station 10259540

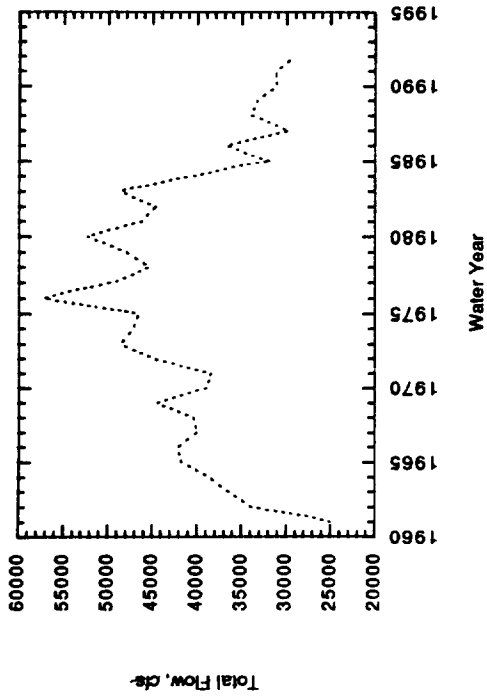


Figure 2

Total Flow for the Alamo River at Niland 1961-1993
Hydrodate: USGS Station 10254730

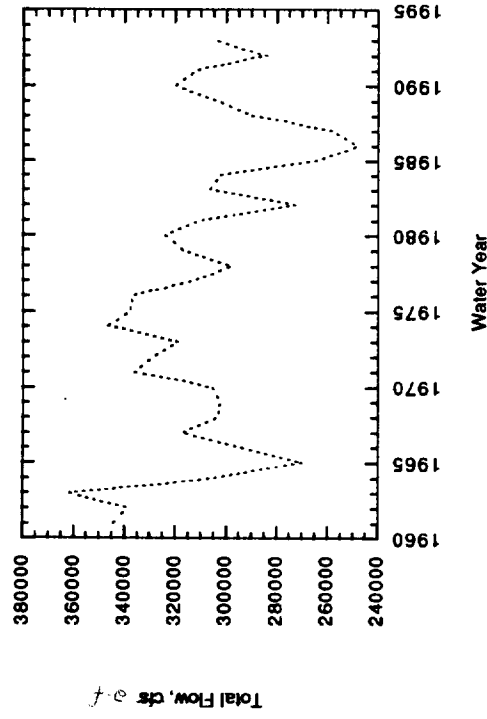


Figure 3

Total Flow for Salt Creek Near Mecca 1961-1990
Hydrodate: USGS Station 10254050

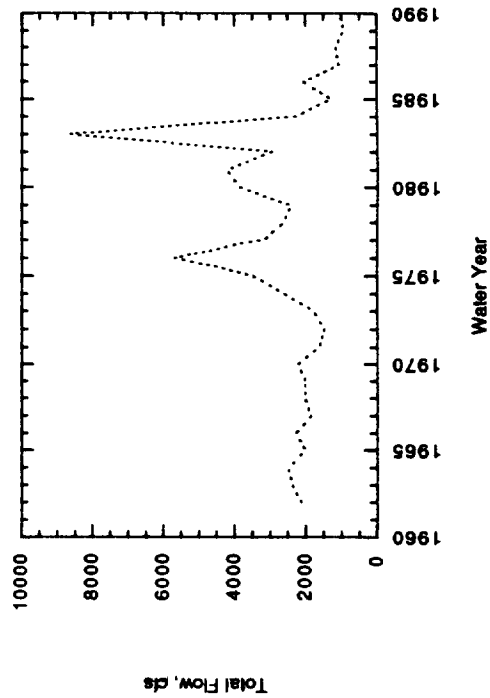


Figure 4

Total Flow for the New River at Westmorland 1944-1993
Hydrodate: USGS Station 10255550

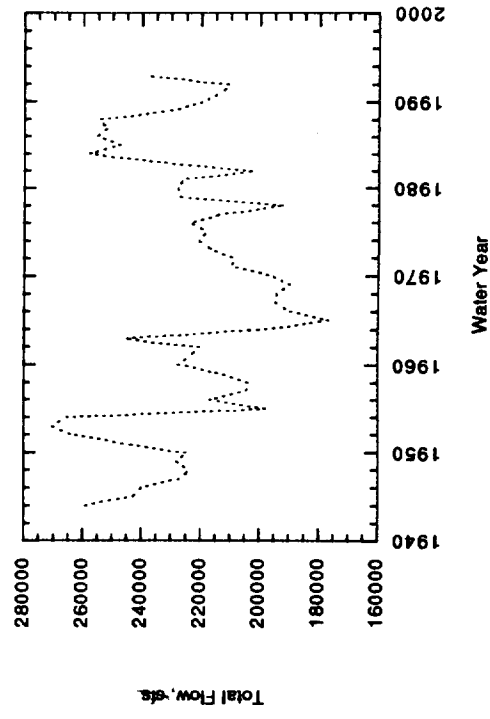


Figure 5

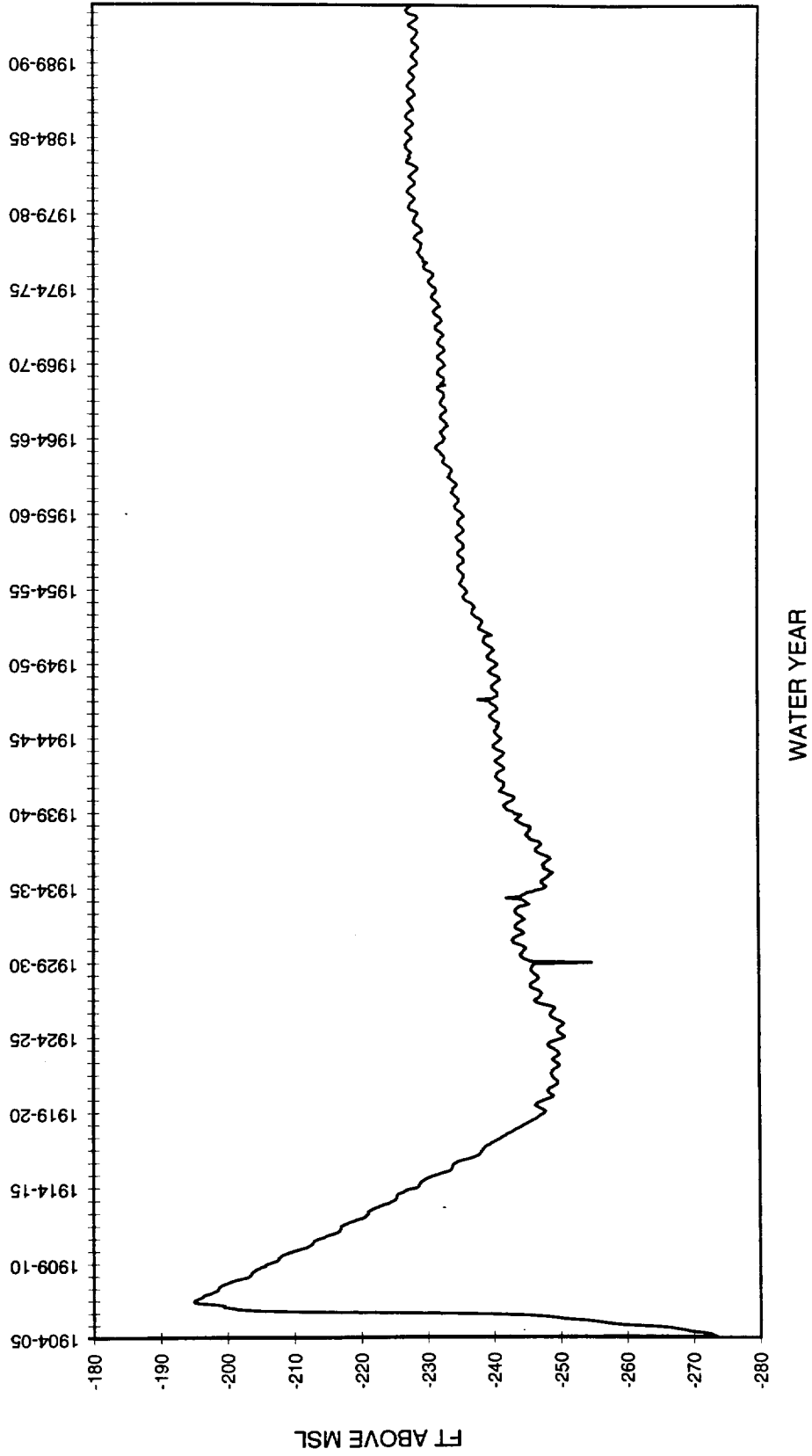


Figure 6. Elevation of Salton Sea for Water Years 1904-1993

ratio is only 14.3% of the total Sea volume at elevation -227.9 msl. Because tributary inflows constitute such a relatively small part of the total volume in the Sea, it follows that the momentum imparted to the general circulation pattern is correspondingly small. Therefore, the effects of tributary inflows were not represented in this phase of the study, which was concerned with large scale circulation. The effects of tributaries will be investigated in future phases, particularly in relation to water quality issues where tributaries play major roles in supplying constituent loads, e.g. nutrients, toxins, etc., to the Sea.

4. MODEL APPLICATION TO THE SEA

4.1 Brief Model Description

Hydrodynamic modeling is based on the general principles of conservation of mass (continuity equation), momentum (founded in the Navier-Stokes equations), and energy, with appropriate state equations, and initial boundary conditions. The solution of these equations depends on the entity being modeled, e.g., lake, river, estuary, etc.. Usually, there are no analytical solutions to the general equations, except for unique special cases that are unlikely to correspond to real environmental situations. Also, irregular geometries and unsteady driving forces typical of the real world make such simple idealizations impractical. Therefore, numerical methods are the solution strategies most widely used in modeling real systems. For this project, the models RMA-2 and RMA-10 utilize a finite element solution method which has been found to have the requisite properties for describing circulation in water bodies like the Salton Sea.

The finite element method is based upon a defined network or grid that represents the geometry (or bathymetry in this case) of the system being modeled and for which the solutions of the governing equations must be obtained. Over the boundaries of the grid, conditions such as surface roughness, wind stress, inflow, etc. must be specified. A unique advantage of the finite element method is its flexibility to adjust to irregular boundaries, such as the shore line around the Salton Sea. The locations and shapes of elements around the perimeter of the grid can be easily changed to simulate the irregularities that are generally found in any natural water-body.

RMA-2 is a model designed for the simulation of one- and two-dimensional depth-averaged hydrodynamic systems. A one-dimensional system would only allow for variation of velocity along a single axis, such as along the centerline of a river; hence it is not appropriate for the Salton Sea. However, RMA-2 can be applied to the Salton Sea using a two-dimensional finite element network, meaning that variations in circulation can occur across the Sea in the horizontal plane. Velocities in a given horizontal location are independent of depth, and as

such there are no vertical velocities. Friction losses, Coriolis effects, and surface wind stresses have also been incorporated into the model. The model is capable of simulating either time-dependent or steady-state conditions. The interested reader is referred to the program documentation (King, 1990 and 1994a) for details on the mathematical description of the model.

RMA-10 is a model designed for the simulation of three-dimensional hydrodynamic circulation where vertical velocities are important and stratification may be an important factor. The model is capable of simulating stratification due to suspended sediment, temperature, and salinity density gradients, although in Phase I of this project, the fluid was assumed to be homogenous, i.e. not stratified. As with RMA-2, friction losses, Coriolis effects and surface wind stresses are also represented. The model may be used to simulate time-dependent or steady-state conditions. The interested reader is referred to the users guide (King, 1994b) for details on the mathematical description of the model.

To clarify the differences between two-dimensional depth-integrated and three-dimensional velocities, consider the velocity profiles shown in Figure 7 for a specific location in the Salton Sea. The three-dimensional result allows wind to drive the water in the direction of the wind along the surface, with return flow occurring along the bottom. In the two-dimensional case however, the equations have been integrated over the depth to simplify the solution, so only the mean velocity applies at this location, i.e. it is the same at all depths. In large water bodies, such as the Salton Sea, in which circulation is mainly the result of wind-driven stresses and where there will be significant variations in the magnitude and direction of the water from surface to bottom, the two-dimensional solution results in a loss of useful information. This loss of information may change the simulated transport direction and hence, may not provide an adequate base for water quality simulation. The three dimensional alternative is to be preferred for the case of the Salton Sea.

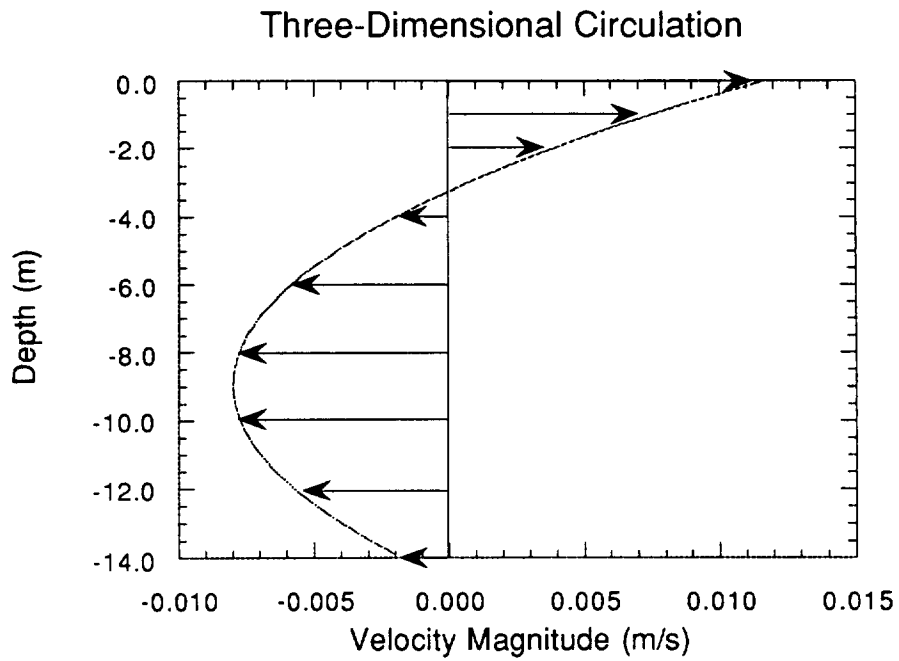
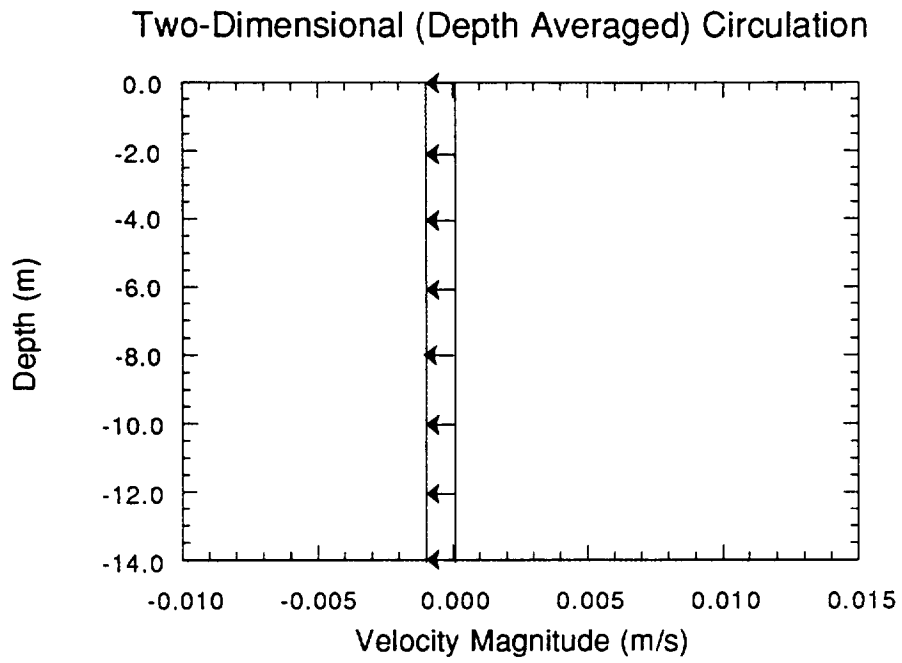


Figure 7. Velocity Variation with Depth at a Single Location for Wind-Driven Circulation. Comparison Between Two-Dimensional and Three-Dimensional Results

4.2 Model Representation of the Physical System

4.2.1 Bathymetry and the Finite Element Network

The bathymetry file obtained from the US Bureau of Reclamation provides the basis for formation of the finite element network. The two-dimensional network was initially constructed conforming to lines of constant elevation within the Sea. The excellent detail provided by the Bureau allows for construction of a very detailed finite element network. Grid detail developed during Phase I was kept at a modest level, consistent with demonstrating the capability of the model. The more detail added, the more elements that are required, and consequently the longer the time required by the computer to arrive at a solution.

As more specification is provided for alternatives to be studied in future phases, appropriate modifications can be made in the grid. Figure 8 shows a graph of the finite element network superimposed onto the bathymetry data points provided. For clarity in the figure only one in every 5000 data points is shown. If all bathymetry data points were displayed, the figure would appear as a solid surface, difficult to distinguish from the element network. It is expected that refinements will be made in the network during Phase II.

4.2.2 Hydrologic Inflows

Relative magnitudes of gaged surface inflows in comparison to Salton Sea volume indicated that they could be neglected in Phase I. As discussed in Section 3.2, it was decided that the momentum transferred by these flows was so small that it would have little effect on the overall circulation of the sea. Again, it should be recognized that these inflows will be incorporated in Phase II, where water quality issues will be considered.

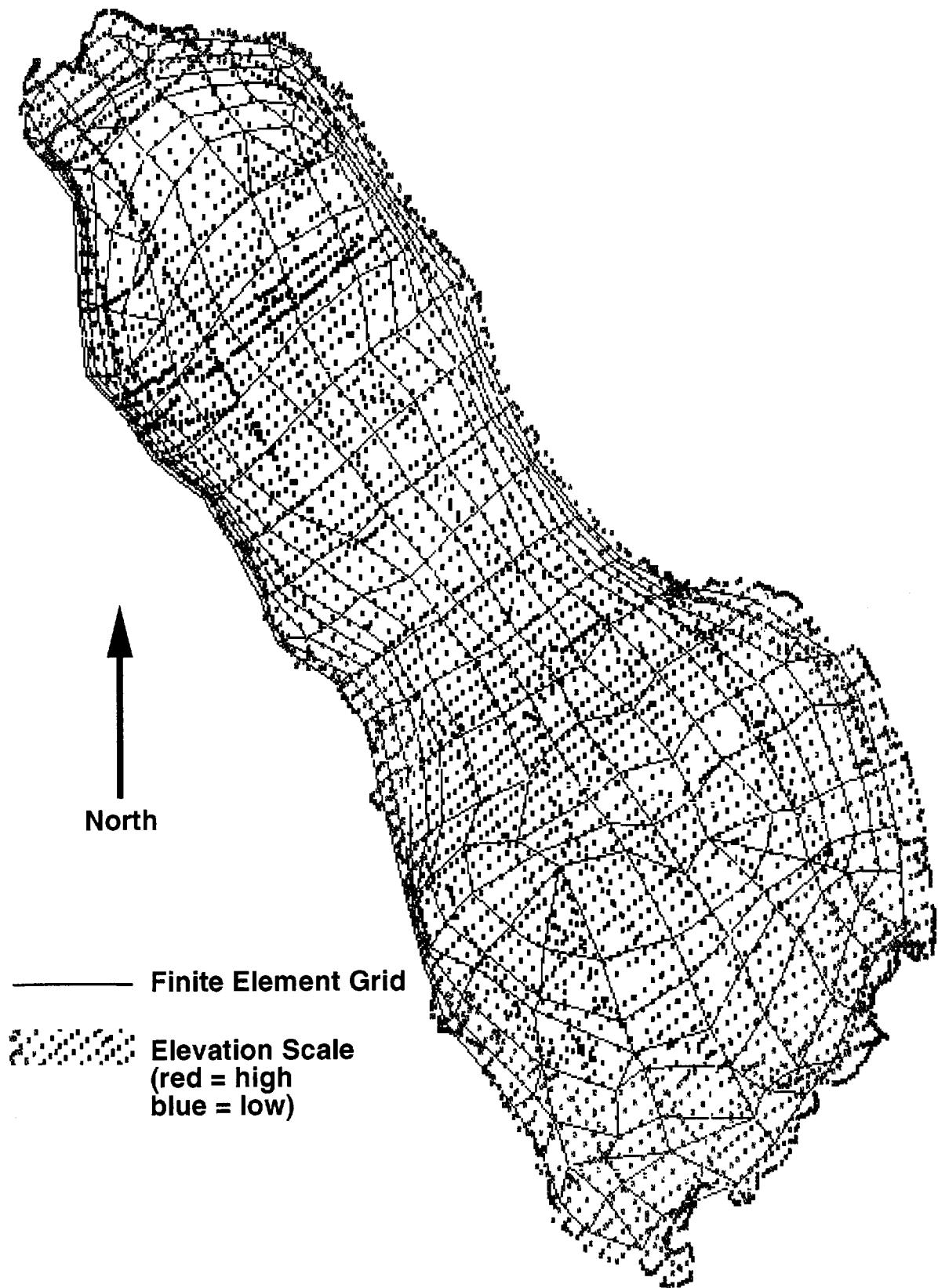


Figure 8 Bathymetry and Two-Dimensional Finite Element Grid

4.2.3 Meteorologic Information

The only meteorologic data utilized in this phase of the project were wind magnitude and directions at the three CIMIS stations. Solar radiation measurements will be useful in Phase II because effects of stratification induced by vertical temperature variations are to be modeled.

Wind blowing over the Sea's surface imparts a shear stress that results in movement of water. The greater the wind stress, the greater the resulting circulation. Translation of a mean wind velocity into a shear stress at the water surface has been the subject of much research. For the purposes of this preliminary study using an uncalibrated model, wind stresses were applied uniformly, both in magnitude and direction, along the entire surface of the sea using a simple relationship in which the stress was made proportional to the square of the wind velocity.

5. MODEL RESULTS FOR PHASE I

5.1 Description of Base Case

A base case requires that certain boundary and initial conditions be applied to a model, so that when simulated the resulting circulation forms a reference for comparison of results between different models. For Phase I, the wind boundary conditions were developed from observations in March and April of 1995 at Stations 127 and 128. From this wind data a mean representative wind was chosen to have a mean velocity of 6.51 mph and an average prevailing direction of west northwest (an azimuth angle of 292.5 degrees). This wind was applied uniformly over the entire surface of the Sea.

All model runs in Phase I are steady-state solutions. This means that circulation generated by the model is that that would be induced by the representational wind blowing constantly with the same magnitude and direction for an infinite period of time.

Base case circulations are generated solely by wind stress and Coriolis forces. Tributary effects were not simulated in Phase I.

5.2 Two-Dimensional Results from RMA-2

Two-dimensional results for the Salton Sea allow for variations in circulation velocities in the horizontal plane, but not in the vertical. Figure 9 shows the resulting velocity field for the base case.

The results shown in Figure 9 follow trends that would be expected for a two-dimensional depth-averaged solution of a wind-driven water body. Because shallow water requires less momentum to sustain movement, water masses in the Sea's shallow areas move more rapidly, generally in the direction of the wind. Because of mass continuity, water in the deeper areas must then move to replace the water flowing out of the shallow areas. This pattern is seen in Figure 9, where

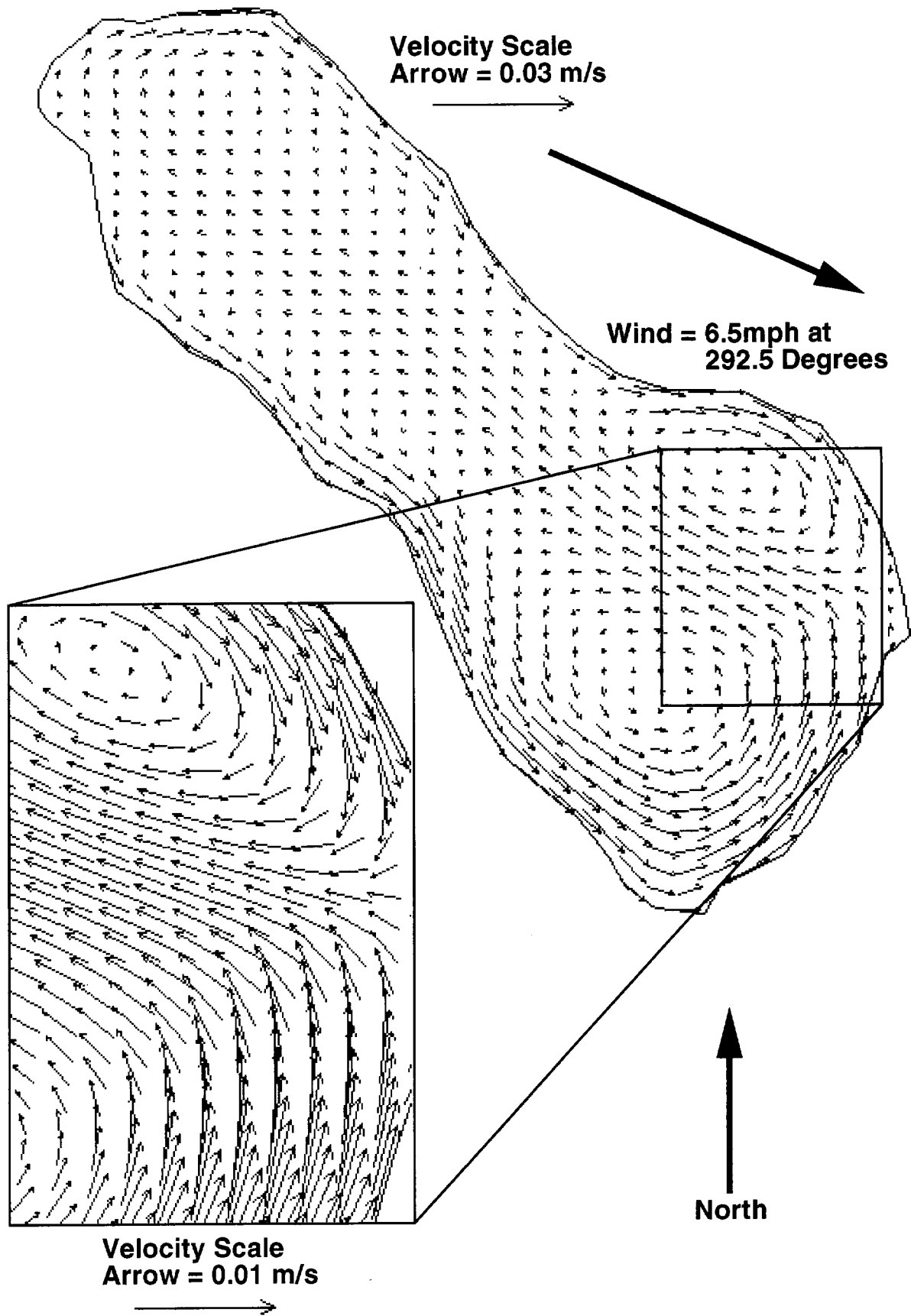


Figure 9 Two-Dimensional Circulation Results

water masses in the shallow areas near the shore are induced by wind shear to move in the direction of the wind and water masses in the deep areas, e.g., along the centerline of the Sea, move generally in directions opposite to the wind.

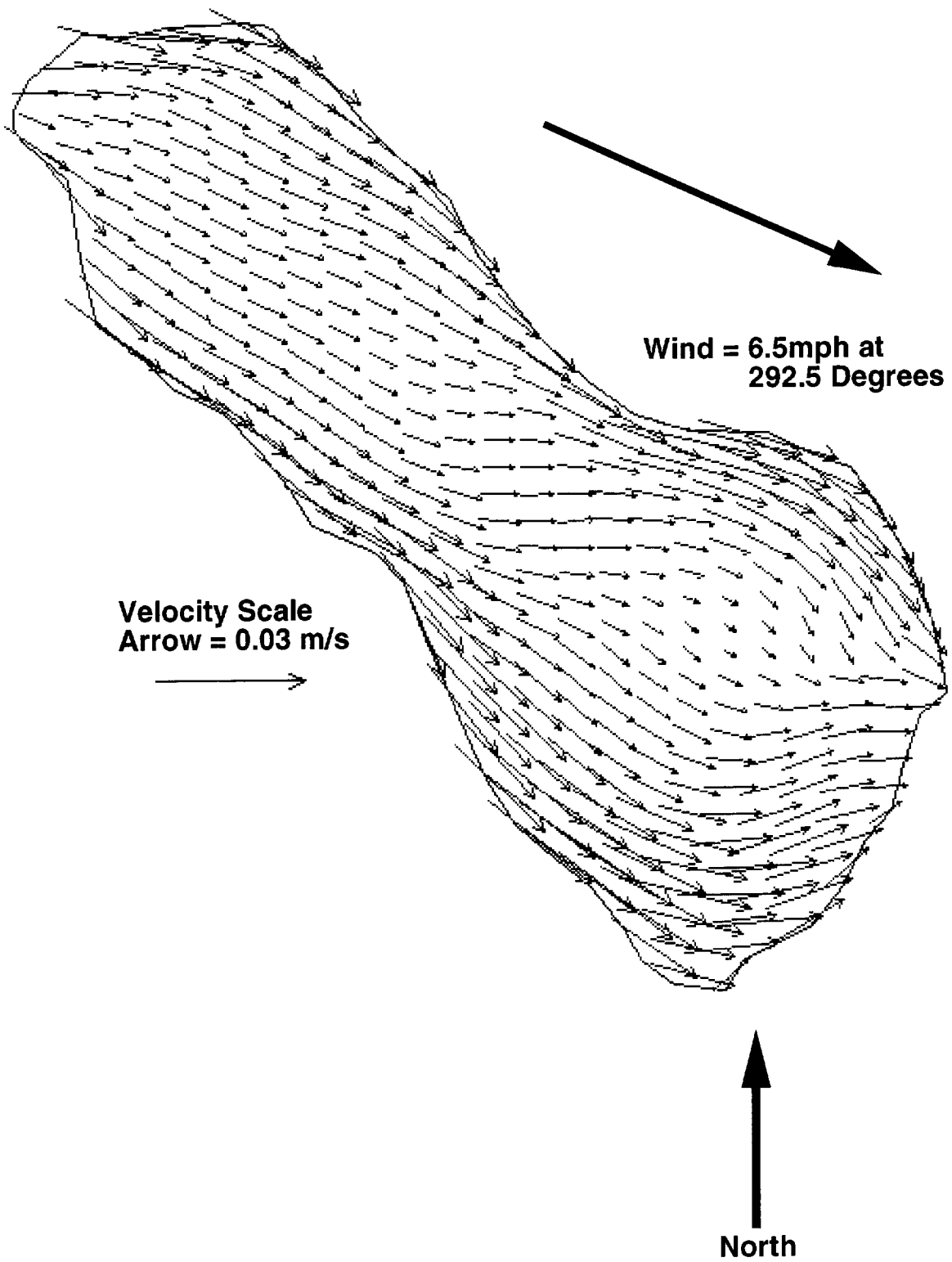
Several gyres can be seen in Figure 9. These are circulation features that occur where flow is found to rotate in either a clockwise or counter-clockwise fashion. Pollutants or other materials situated near the center of these gyres would tend to remain in the proximity of the gyre center for extended periods of time, a factor which could be important from a water quality perspective. Water in these areas could contain high nutrient loads, and thus be more biologically active.

It should be emphasized that these results are for depth-averaged conditions over the full water column, using an uncalibrated model. Further investigation and calibration is required before this model can be considered as representative of actual system behavior.

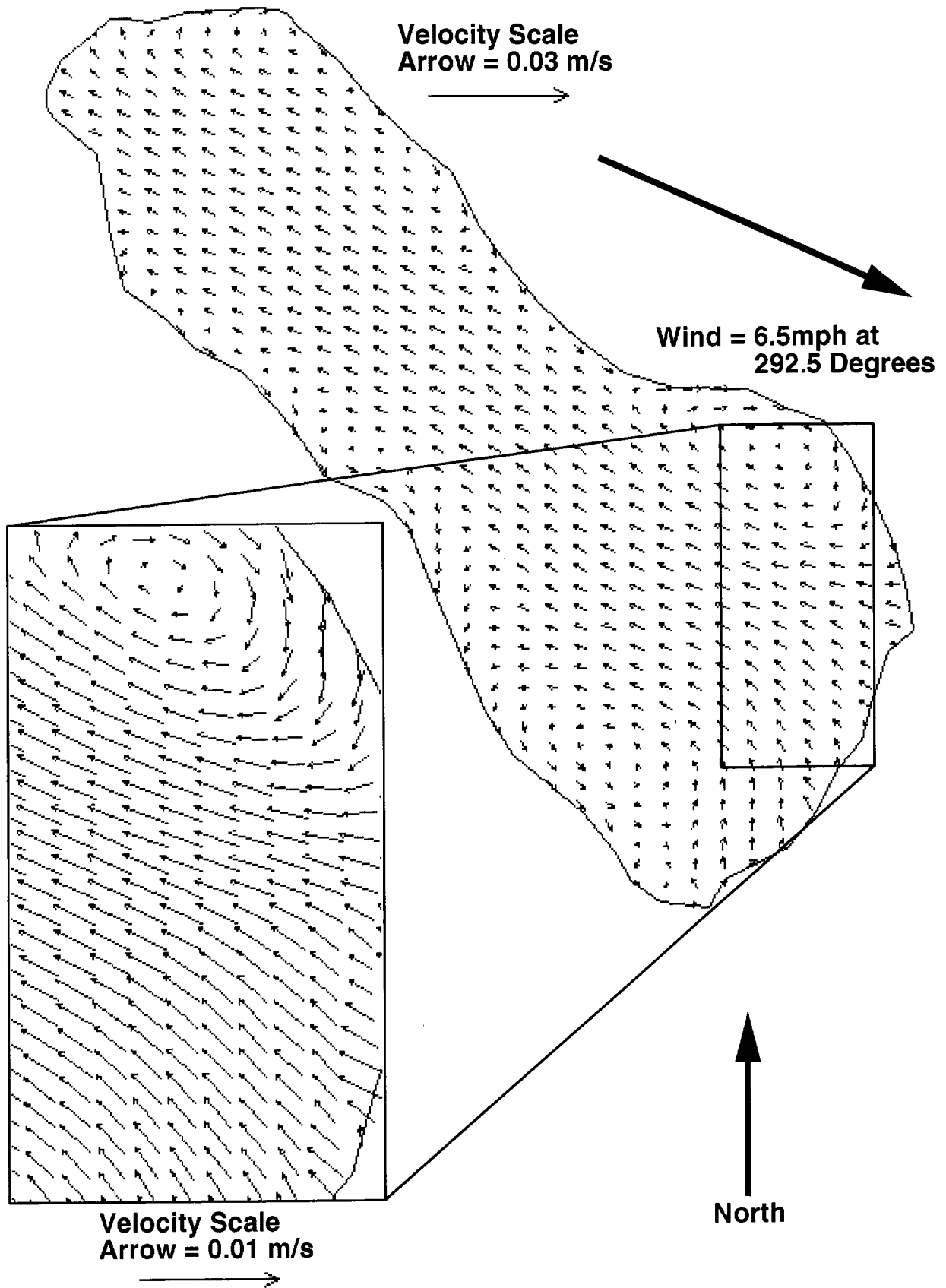
5.3 Three-Dimensional Results from RMA-10

Three-dimensional results for the base case solution are shown in Figures 10 through 12. These figures represent horizontal velocity fields at the surface (zero depth), mid-depth, and near bottom, respectively.

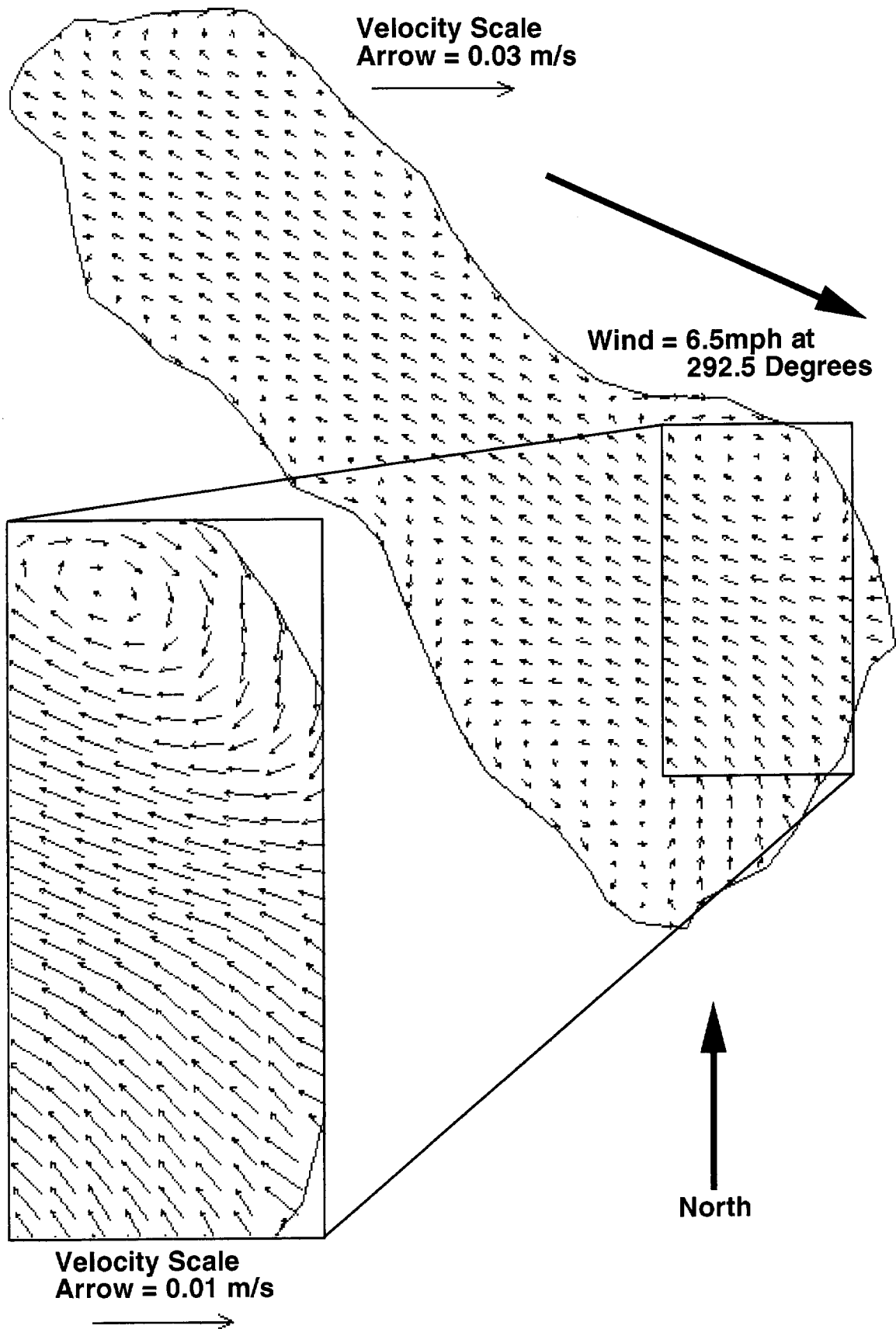
The circulation results in Figures 10 through 12 follow trends that are expected for a three-dimensional steady state circulation in a wind driven water body. The surface layer exhibits high velocity vectors generally in the direction of the wind. Flow near the surface of the sea is seen to travel southeast until it comes close to the shoreline. At the southeast end of the Sea, the water surface level rises slightly due to the flow along the surface, which generates an increased hydrostatic pressure, resulting in a downward flow, or a downwelling (negative vertical velocities). Along the bottom, the flow is for the most part in a direction opposite to the wind, returning water back toward the northwest part of the Sea. As the flow approaches the northwest boundary, water rises upward to the surface, creating an upwelling (positive vertical velocities). At exactly the mid-depth of the sea, the flow is generally in a direction opposite to the wind. It is in this mid-depth region that gyres are most visible. These gyres can be seen at several locations,



**Figure 10 Three-Dimensional Circulation Results
Surface Velocity Vectors**



**Figure 11 Three-Dimensional Circulation Results
Mid-Depth Velocity Vectors**



**Figure 12 Three-Dimensional Circulation Results
Near Bottom Velocity Vectors**

the strongest of which are found in the southern part of the Sea. Flow in these gyres not only circulates horizontally around the center of the gyre, but also vertically. For example, consider water quality contaminants at the surface of the Sea. These contaminants could be driven downward in the water column, as well as circulating horizontally around the center of the gyre.

The results presented in these figures are for an uncalibrated model, and should be treated accordingly. Calibration of the model to different meteorologic conditions, water quality parameters (such as gradients of temperature and salinity) and turbulence exchange coefficients could significantly change the results shown here. However, given the limitations of the data presently available and the approximations described above the results are encouraging. There is no evidence of behavior that is inconsistent with the fundamental principles of hydrodynamics as they apply to surface water systems.

5.4 Particle Tracking Program

Once RMA-2 and RMA-10 generated solutions for the base case, it was possible to use another program, RMATRK, that introduces hypothetical discrete particles at selected locations within the Sea, and then to observe how these particles move over time. These particles can be assigned unique properties of different entities, including algae cells, fish eggs, larvae, and discrete parcels of conservative or non-conservative substance.

The value of this particle tracking technique is manifold. First, it allows for excellent visual representation of the flow because one is able to see how particles introduced at a particular location circulate within the flow field. Second, it provides an indication of how long it takes for a particle to travel from one location to another. Third, it provides a base for statistical measurement of dispersion in the water body. The properties of RMATRK will also be useful in simulating the fate of specific life stages (e.g., fish eggs or larvae) of threatened species within the Sea.

A video tape of model results using the particle tracking algorithm has been developed in Phase I. It is available for demonstration purposes.

6. RECOMMENDATIONS FOR FUTURE INVESTIGATIONS

6.1 Simulation of in Sea Evaporation Ponds

The flexibility of the finite element method to changes in bathymetry allows for simulation of evaporation ponds within the boundaries of the Sea. The element network could be changed, following suggestions from the Salton Sea Authority, to simulate proposed impoundments. Any impoundment constructed within the Sea would effect circulation and hence the transport of nutrients. Care must be taken so that the location of such an impoundment does not in fact harm the delicate ecosystem within and near the Sea. For example, build up of nutrients in locations with reduced circulation may cause large, foul smelling algae blooms or conditions that may be lethal to fish species. Model results would allow for comparison between various proposals so that an impoundment location is chosen that causes the least amount of detrimental effect to the Sea's circulation.

6.2 Multi-Directional Dynamic Wind Testing

Wind stress applied to the surface of the Salton Sea during Phase I was uniform in direction and magnitude over the entire sea. Analysis of wind data from the three CIMIS Stations near the Sea indicates that during the spring the wind gradually changes direction as it flows from the Coachella Valley to the Imperial Valley (see Figure 1 and Table A.1). A wind that represents this curvilinear path could be applied to the surface of the sea in the hopes of generating circulation results that more closely match actual patterns. Variations in wind magnitude during the day, such as low during the morning and high during the late afternoon, could be simulated. Investigation into how sensitive the Sea's circulation patterns are to multi-directional dynamic wind stresses, especially with respect to how this affects stratification and transport of constituents within the Sea, would be very insightful.

6.3 Stratification Due to Temperature and Salinity

Stratification impedes the vertical movement, and hence mixing, of water within the water column. Stratification in the Salton Sea could be caused by several factors, the most important of which are gradients of salinity and temperature. If mixing in the Sea is prevented by stratification, then the transfer of oxygen from the surface is prevented, with a potential for harm to the aquatic ecosystem. The duration and intensity of existing stratification within the Sea is an important factor to understand before changes to the Sea's circulation pattern are performed; such as what would happen if in-Sea evaporation ponds were constructed. Stratification should be investigated by sampling both salinity and temperature at several locations within the Sea. It is plausible that the surface of the Sea, especially during summer, is much warmer than at the bottom (i.e., a temperature gradient exists). This would cause stratification if salinity is constant throughout the water column. However, variations of salinity could cause density variations that would tend to counteract this effect, such that the water column may not stratify. As was discussed in Section 2.4 of this report, existing data is inadequate to model these effects. However, if additional data becomes available in the future, the effects of temperature and salinity can be investigated.

6.4 Water Quality Investigations

The models used in Phase I can be linked with separate water quality models to simulate the transport of water quality parameters other than temperature, salinity, or sediment, including toxic substances. These models permit simulation of additional constituents entering the Sea from tributary sources, such as the New or Alamo River. It would then be possible to investigate how the transport of these constituents would change if impoundments, such as those discussed above, were constructed.

The two-dimensional model, RMA-2, is also appropriate to model the New and Alamo Rivers. The water quality models could then be linked with the river and Sea models to simulate transport from the point of pollutant entry to its terminus within the Sea. The models could be used to simulate the effects of in-Sea

impoundments combined with changes of water quality in these tributaries, such as the New River. A dramatic change in the quality and/or quantity of flow entering the Sea may have a significant impact on solution strategies necessary to improve water elevation and quality. Various scenarios investigating the future impacts of these scenarios could be completed as they become known to the Authority.

6.5 Water Balance of the Sea

A hydrologic balance of the Sea, comparing the relative magnitudes of inflow, outflow, and storage within the system, is an important step in understanding how the system will perform if it is changed, for example by construction of evaporation ponds. To date not enough information is available to permit development of an accurate water balance. It is expected that in later phases additional reliable information will be discovered about surface inflows from non-gaged returns and groundwater flows.

Water temperature data is also required to perform a water balance, so deployment of continuous temperature recording devices is desirable. This is an essential step if an energy balance technique is used to calculate evaporation rate.

Evaporation, which is the only outlet of water from the Sea, is also a function of salt content. As the salinity of the sea increases, the rate of evaporation decreases. This could be an important consideration, especially if the Sea's salinity continues to rise. It could also be of importance in design and management of evaporation ponds, within which salinity levels may be expected to be significantly greater than that of the main body of the Sea. Additional investigation of alternative methods of determining evaporation rate are required.

7. SUMMARY AND CONCLUSIONS

Problems of increasing water levels and salinity are threatening the viability of the Salton Sea as a recreational and ecological resource. Solutions are being proposed that may alter the configuration of the Sea, by isolating certain portions with physical barriers. Possible consequences of such alternatives include changes in circulation and related redistribution of nutrients, sediments, and water quality constituents that affect ecological and recreational values. To examine effects on the Sea's circulation, the Modeling Group of the Center for Water Resources and Environmental Engineering at the University of California at Davis adapted two finite element models to the bathymetry of the Sea and simulated circulation patterns induced by wind friction on the surface. Wind velocities and directions for the Phase I study were derived primarily from local meteorological stations located on the west and southeast sides of the Sea. In initial studies wind-induced circulation was simulated with the two-dimensional hydrodynamic model, RMA-2, assuming complete vertical mixing. In a subsequent simulation, a three-dimensional model, RMA-10, was used to provide more realistic representation of vertical motions accompanying shear stresses imposed on the Sea's surface. Both models indicated the likely presence of large scale gyres (rotational patterns) which could result under conditions of steady wind at about 6.5 miles per hour from the west northwest. The three-dimensional model provided the most credible results, from a fundamental hydrodynamic viewpoint.

A capability is now available to describe the general circulation patterns in the Sea and to evaluate the effects of structural modifications aimed at controlling salinity. Additional improvements are needed to account for the effects of stratification related to vertical differences in temperature and salinity, to accommodate the influences of inflows on water quality, and to consider variations in wind strength and direction over the Sea surface. There is a need to obtain direct measurements of water currents, wind and other atmospheric characteristics, and water quality in support of model development and application.

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APPENDIX A

Wind Analysis Results

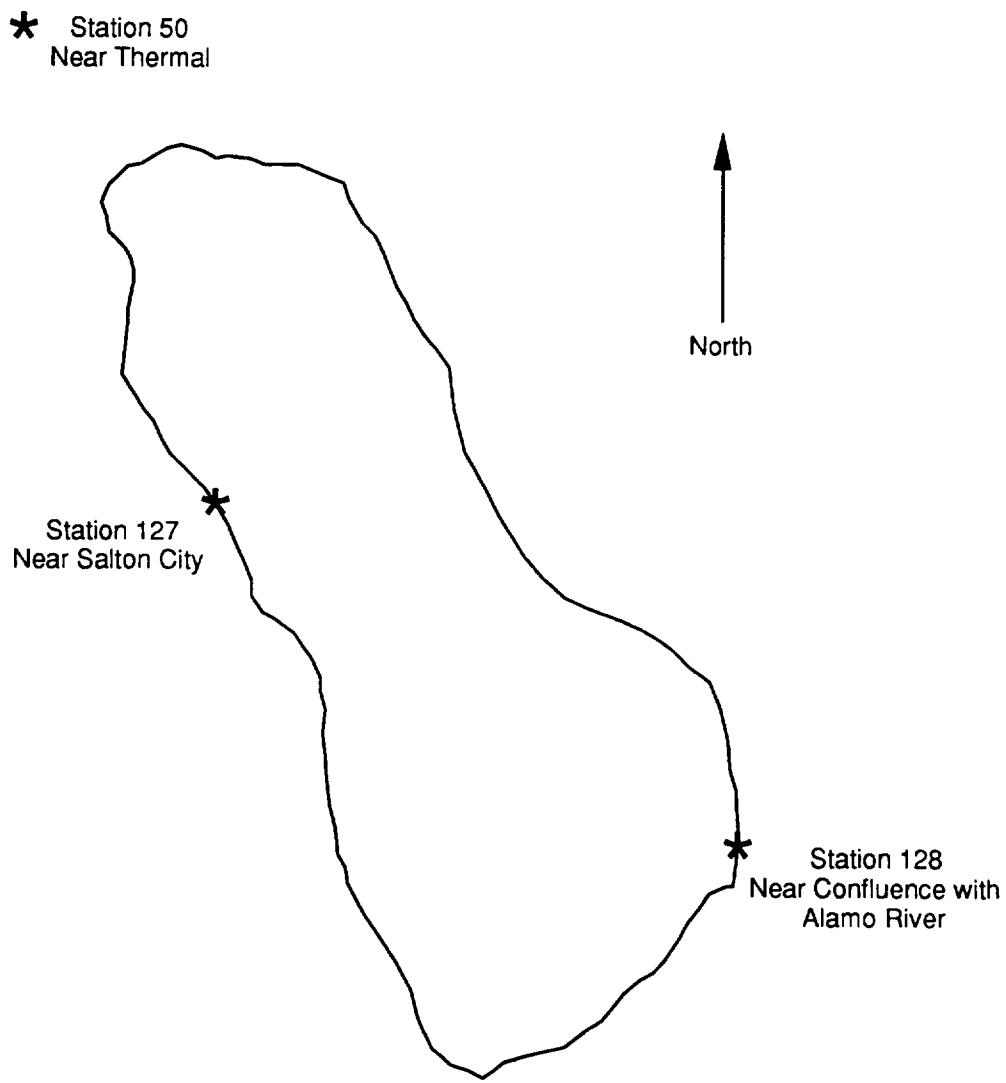


Figure A.1 Map of CIMIS Station Locations

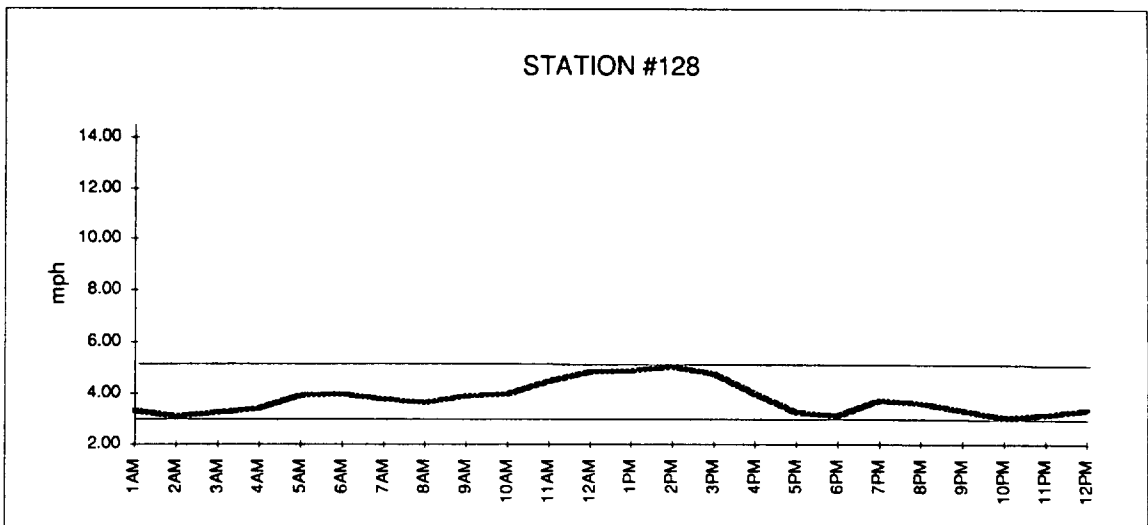
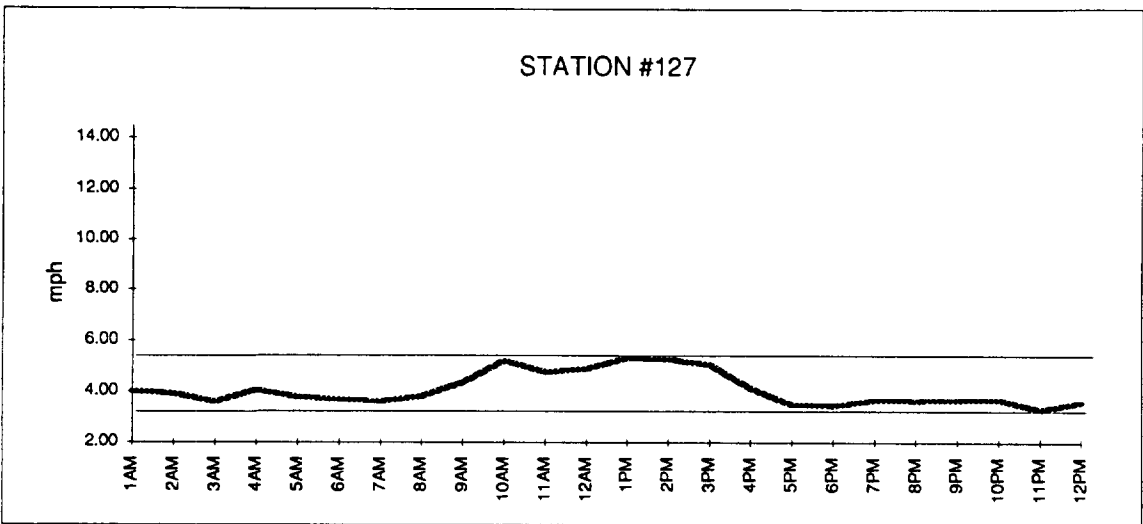
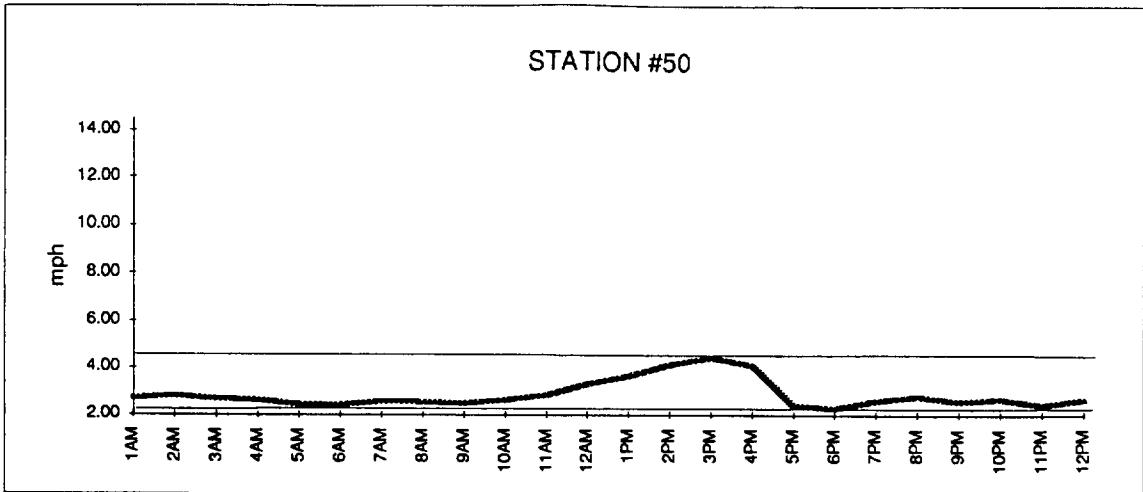


Figure A.2 Hourly Wind Averages for December 1994

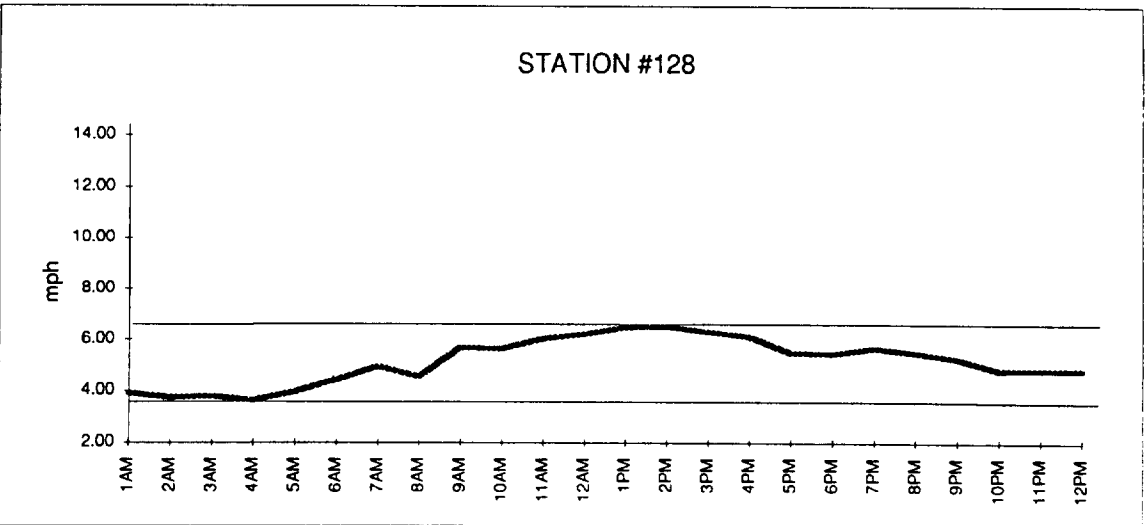
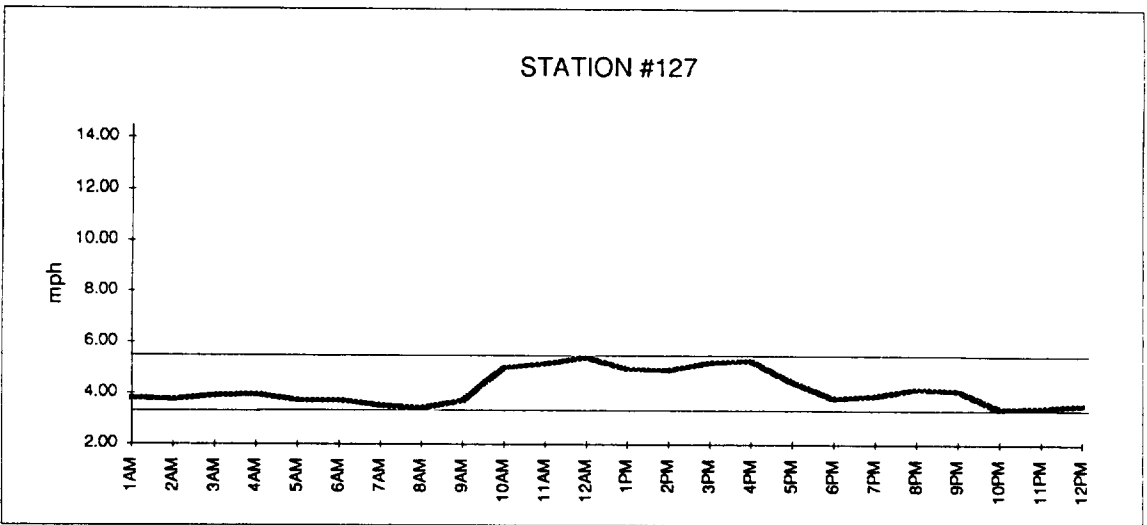
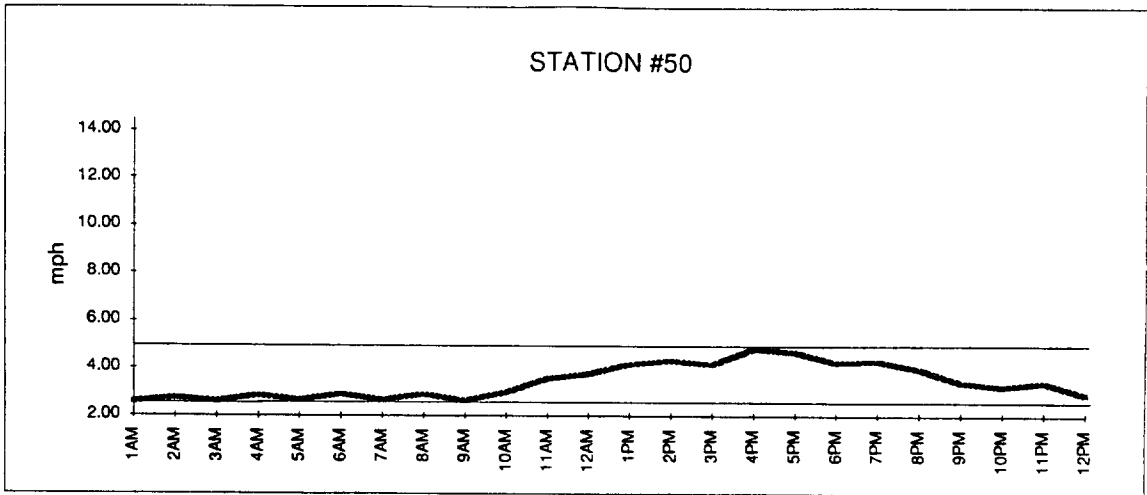


Figure A.3 Hourly Wind Averages for January 1995

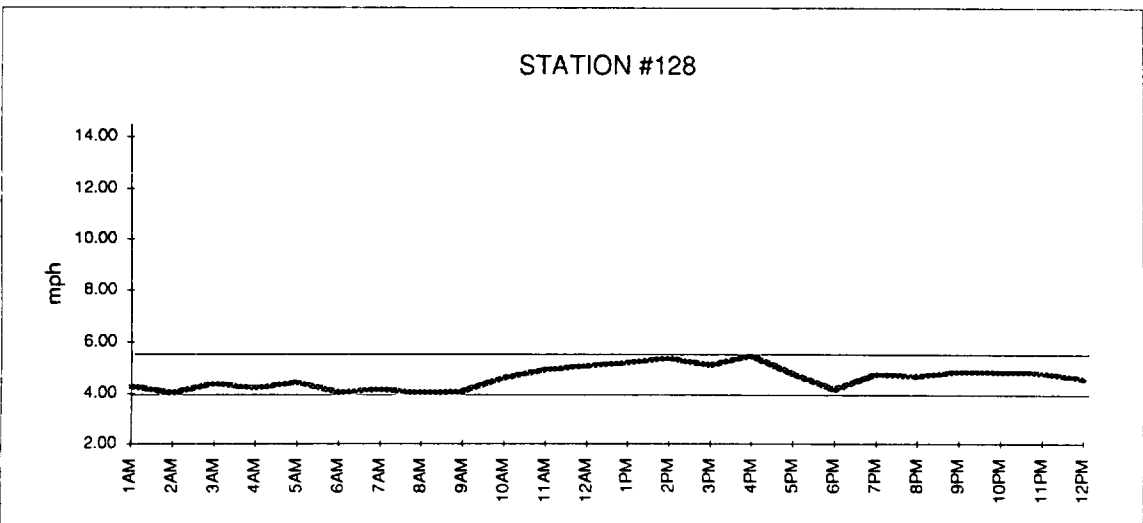
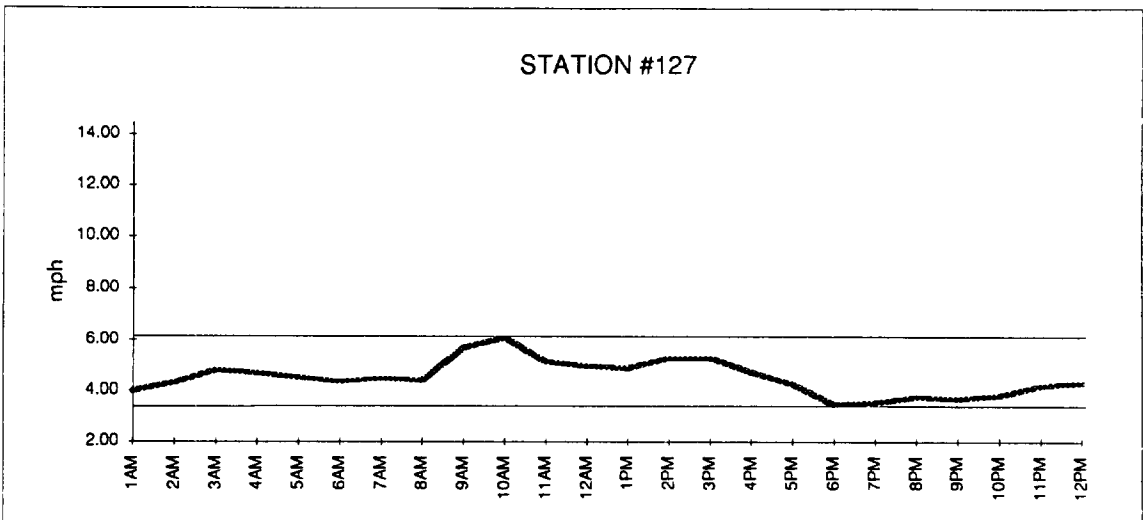
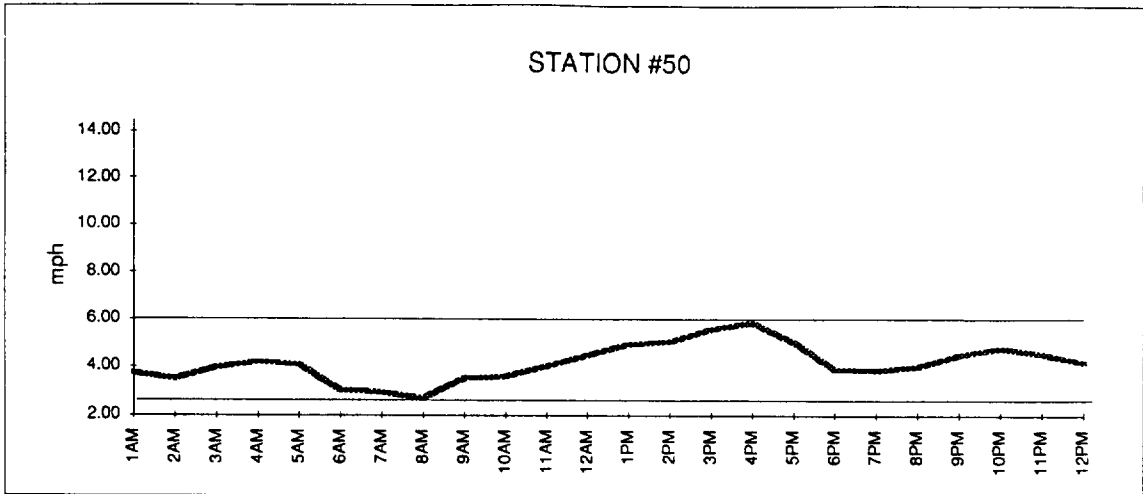


Figure A.4 Hourly Wind Averages for February 1995

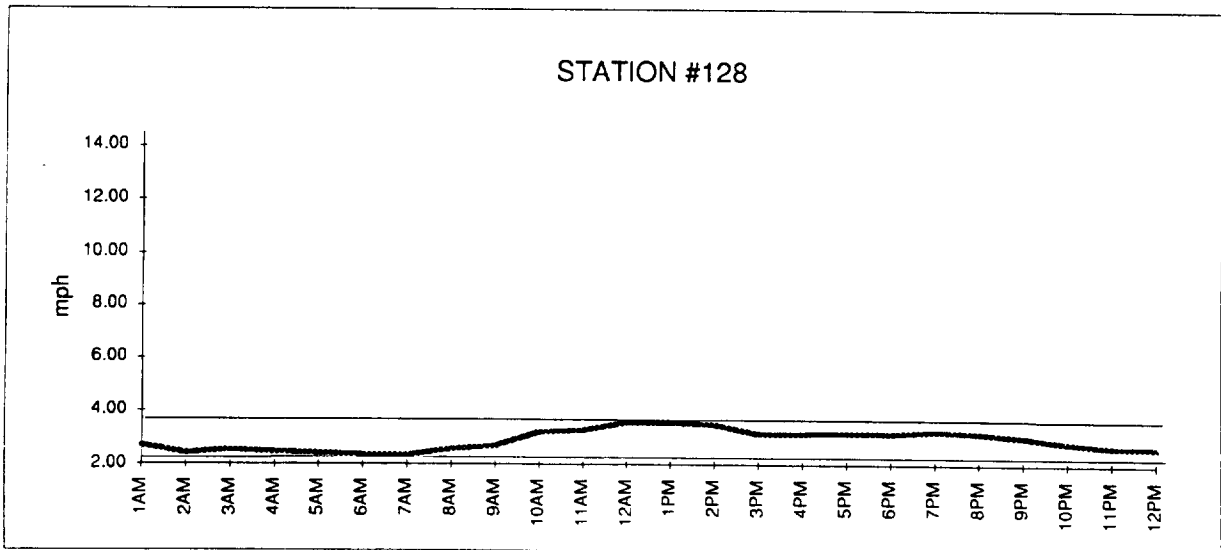
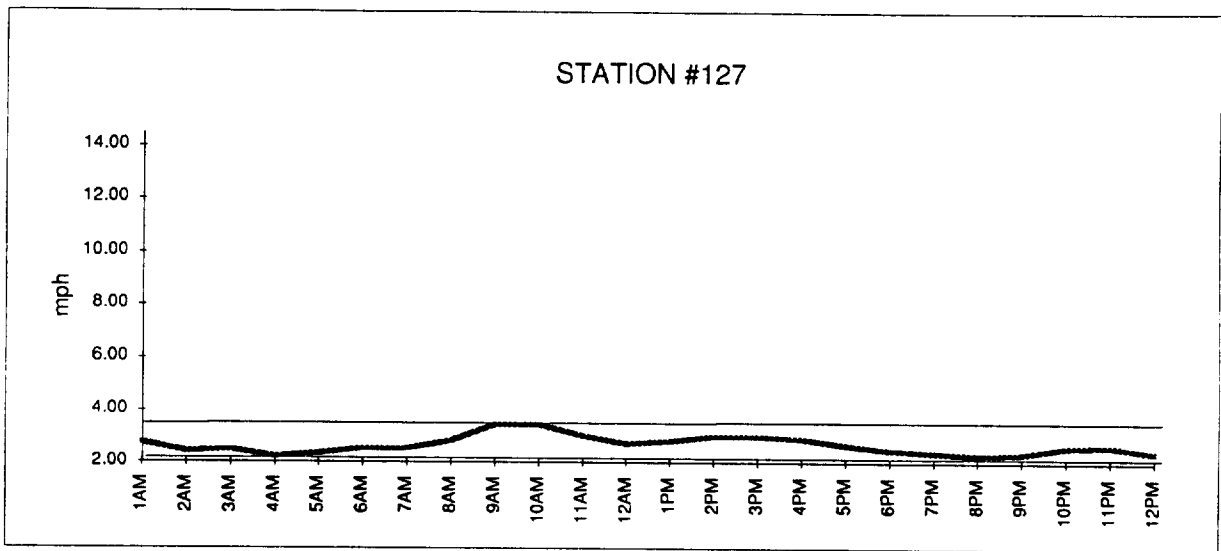
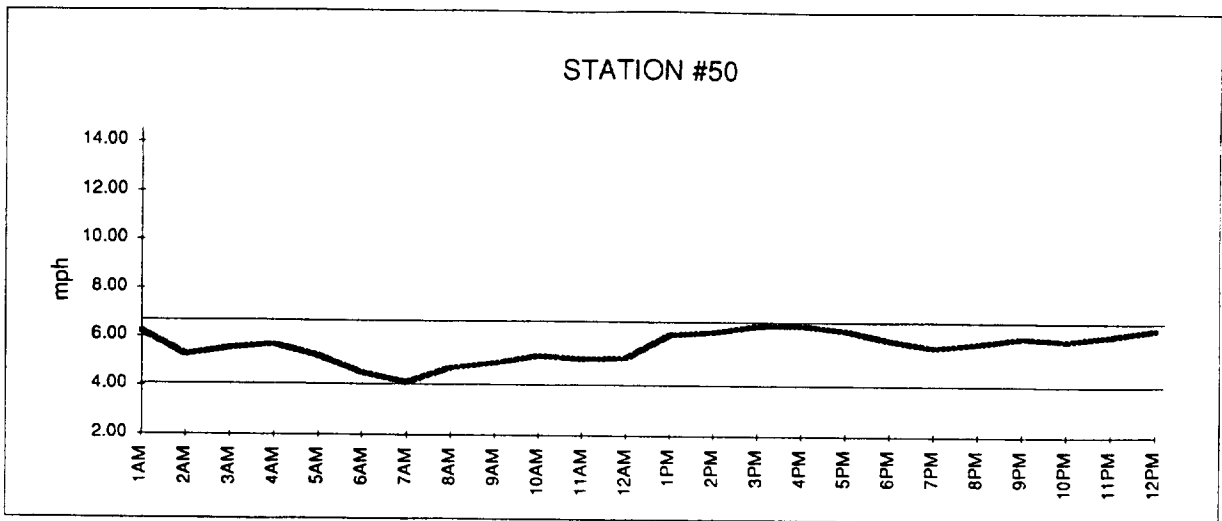


Figure A.5 Hourly Wind Averages for March 1995

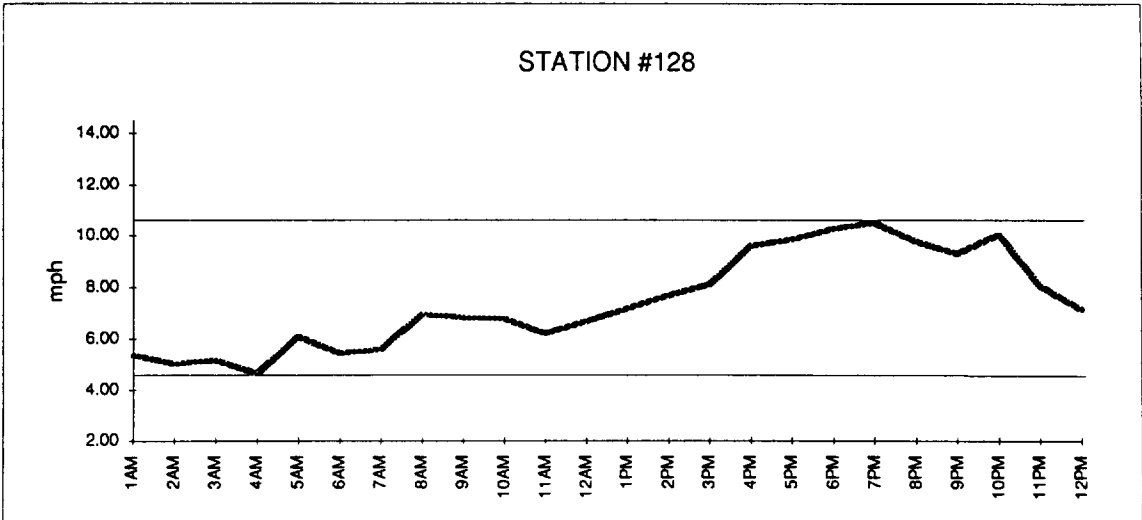
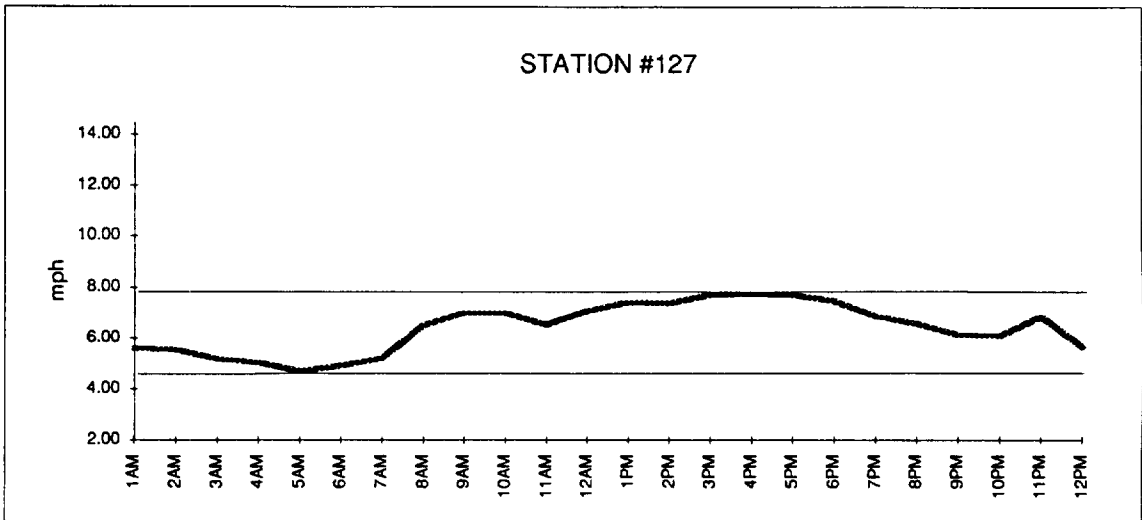
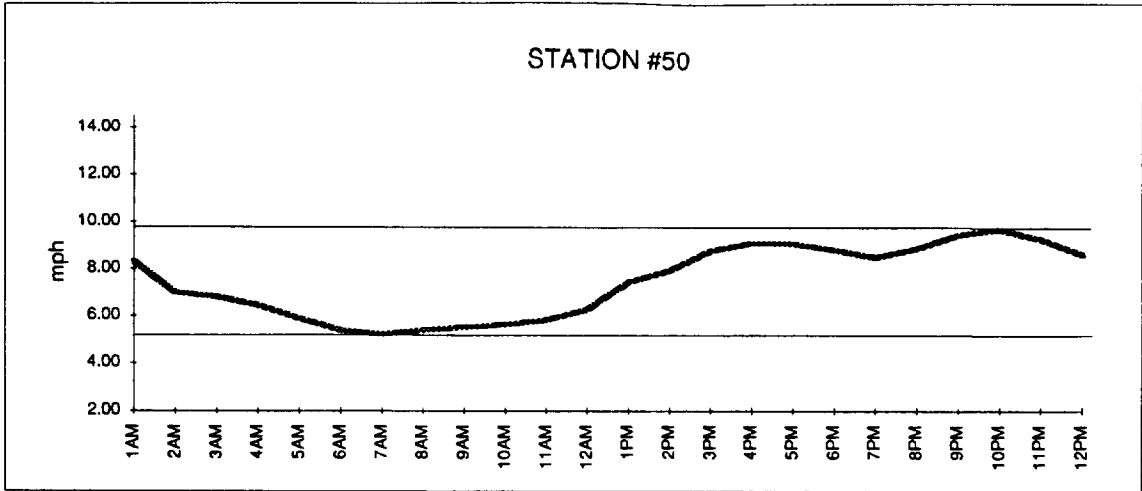


Figure A.6 Hourly Wind Averages for April 1995

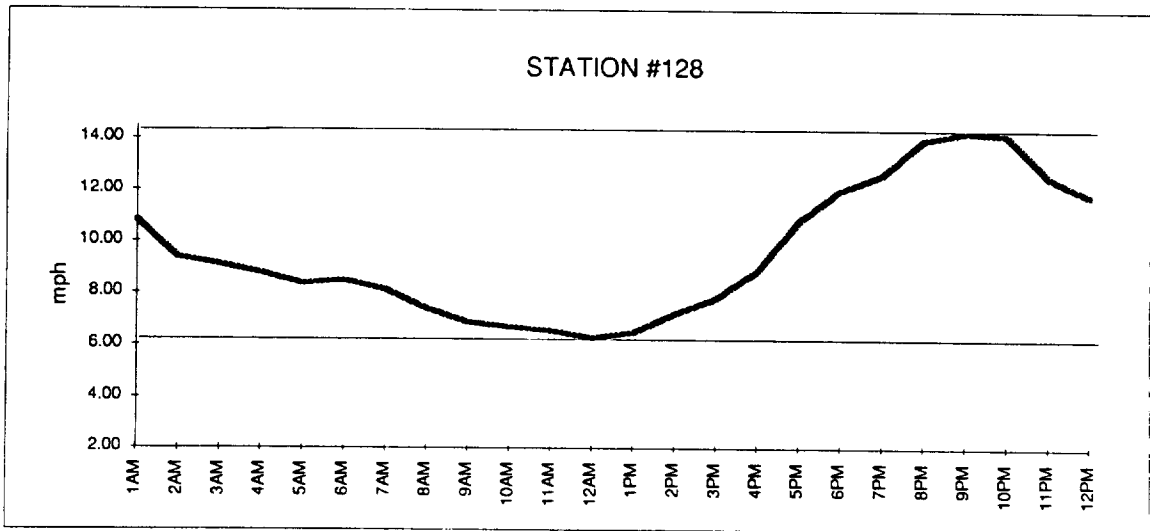
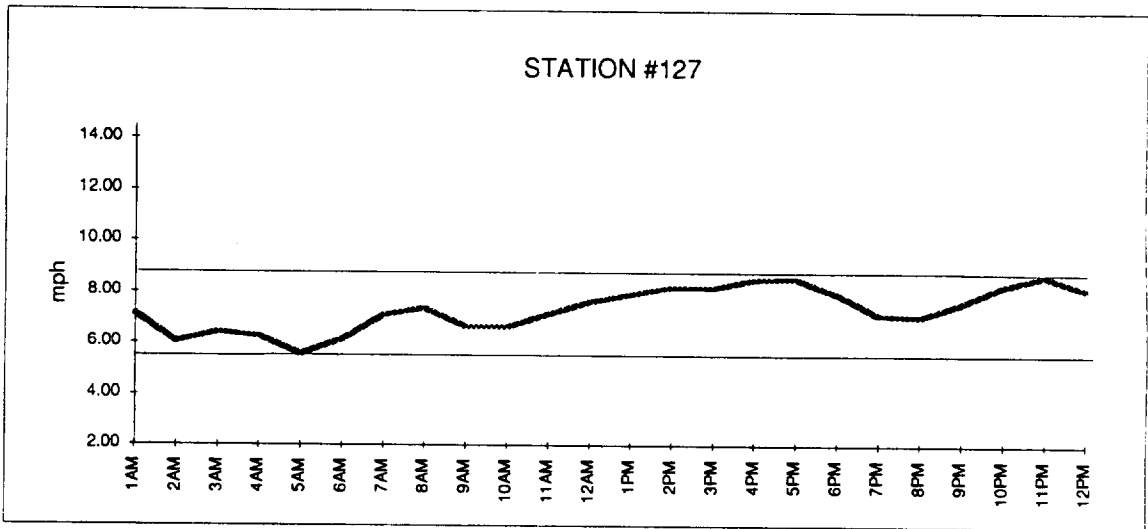
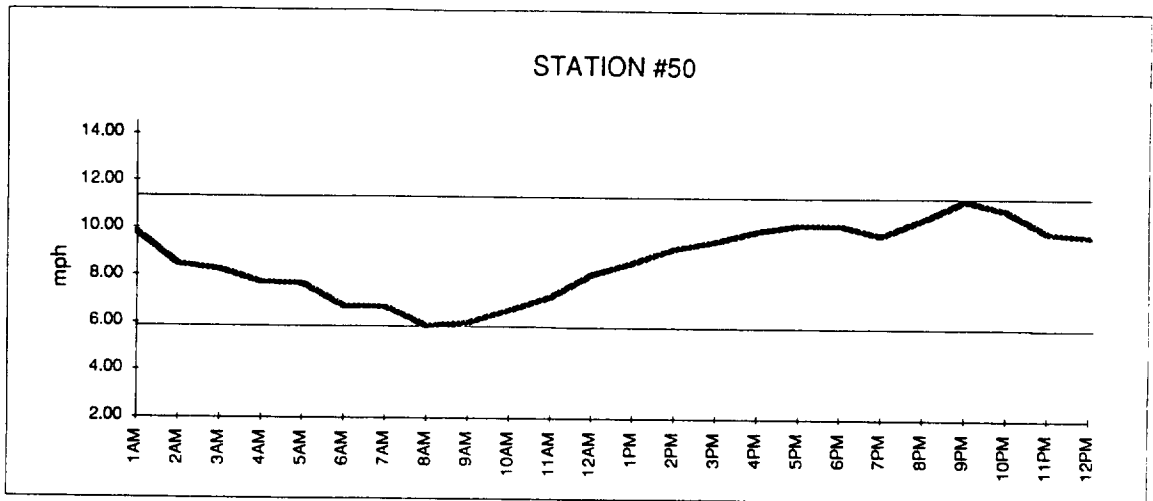


Figure A.7 Hourly Wind Averages for May 1995

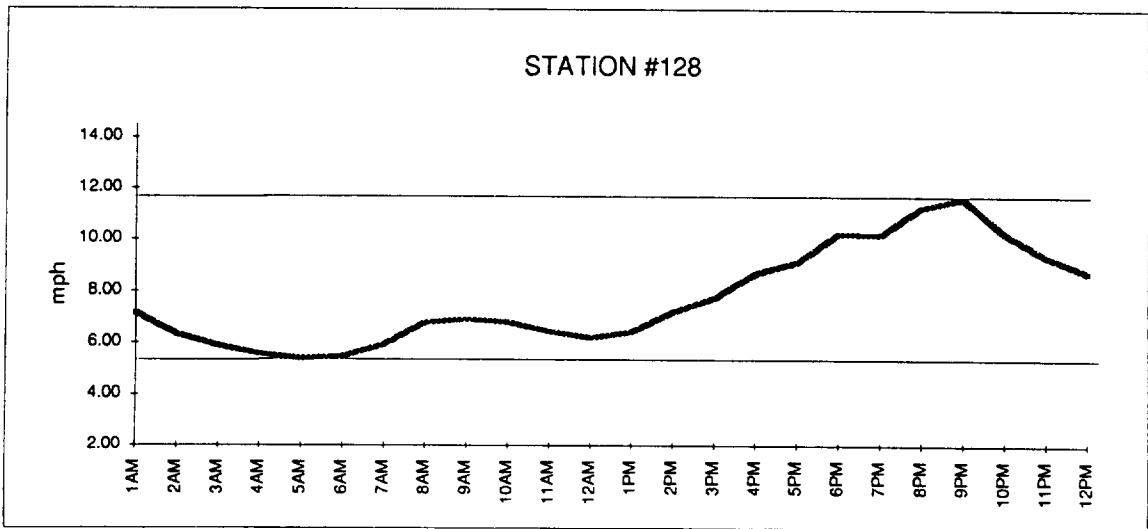
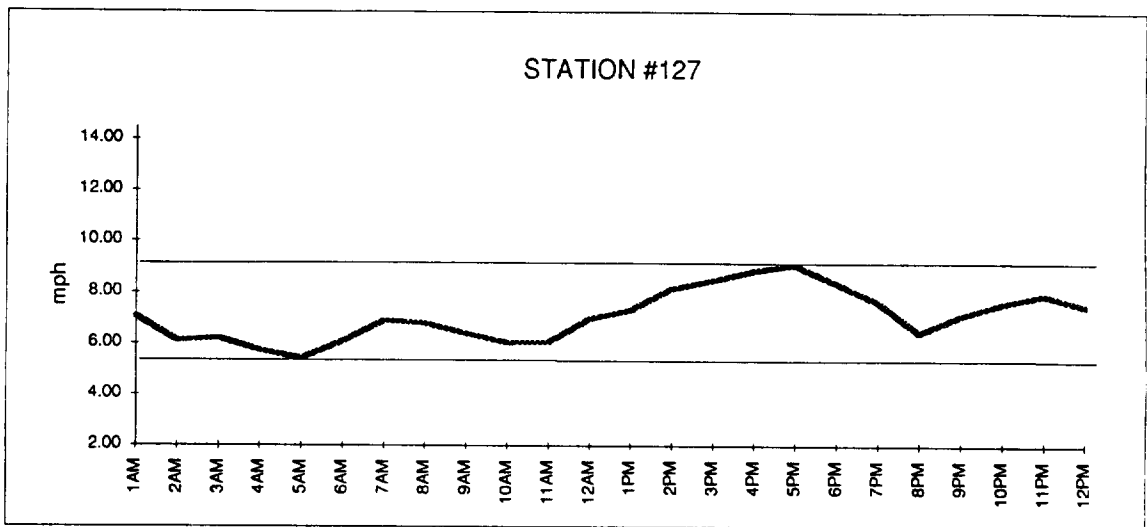
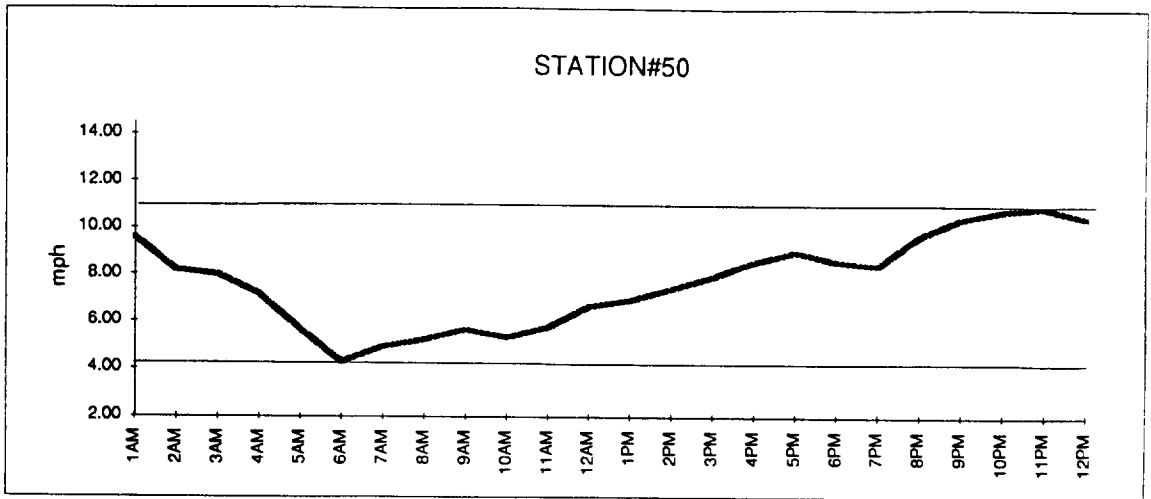


Figure A.8 Hourly Wind Averages for June 1995

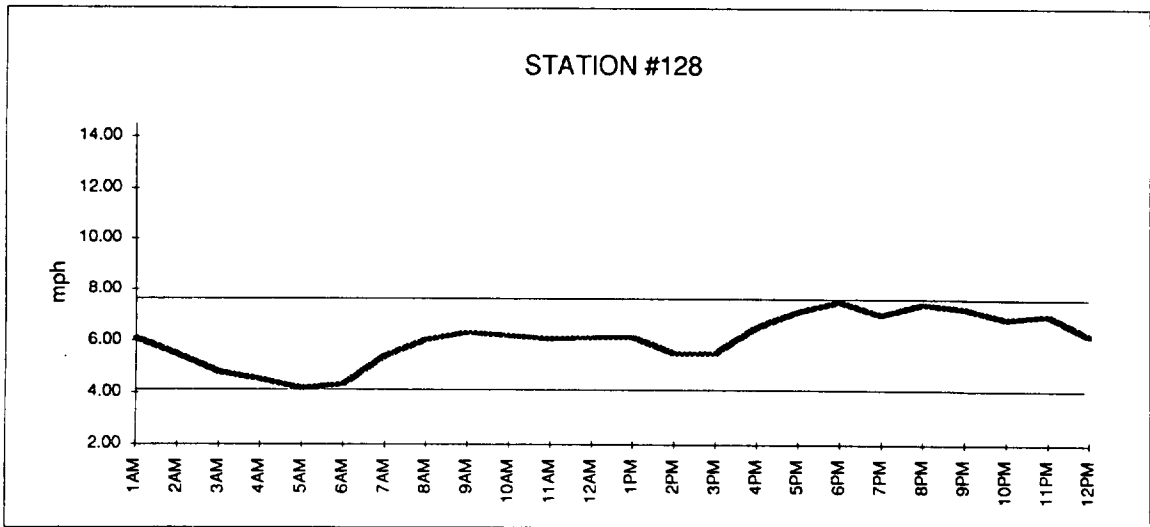
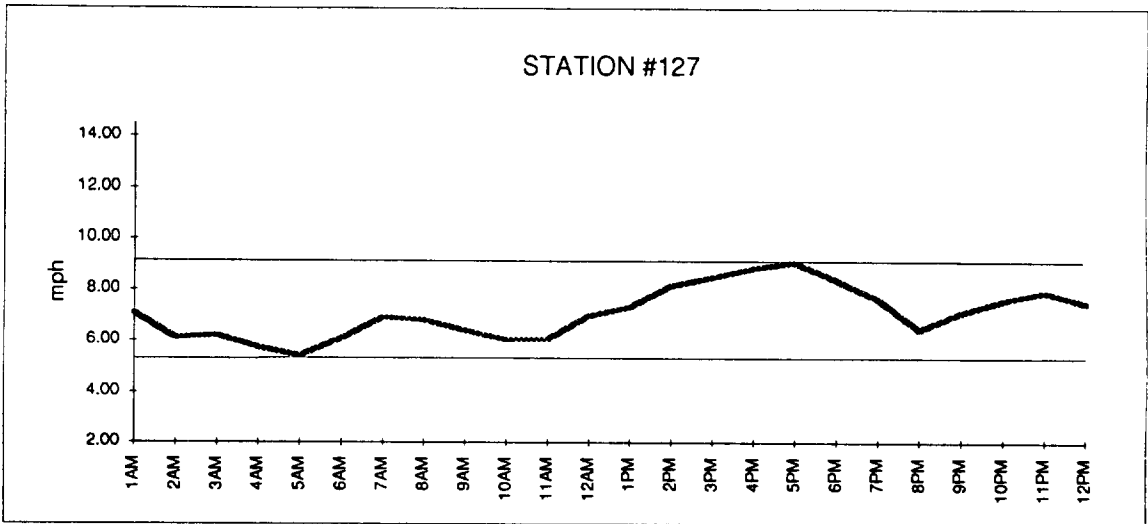
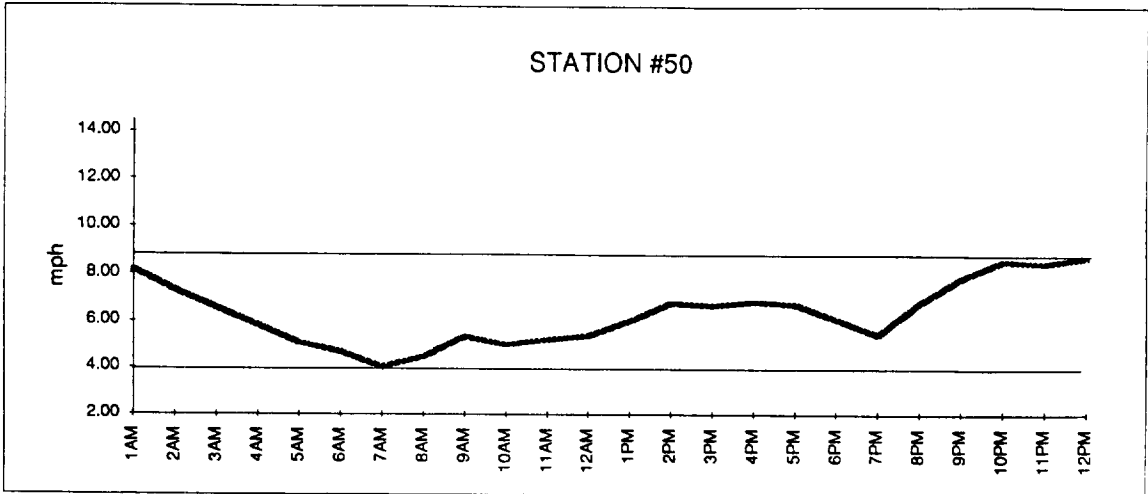


Figure A.9 Hourly Wind Averages for July 1995

Table A.1
Wind Data Summary
December 1994 to July 1995

December 1994					
	Station #	Predominant Direction	Velocity Mean	Velocity Min.	Velocity Max.
North of Sea	Station 50	N	2.86	0.99	12.37
East Salton Sea	Station 127	SW or W	4.08	1.22	19.80
West Salton Sea	Station 128	E or SE	3.77	1.17	13.97
January 1995					
	Station #	Predominant Direction	Velocity Mean	Velocity Min.	Velocity Max.
North of Sea	Station 50	N	3.45	1.00	23.69
East Salton Sea	Station 127	NW	4.19	1.02	15.30
West Salton Sea	Station 128	E or SE	5.16	1.25	23.71
February 1995					
	Station #	Predominant Direction	Velocity Mean	Velocity Min.	Velocity Max.
North of Sea	Station 50	N	4.18	1.15	20.29
East Salton Sea	Station 127	NW	4.53	1.25	16.60
West Salton Sea	Station 128	SE	4.62	1.21	18.92
March 1995					
	Station #	Predominant Direction	Velocity Mean	Velocity Min.	Velocity Max.
North of Sea	Station 50	N	5.66	1.07	24.81
East Salton Sea	Station 127	NW	6.03	1.33	18.59
West Salton Sea	Station 128	W	6.28	1.68	27.74
April 1995					
	Station #	Predominant Direction	Velocity Mean	Velocity Min.	Velocity Max.
North of Sea	Station 50	N	7.48	1.49	32.57
East Salton Sea	Station 127	NW	6.71	1.38	20.00
West Salton Sea	Station 128	W	8.13	1.74	29.44
May 1995					
	Station #	Predominant Direction	Velocity Mean	Velocity Min.	Velocity Max.
North of Sea	Station 50	N	8.72	1.37	28.57
East Salton Sea	Station 127	NW	7.35	1.74	20.96
West Salton Sea	Station 128	W	9.57	1.58	31.90
June 1995					
	Station #	Predominant Direction	Velocity Mean	Velocity Min.	Velocity Max.
North of Sea	Station 50	N	7.73	1.23	29.97
East Salton Sea	Station 127	NW or E	7.06	1.45	20.13
West Salton Sea	Station 128	W	7.75	1.63	29.42
July 1995					
	Station #	Predominant Direction	Velocity Mean	Velocity Min.	Velocity Max.
North of Sea	Station 50	N	5.77	0.33	16.02
East Salton Sea	Station 127	NW	5.74	0.21	16.65
West Salton Sea	Station 128	W or SW or SE	5.63	0.24	23.38