Appendix I

DISPERSION CHARACTERISTICS FOR PALM BEACH AND PORT EVERGLADES OCEAN DREDGED MATERIAL DISPOSAL SITES (ODMDSs)

Miscellaneous Paper CHL-98-xx
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US Army Corps
of Engineers
Waterways Experiment
Station

Dispersion Characteristics for Palm Beach and Port Everglades Ocean Dredged Material Disposal Sites (ODMDSs)

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Coastal and Hydraulics Laboratory

Approved for Public Release; Distribution is Unlimited

Prepared for U.S. Army Engineer District, Jacksonville

Preface

The study reported herein was conducted by the U.S. Army Engineer, Waterways Experiment Station (WES), Coastal and Hydraulics Laboratory (CHL) for the U.S. Army Engineer District, Jacksonville (SAJ). The work was conducted during the period July 1997 through May 1998 under the general supervision of Dr. James R. Houston, Mr. Charles C. Calhoun, Jr., Director and Assistant Director, CHL, Mr. Thomas R. Richardson, Chief, Coastal Sediments and Engineering Division, CHL, and Mr. Bruce A. Ebersole, Chief, Coastal Processes Branch, CHL. Principal Investigators for this study were Ms. Mary A. Cialone, Research Hydraulic Engineer, CHL, and Ms. Linda Lillycrop, Research Hydraulic Engineer, CHL. This report was prepared by Ms. Cialone and Ms. Lillycrop.

Acknowledgments are extended to the following for their contributions to this study: Don Fore, SAJ, for sponsoring this project; Chris McArthur, EPA, and Lynn Griffin, Florida DNREC for reviewing data analysis performed for this project; Doug Wilson, NOAA, for providing velocity data used in this project; Mary Claire Allison, CHL, for data analysis; and Paul Schroeder, EL, Norm Scheffner, Joe Gailani, and Jim Clausner, CHL, for assistance in model applications and interpretation of model results.

Director of WES during the investigation and publication of this report was Dr. Robert W. Whalin. Commander was COL Robin Cababa.

1 Introduction

Dredging of coastal inlets and harbors in the United States is often required to maintain navigable depths. The designation of acceptable disposal sites for this material is, however, becoming increasingly difficult. Open water disposal sites are often selected as a means of minimizing any adverse effects resulting from the disposal of material in the vicinity of the dredging operation. The designated open water site must be far enough removed from any environmentally-sensitive areas so that material leaving the site, if any, will not adversely impact these sensitive areas. The selection of an environmentally-acceptable placement location for the dredged material requires some means of predicting the fate of the disposed sediment. Numerical models can be used to simulate the short- and long-term fate of dredged material.

This report documents a technical study conducted by the U.S. Army Engineer Waterways Experiment Station (WES) for the U.S. Army Engineer District, Jacksonville (SAJ) to estimate the short- and long-term sediment dispersion characteristics of the Palm Beach Harbor and Port Everglades Harbor Ocean Dredged Material Disposal Sites (ODMDSs). Modeling of the short-term fate was performed with the STFATE model (Johnson et al., 1993) and modeling of the long-term fate was conducted with the LTFATE model (Scheffner et al., 1995). Entrainment and transport of material both during the disposal operation and following deposition of material within the ODMDSs will be discussed. Each site is expected to accommodate the annual disposal of 38,230 m^3 (50,000 c.y.) of material to be dredged for maintenance of both the Palm Beach Harbor Federal Project and the Port Everglades Harbor Federal Project.

The Environmental Protection Agency (EPA) has expressed concern regarding the fate of dredged material disposed at the ODMDSs due to its proximity to the Gulf Stream and its spin-off eddies. Apprehension arises from the belief that these eddies will cause material to be transported onto shore-parallel coral reefs located 1.9-3.7 km (1-2 n.m.) offshore of the barrier islands (5.3-6.1 km (2.9-3.3 n.m.) from the ODMDSs). The possibility of resuspension and material transport from the ODMDS during storm events is also an expressed concern.

Project Locations

Port Everglades Harbor, Florida. The ODMDS is located east-northeast of Port Everglades and approximately 7.4-9.2 km (4-5 n.m.) offshore (Figure 1). The 3.4 km^2 (1 square nautical mile) site is defined by the following corner points:

26° 07' 30"N, 80° 02' 00"W
26° 07' 30"N, 80° 01' 00"W
26° 06' 30"N, 80° 02' 00"W ok
26° 06' 30"N, 80° 01' 00"W

The site is centered at 26° 07' 00"N, 80° 01' 00"W. The ODMDS is located on the upper continental shelf with depths ranging from 176 to 217 m (577 to 712 ft) (Figure 2).

Palm Beach Harbor, Florida. The ODMDS is located east-northeast of Lake Worth Inlet and approximately 8.3 km (4.5 n.m.) offshore (Figure 3). The 3.4 km^2 (1 square nautical mile) site is defined by the following corner points:

26° 47' 30"N, 79° 57' 09"W
26° 47' 30"N, 79° 56' 02"W ok
26° 46' 30"N, 79° 56' 02"W
26° 46' 30"N, 79° 57' 09"W

The site is centered at 26°47'00"N, 79°56'33"W. The ODMDS is located on the upper continental slope with depths ranging from 155 to 185 m (509 to 607 ft) (Figure 4).

Previous Studies

Numerous investigators have examined sediment and current characteristics in the vicinity of the present project sites (Lee et al., 1977; Williams and Lee, 1987; Bane and Brooks, 1979). Lee et al. (1977) found that although the Florida Current has complex structure and variability, available data could be used to determine statistical mean and typical deviations of the horizontal distribution of currents and related quantities at several representative levels of depth. For a summary description of the Gulf Stream and Gulf Stream meanders, the reader is referred to Maritimes, Vol 35, No 1, February 1991 (this issue is devoted to Focus on the Gulf Stream) or Scheffner and Swain (1989).

Several studies of sediment dispersion characteristics have been accomplished as well (Scheffner and Swain, 1989; Thevenot and Johnson, 1994; Tsai et al., 1992; Proni et al., 1991). Scheffner and Swain (1989) investigated the suitability of sediment disposal sites off the coast of Miami and Fort Pierce and their potential impact on shore-parallel coral reefs located approximately 1.9-3.7 km (1-2 n.m.) offshore. Model simulations of disposal and sediment transport as a function of local velocity fields indicated little possibility of reef contamination from the proposed ODMDSs. (The present study sites are located between the Miami and Fort Pierce sites.) Thevenot and Johnson (1994) monitored dredged material plumes offshore of Miami to assess the validity of a short-term fate numerical model for predicting the fate of dredged material. They found the model properly simulates the behavior of dredged material disposed in open water and accurately predicts suspended sediment concentrations and the dilution of those concentrations. This model was used in the present study.

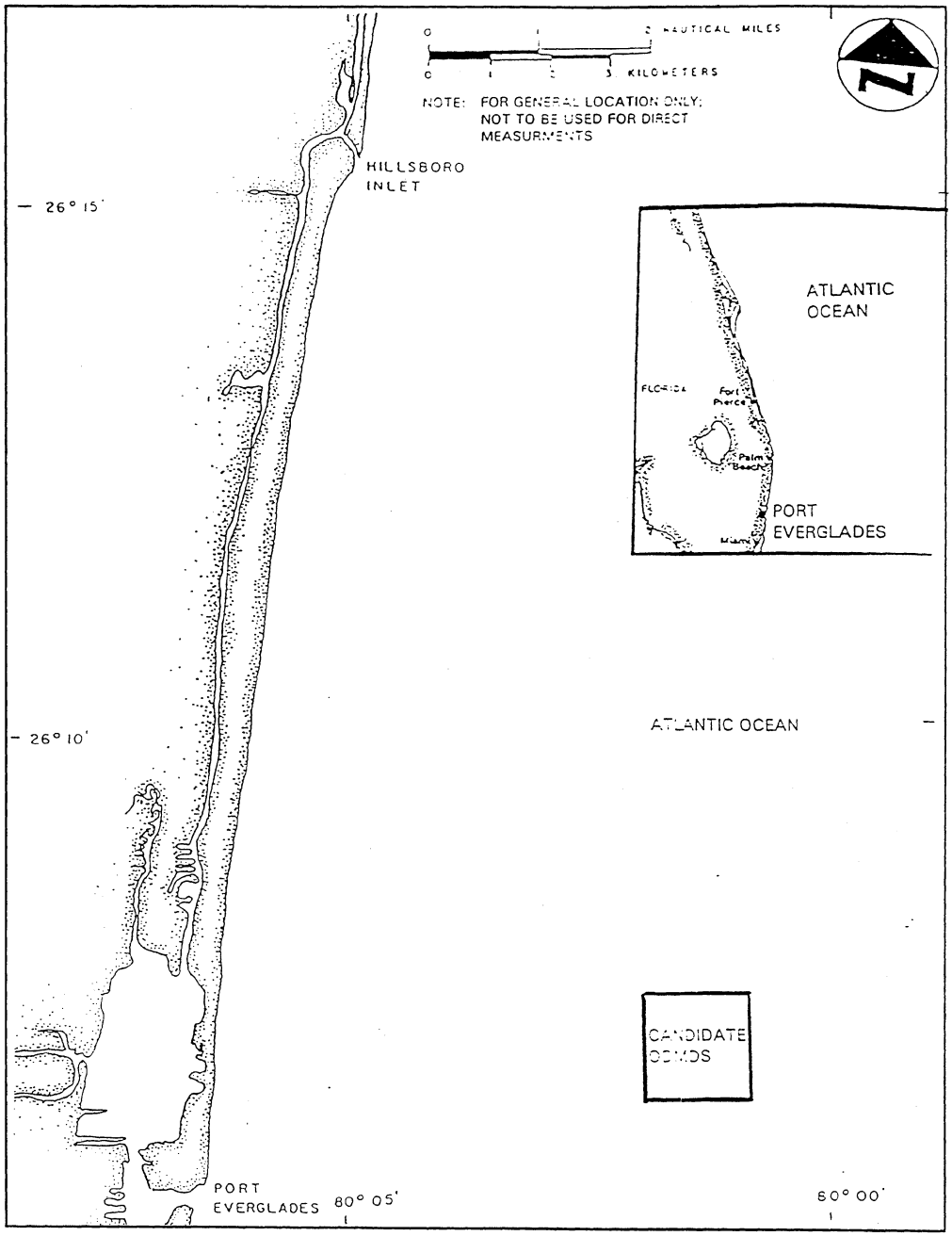


Figure 1. Location map of the Proposed ODMDS, Port Everglades, FL (from Continental Shelf Associates, Inc. 1989)

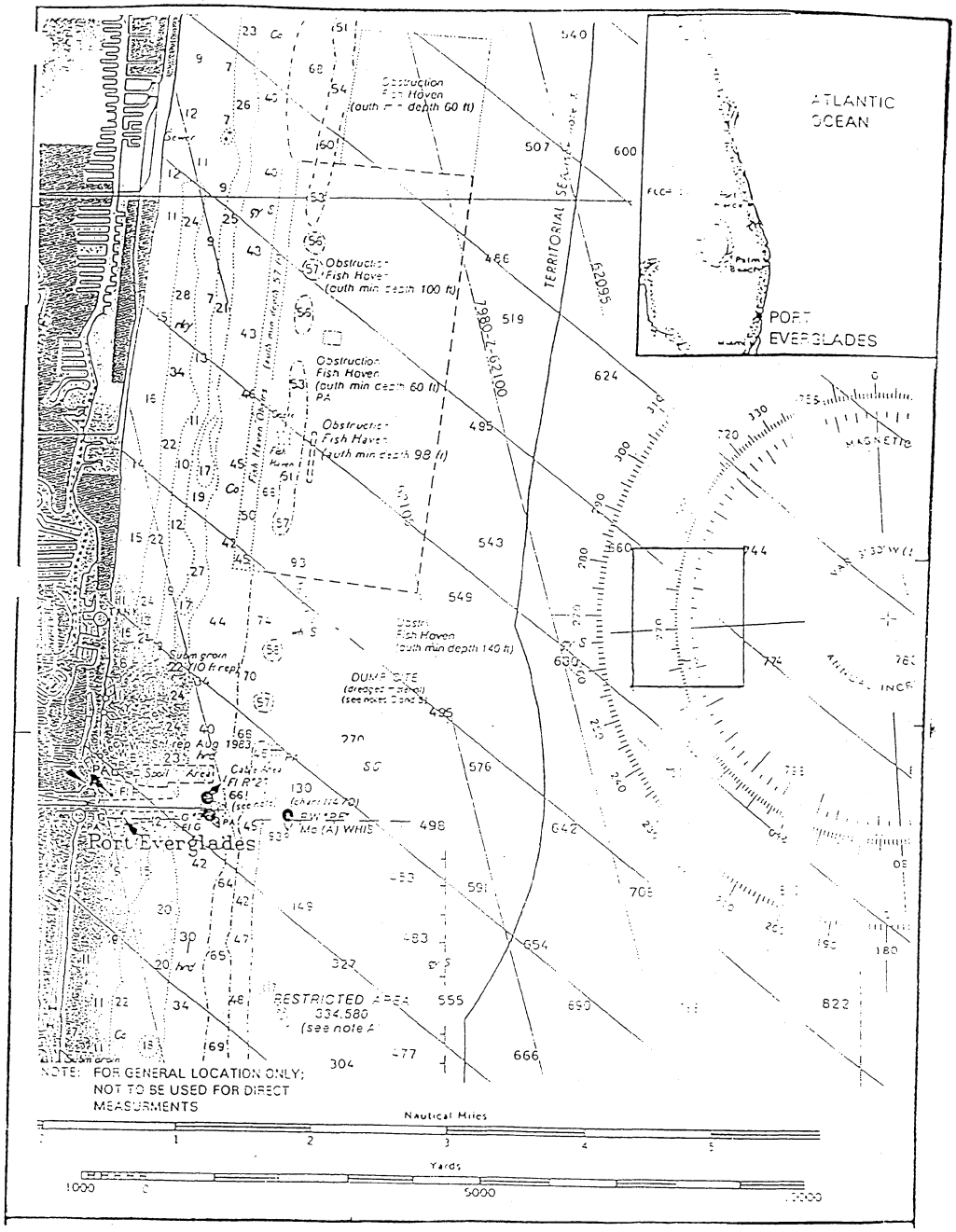


Figure 2. Bathymetry in the vicinity of the proposed Port Everglades Harbor ODMDS (from NOAA, 1989)

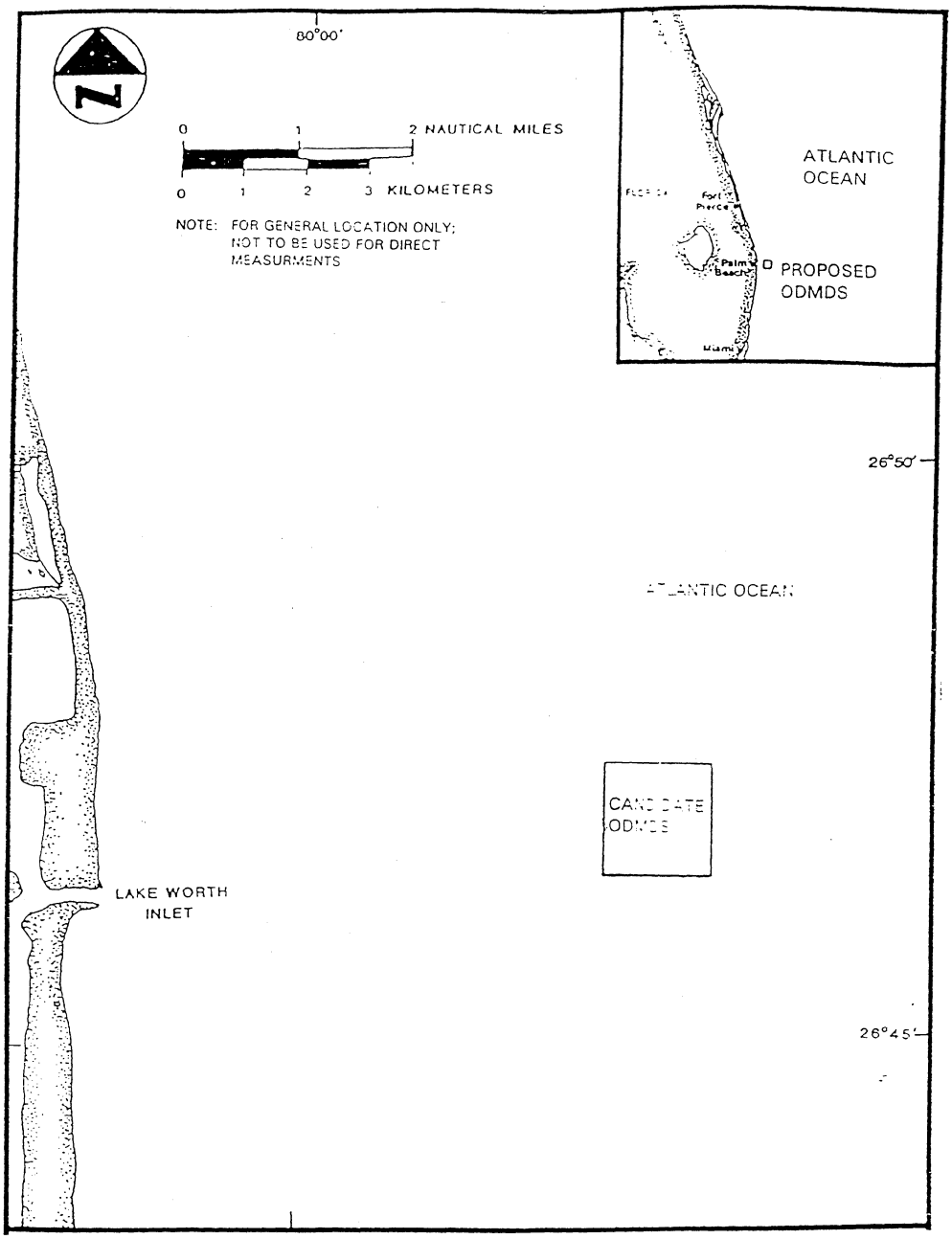


Figure 3. Location map of the proposed ODMDS, Palm Beach Harbor, FL (from Continental Shelf Associates, Inc., 1989)

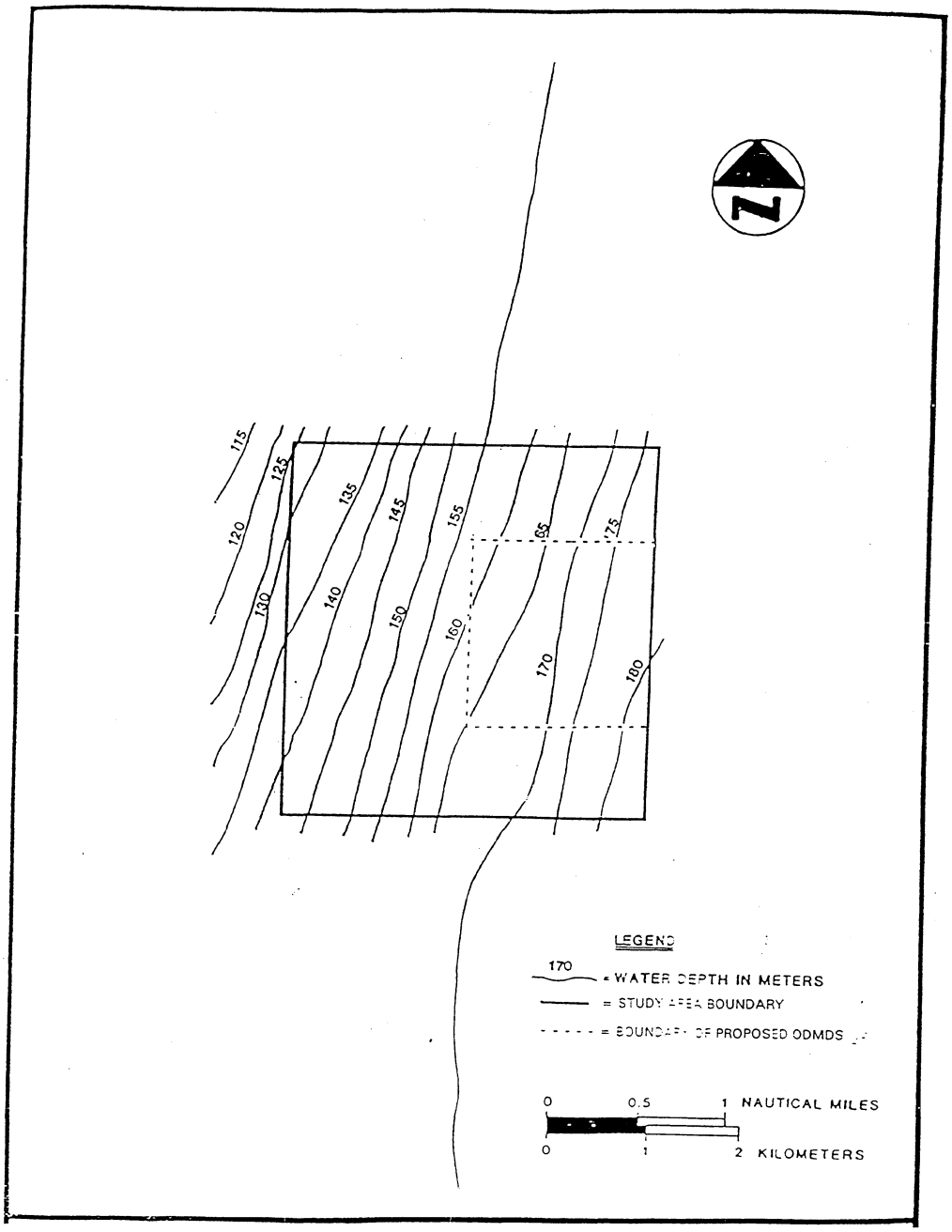


Figure 4. Bathymetry in the vicinity of the proposed Palm Beach Harbor ODMDS (from Continental Shelf Associates, Inc., 1989)

2 Short-term Fate Modeling

The short-term fate modeling phase of the project involved simulation of the descent and collapse of the dredged material plume as it falls through the water column from the barge to the ocean floor. This task required use of the Short-Term Fate (STFATE) model to estimate the dynamics of the sediment cloud following its release from the dredge (Johnson et al., 1993). The model computes the time-history of a single disposal operation from the time the dredged material is released from the barge until it reaches equilibrium. Model simulation data requirements include local water depths, currents, density gradients, disposal description, and sediment characteristics. The following sections describe the theoretical basis of model STFATE, required model input parameters, input data analyses, model simulations, and a summary of results.

Theoretical Basis

The behavior of dredged material during disposal is assumed to be separated into three phases: convective descent, dynamic collapse, and passive transport-dispersion (Figure 5). During the ***convective descent*** phase, the disposal cloud falls under the influence of gravity and its initial momentum is imparted by gravity, continuing until the cloud either impacts the bottom or arrives at a level of neutral buoyancy. In deep water, such as both ODMDSs, this phase can take greater than 3 minutes due to the great depth and the loss of momentum of the disposed material as it travels through the water column. The ***dynamic collapse*** phase begins when descent stops and horizontal spreading of material dominates. If the material is primarily composed of non-cohesive material, this phase represents the settling and consolidation of the sediment into a mound. However, if the sediment contains cohesive material, a combination of buoyancy and suspension may transport the cloud a considerable distance from the point of disposal. The ***passive transport-dispersion*** phase is characterized by material transport and spreading due to ambient currents and turbulent diffusion more than the dynamics of the disposal operation itself. Short-term simulations end with this the end of this phase of transport.

Data from 1995 to 1997 were analyzed initially by north/south and east/west components. Average and maximum velocities for each component, by year, for all data collected in that year, as a function of depth were determined as shown in Figures 6 through 11. Positive velocity values represent velocities directed to the north and east. Negative velocity values represent velocities directed to the south and west. The average east/west velocity and average north/south velocity indicated in each figure is the residual velocity component for that year. Both the north/south and east/west components show current speeds diminish with depth.

To further examine the directional distribution of velocity as a function of depth, four locations (bins) in the water column were selected from the velocity profile and twelve compass angle bands (see Figure 12) were defined. Zero deg represents currents headed north and 270 deg represents currents headed west. Direction bands 1 through 4 contain currents directed offshore and therefore have coarse (45 deg) resolution. Direction bands 5 through 12 contain shoreward-directed currents and therefore were defined with a finer (22.5 deg) resolution. Average velocities and number of occurrences in each angle band were determined for each selected bin, with Bin 5 corresponding to the 90-m depth, Bin 12 corresponding to 60-m depth, Bin 20 corresponding to the 30-m depth, and Bin 25 corresponding to the 10-m depth measured from the water surface. Directional distributions of velocity for 1995, 1996, and 1997 are shown in Figures 13-16,17-20, and 21-24, respectively. Examining these data, currents in Angle Band 1 (0-45 deg) are clearly the most prevalent and also have the greatest average velocity. With the shoreline orientation nearly north/south, (approximately 5 deg east of north), only the first 5 deg from this angle band could possibly direct sediment shoreward toward the reef system. Percentagewise, the shoreward-directed (5 deg) band occurs only 3-10% of the total data collection period. Angle Bands 5 (180-202.5 deg) through 12 (337.5-360 deg) also have shoreward-directed currents with the extreme angle bands (5 and 12) having the greatest average current speeds. Percentagewise, shoreward-directed currents from these angle bands occur only 7.5-15.5% of the total data collection time period. Overall, shoreward-directed currents occur only 17.5-19.4% of the total data collection period, including the 5-deg portion of Angle Band 1.

which band is this? 5° portion of Band 1?

Cumulative probability distribution curves were determined for the bin closest to the surface (Bin 25) for Angle Bands 1, 5, 9, and 12 and the first 5 deg of Angle Band 1 (Figures 25-29). Cumulative probability distribution curves for years 1995, 1996, and 1997 were each represented with a unique symbol. From the three curves, velocities with exceedances of 50% (V_{50}), 10% (V_{90}), 5% (V_{95}), and 1% (V_{99}) were identified for each angle band. In each case, the most conservative value (curve with the greatest current speed, usually 1997) was selected. Based on analysis of these results, Angle Bands 12 (greatest shoreward-directed current speeds) and 9 (shore-normal but lower current speeds) were examined further. The 3-year database of currents was examined for surface currents that matched the 50, 90, 95, and 99th percentile velocities from the selected cumulative probability distribution curves. Fifteen velocity profiles with surface velocities that were equal to each of the four percentile surface velocities were selected, and average 50, 90, 95, and 99th percentile velocity profiles were determined for use in model simulations. The velocity profiles to be simulated at an orientation of 270 deg (the most conservative angle for Angle Band 9) are shown in Figure 30. Angle Band 12 velocity profiles to be simulated with an orientation of 337.5 deg are shown in Figure 31 (again, a conservative selection for current direction).

Outline

The purpose of this study is to evaluate the dispersive characteristics of proposed disposal sites offshore of Palm Beach Harbor and Port Everglades Harbor. Both sites are in deep water (approximately 170-200 m deep) and are in close proximity to the Gulf Stream and its spin-off eddies. There is concern that the proposed eddies could potentially carry material from the ODMDS to environmentally-sensitive coral reefs. Numerical model simulations were selected as the method of evaluating the potential for sediment transport during disposal (short-term fate) and from the disposal mound (long-term fate). This approach requires information documenting the local velocities near the ODMDSs to define a reef-directed component which may be attributable to the Gulf Stream eddies. This report summarizes the data analysis and model simulations performed for the Palm Beach Harbor and Port Everglades Harbor ODMDSs, including an extensive examination of velocities in the vicinity of the ODMDSs. Chapter 2 focuses on the short-term fate of dredged material at each site, including data analysis and model simulations. Chapter 3 focuses on the long-term fate of dredged material at each site, including data analysis and point model simulations. Chapter 4 summarizes findings from the model simulations.

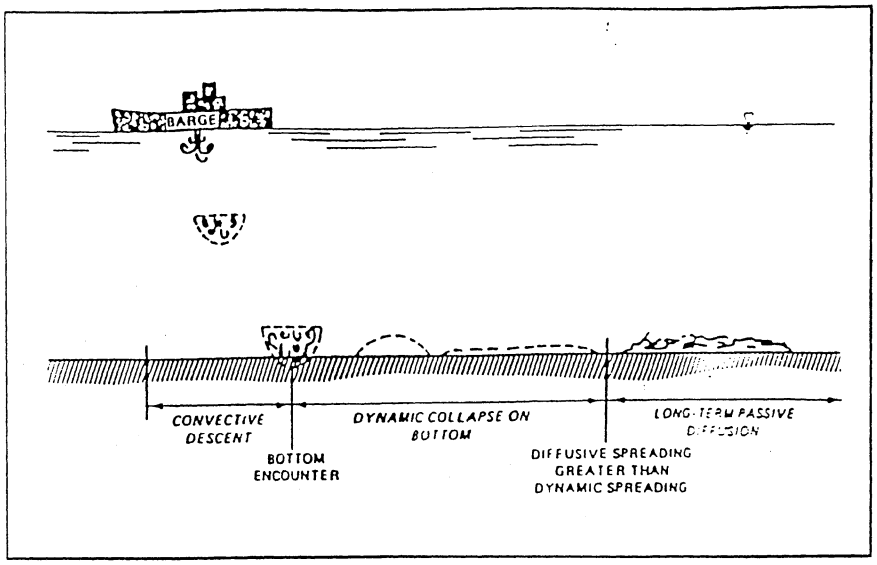


Figure 5. Computational phases of the STFATE model (from Brandsma and Divorky, 1976)

Input Data Requirements

The STFATE model requires site-specific input data to quantitatively predict the short-term fate of a disposal operation. These data include: local environment (depth and velocity fields), dredged material composition, dredge dimensions, and disposal operation, as well as modeling parameters and coefficients. Each of the input requirements will be discussed in the following paragraphs.

Bathymetry. Bathymetry data collected by Continental Shelf Associates in 1986 showed water depths ranged between 175 and 220 m, mean low water (mlw) for the Port Everglades ODMDS and between 155 and 185 m, mlw for the Palm Beach ODMDS. STFATE model simulations covered a broader area than the ODMDS in the event that transport from the ODMDS occurred. The model area was approximately 6700 m by 6700 m with depth values defined every 150 m. Depth values for the modeled regions were taken from NOAA Chart 11469 and 11470 for Port Everglades and from NOAA Chart 11467 for Palm Beach. Figures 3 and 4 show the disposal site bathymetries for Palm Beach and Port Everglades, respectively.

Velocity data. Acoustic Doppler Current Profiler (ADCP) data obtained from the National Oceanographic Data Center (NODC) for location (26° 04.00'N, 80° 03.50'W) in the vicinity of the project sites were analyzed to determine potential velocity profiles that disposed material might be subjected to over the short-term (immediately after disposal). The depth at the ADCP deployment site was 110 m. NODC provided velocity profile data at 4-m depth intervals and 20-minute time intervals for the 1995-1997 time period. The 1995 dataset extended from late August until late December with approximately 7600 velocity profiles. The 1996 dataset was most complete, covering January through early June and late August through December for a total of 19000 velocity profiles. The 1997 dataset extended from January through late May with 8500 velocity profiles.

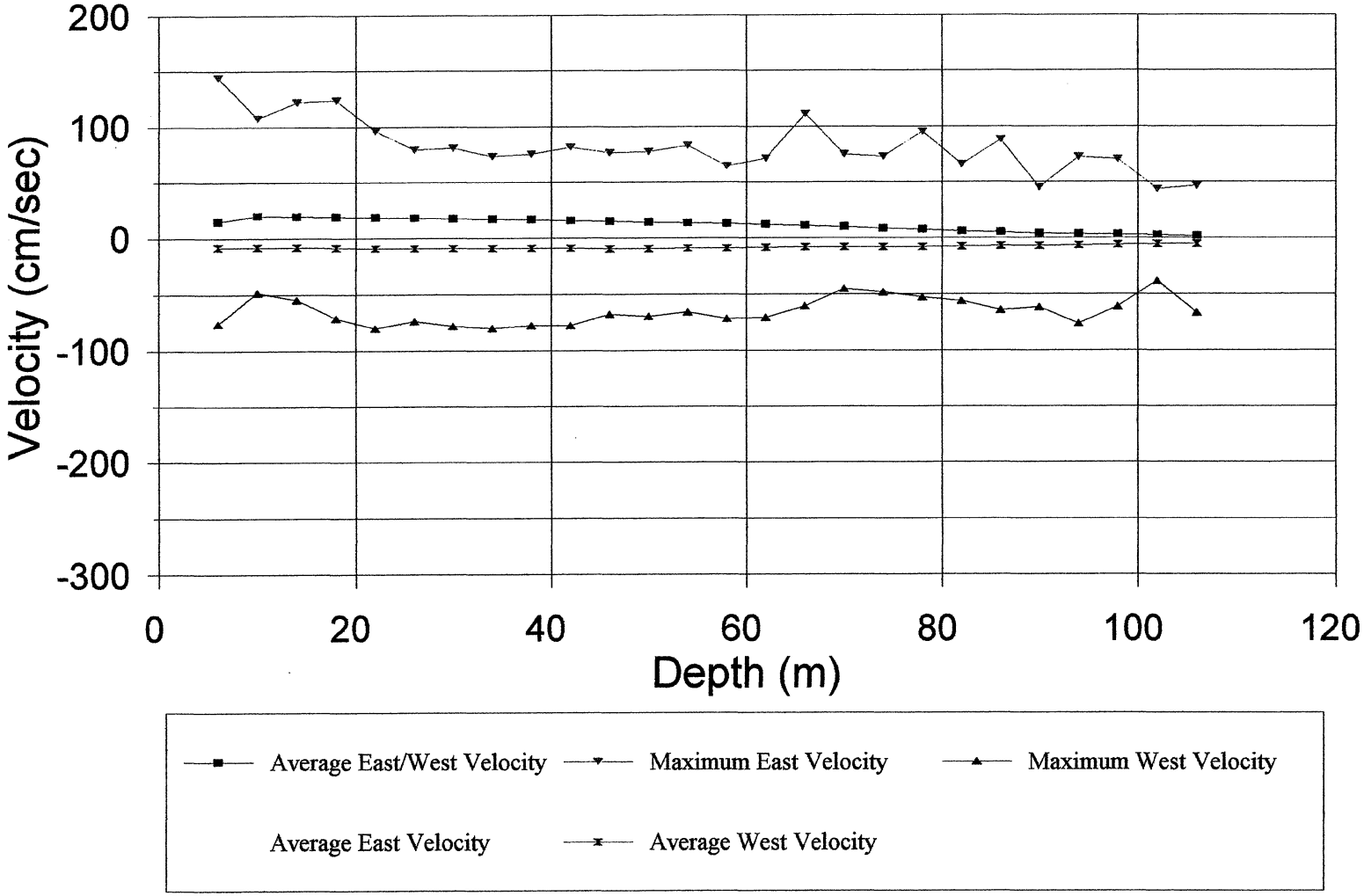


Figure 6. 1995 East/West velocity components

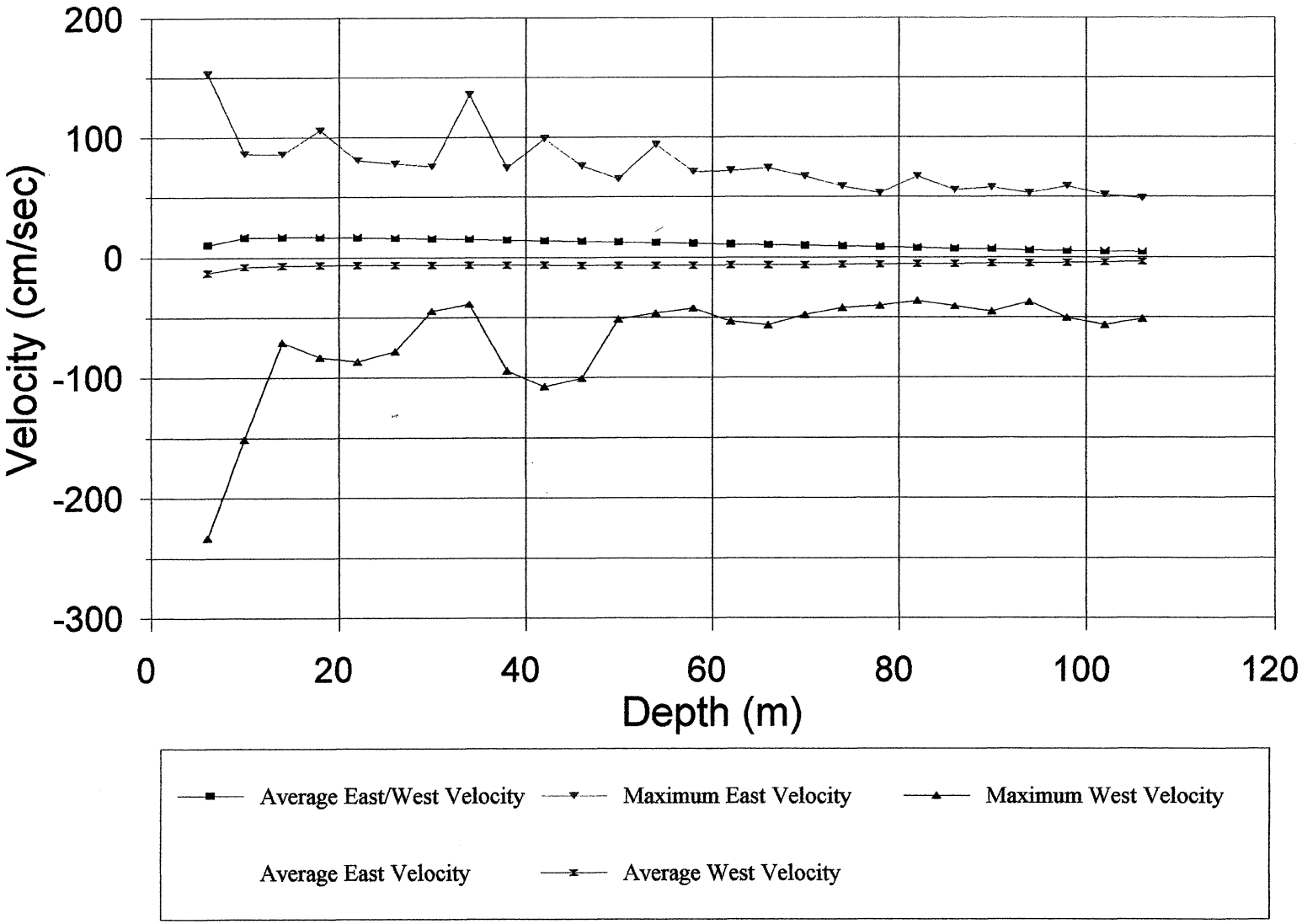


Figure 7. 1996 East/West velocity components

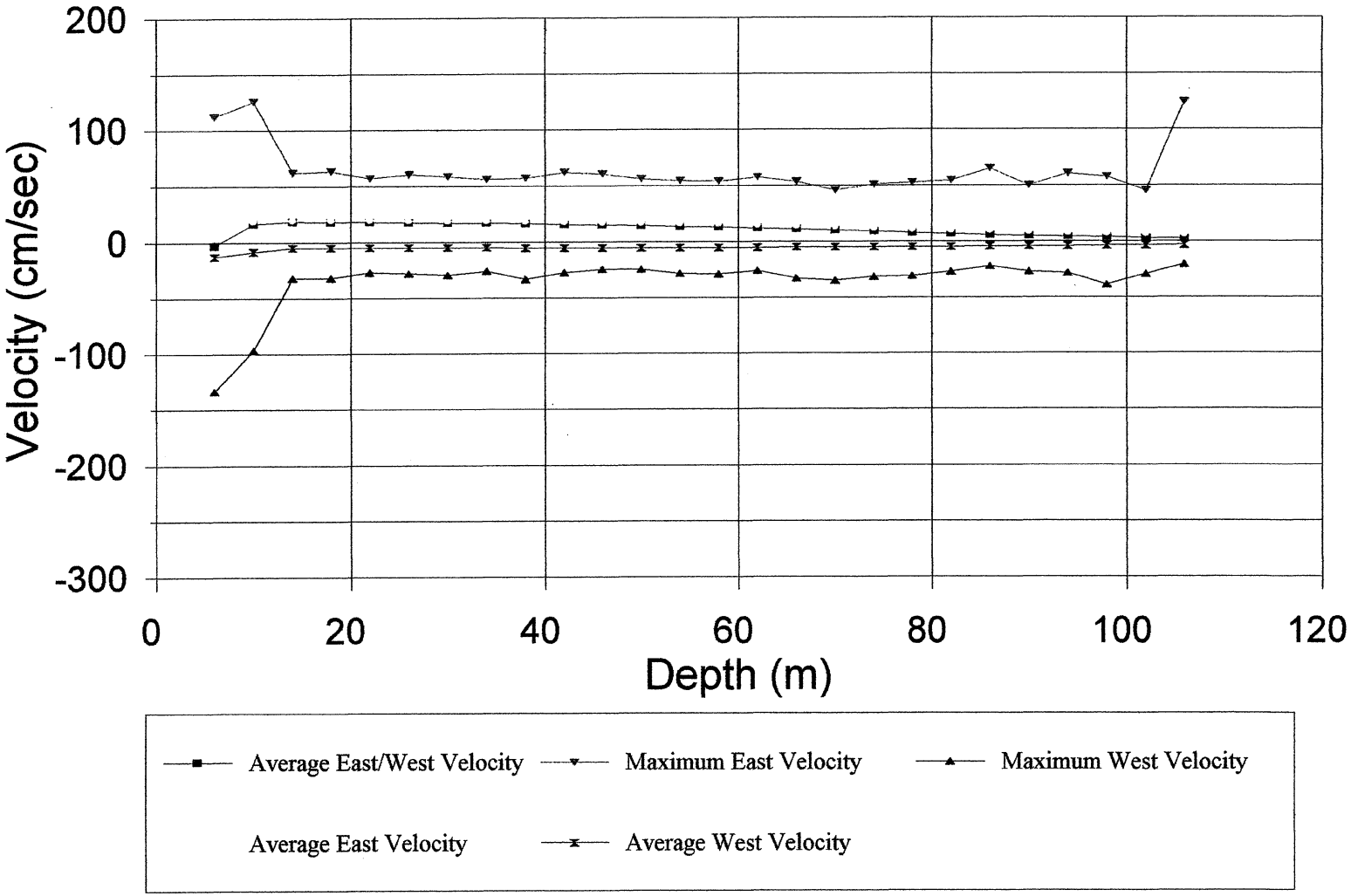


Figure 8. 1997 East/West velocity components

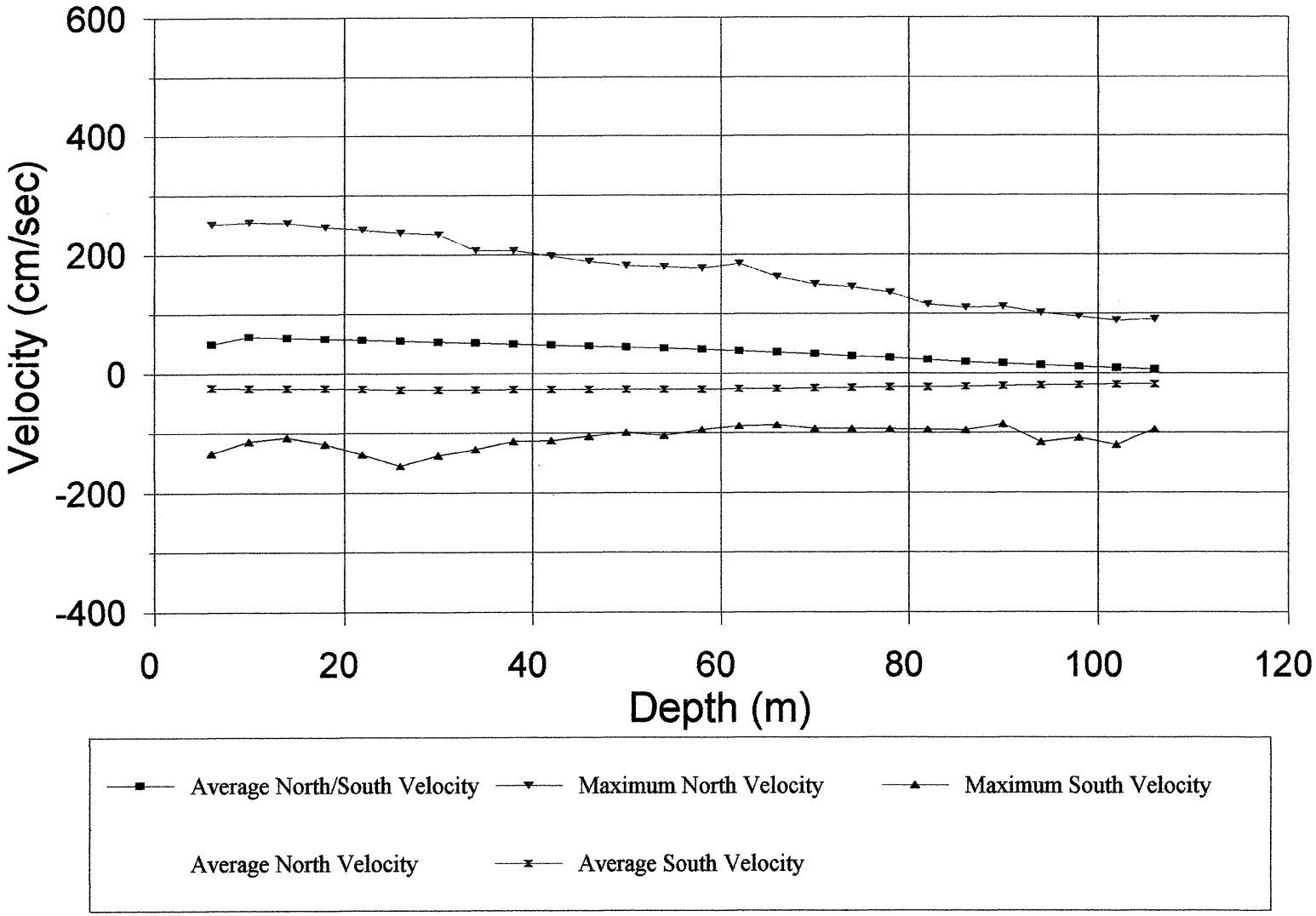


Figure 9. 1995 North/South velocity components

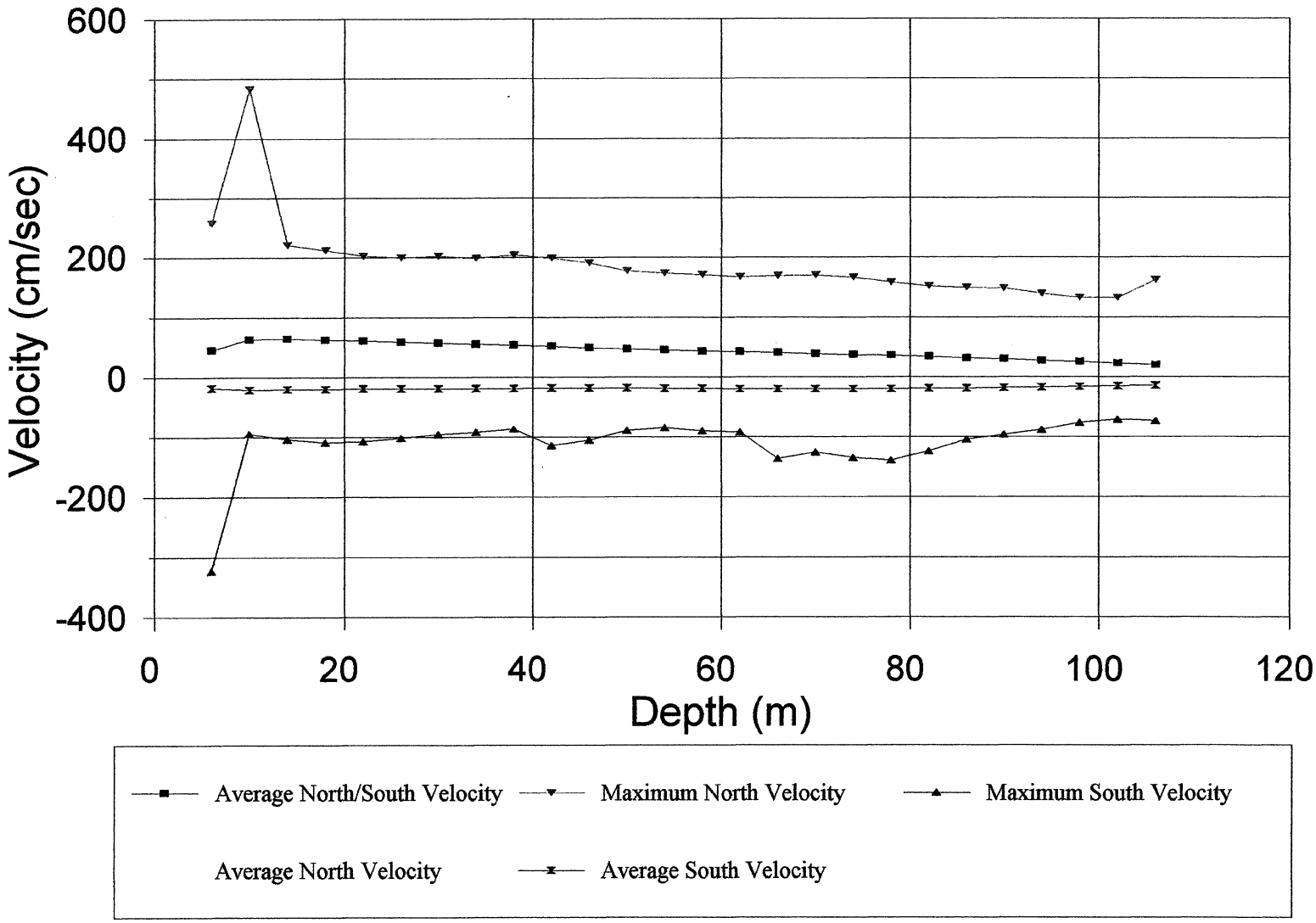


Figure 10. 1996 North/South velocity components

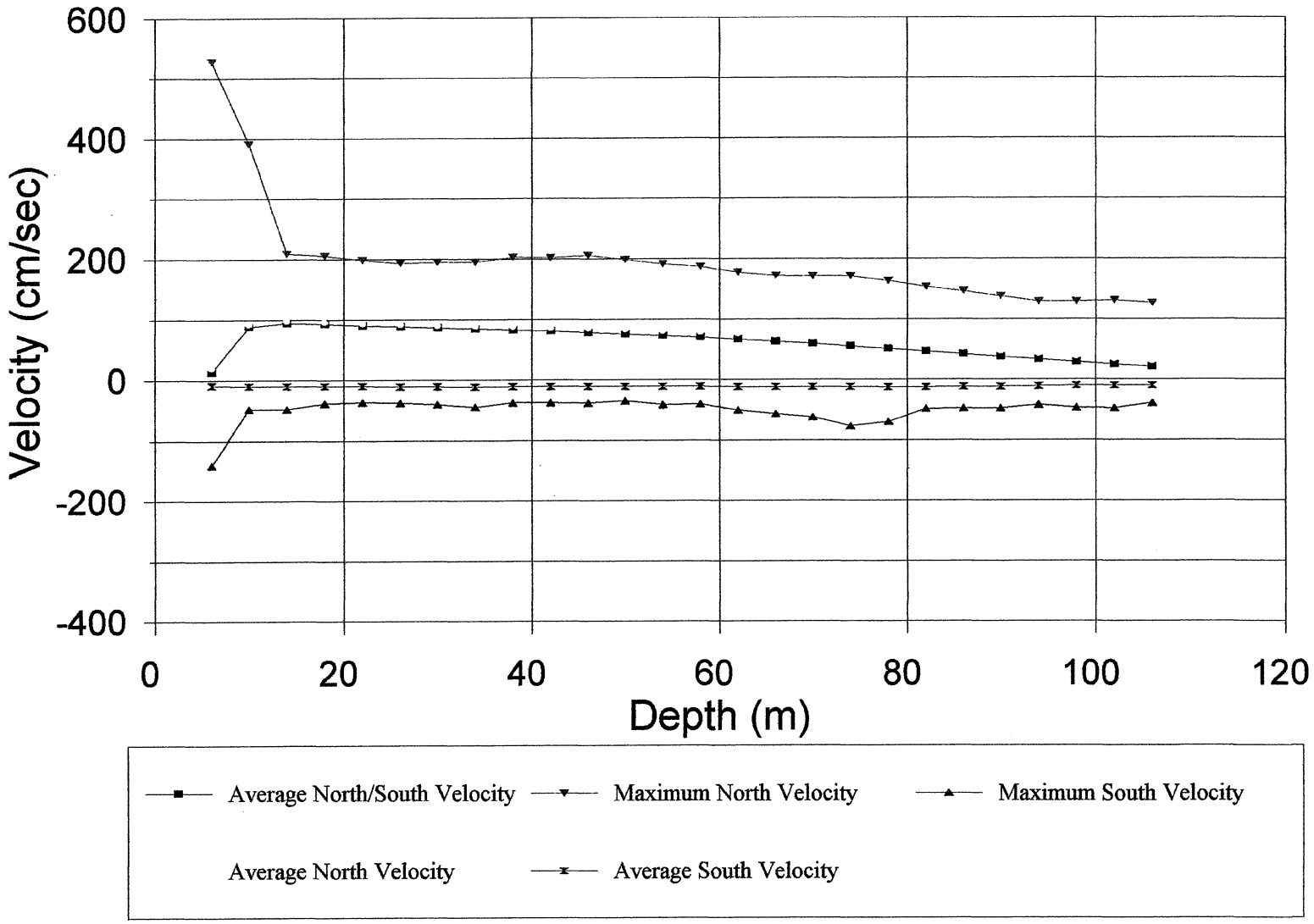


Figure 11. 1997 North/South velocity components

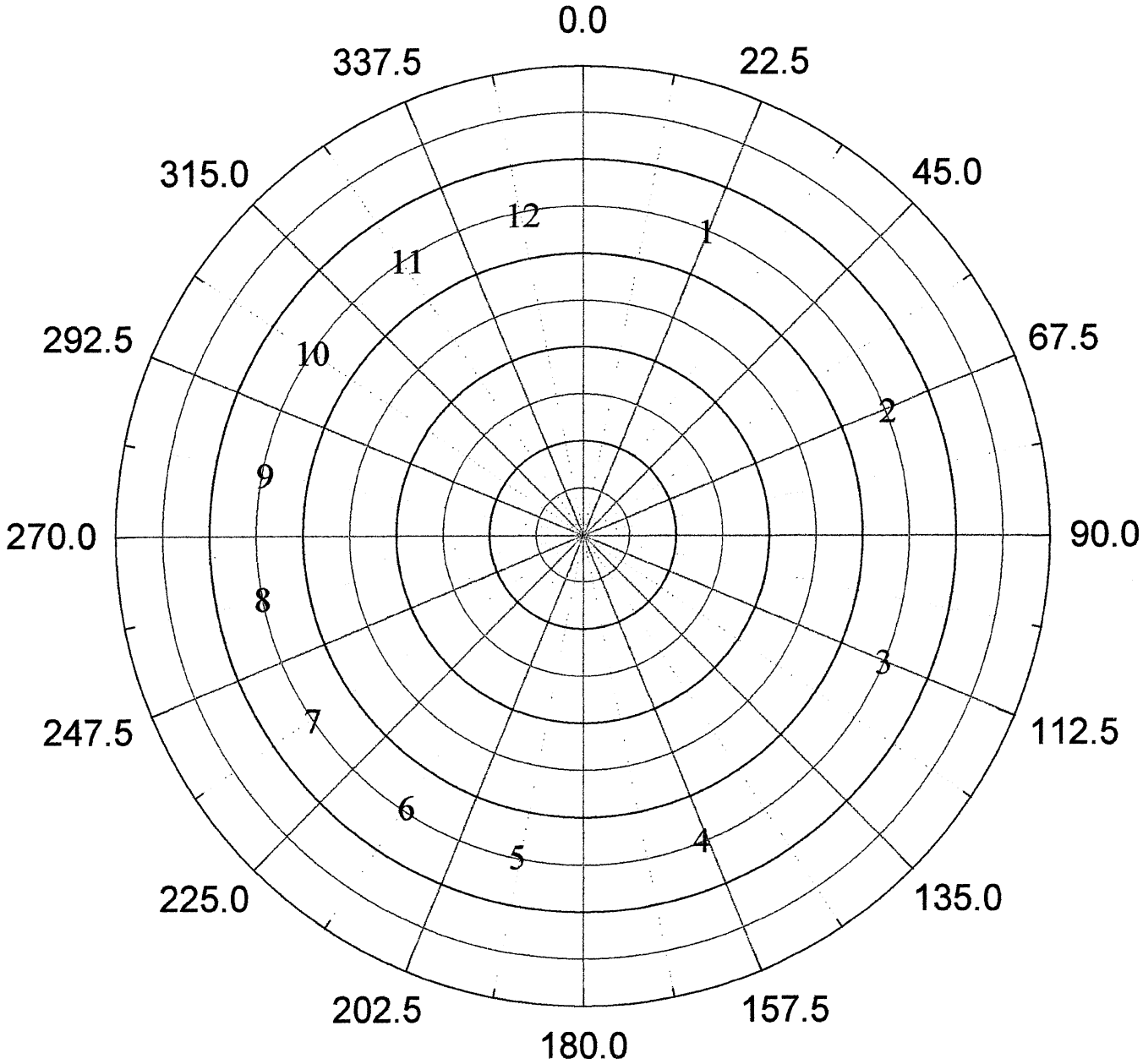


Figure 12. Definition of angle bands

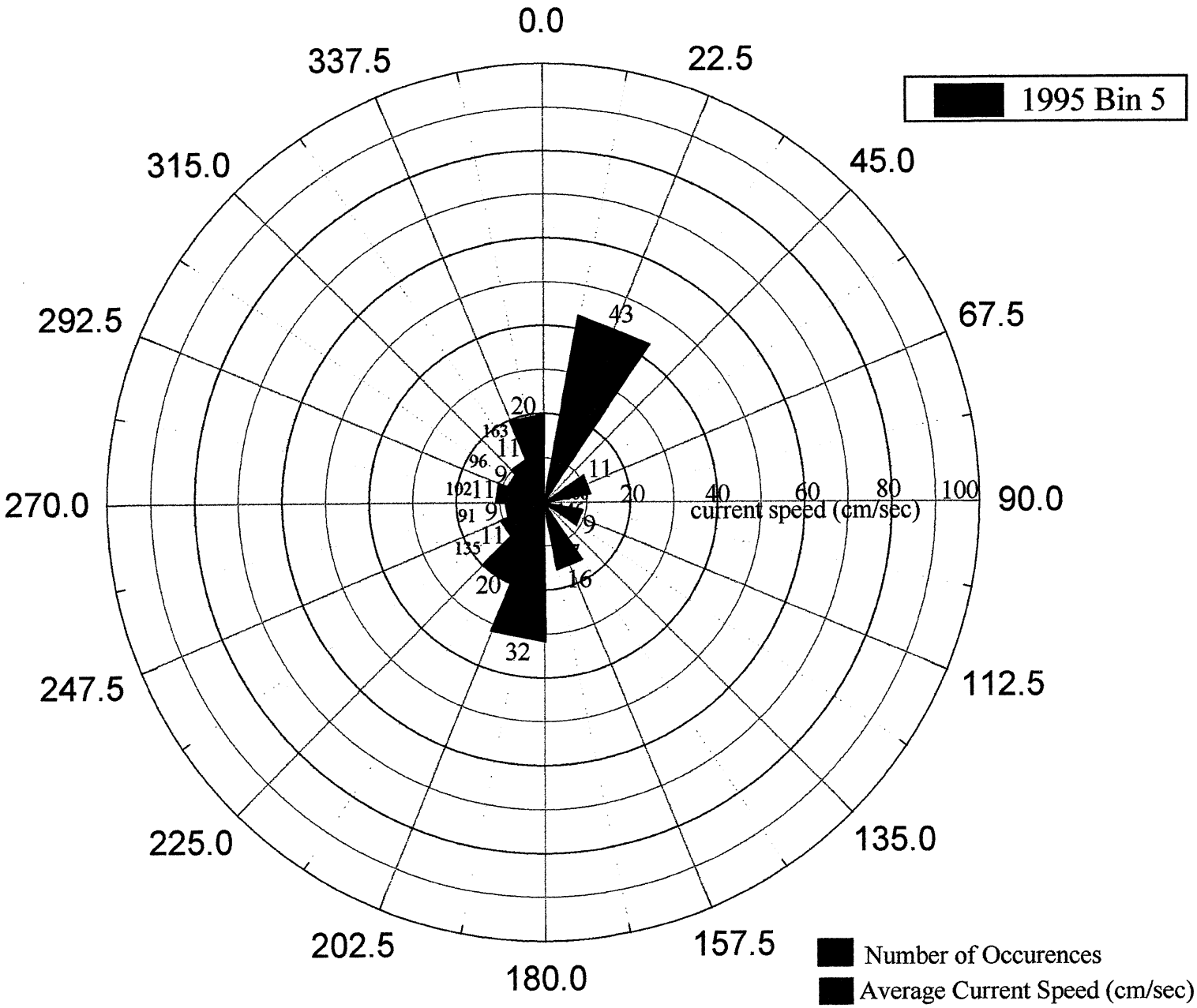


Figure 13. Directional distribution of velocities for 1995-bin 5

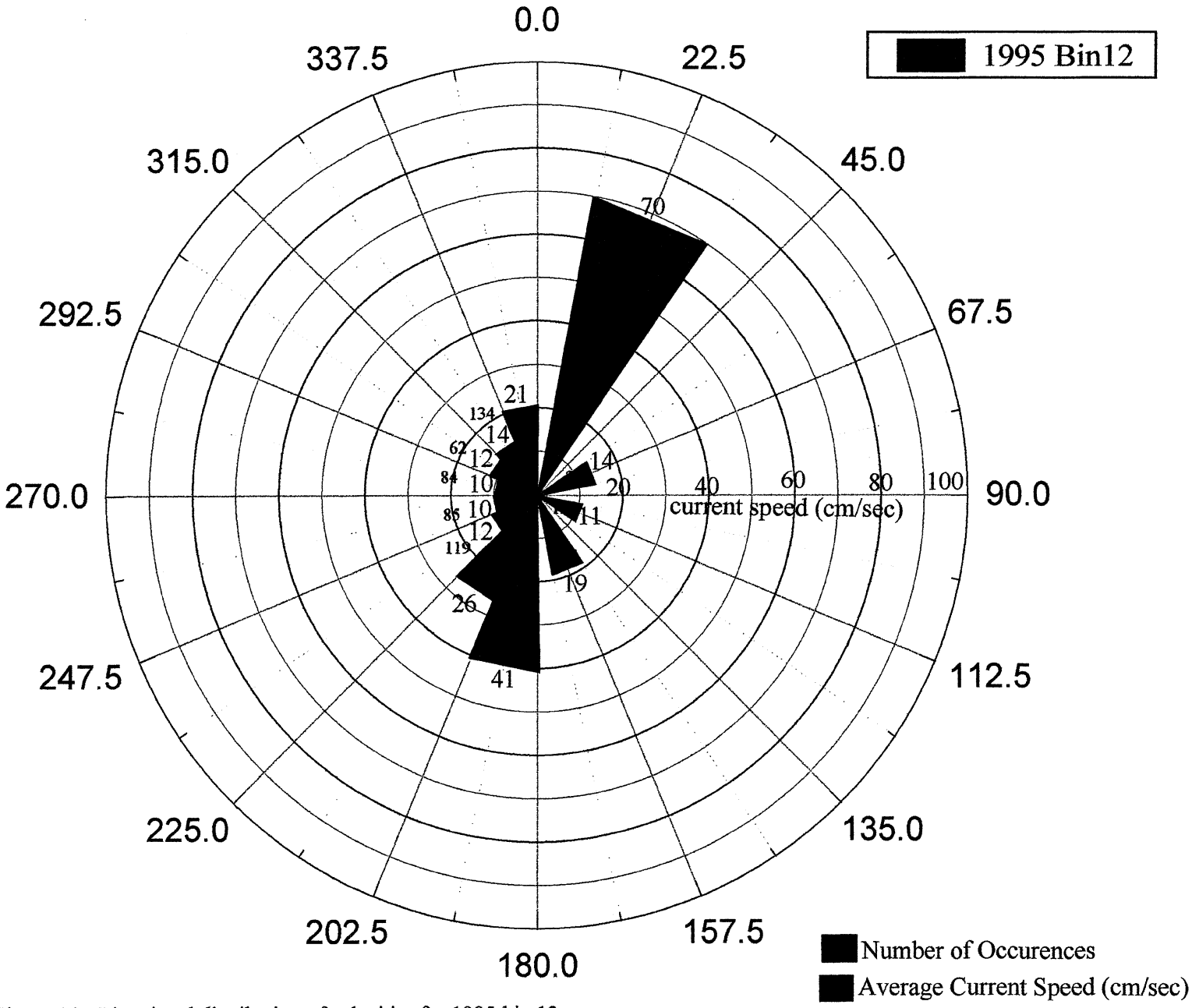


Figure 14. Directional distribution of velocities for 1995-bin 12

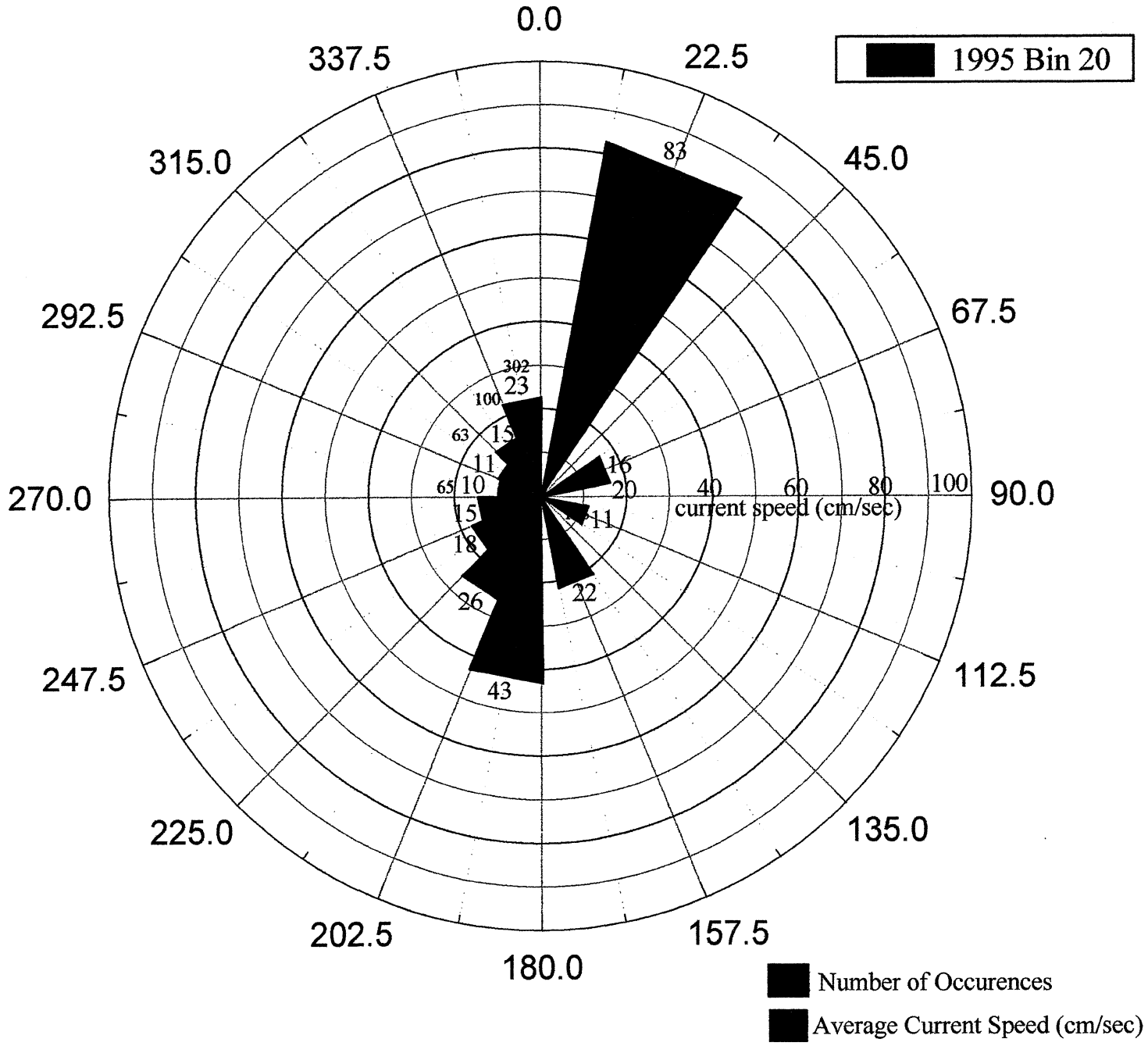


Figure 15. Directional distribution of velocity for 1995-bin 20

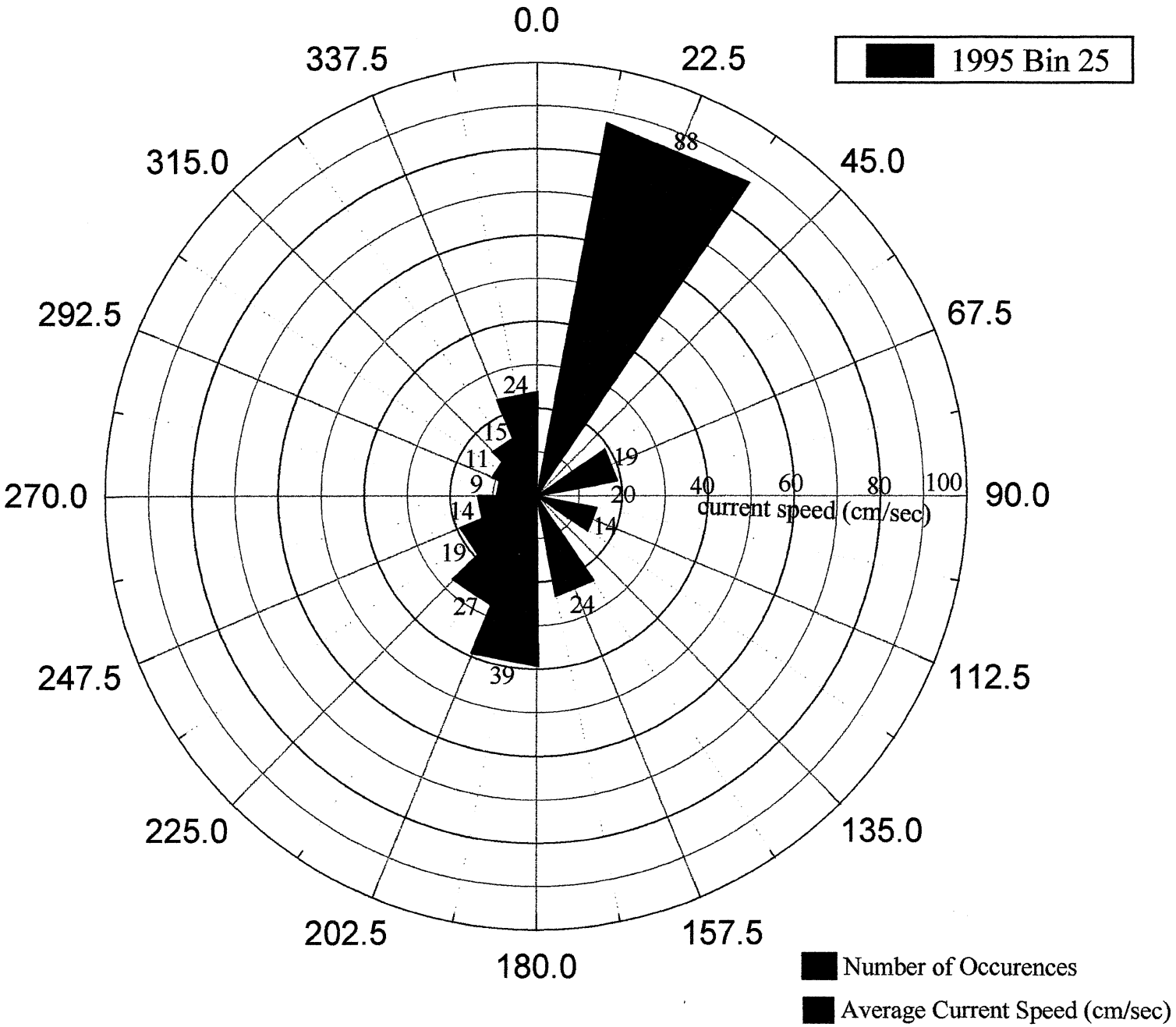


Figure 16. Directional distribution of velocities for 1995-bin 25

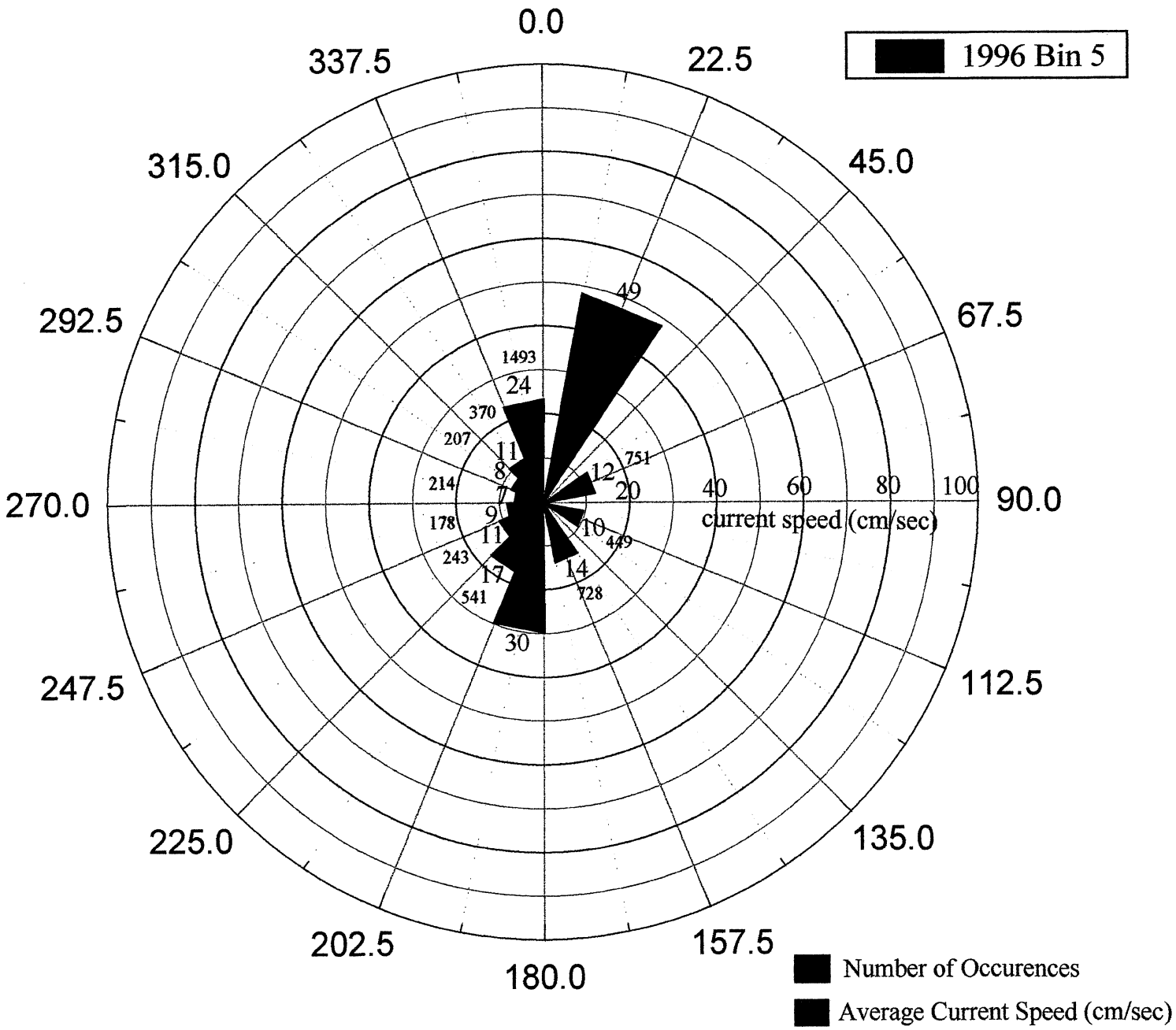


Figure 17. Directional distribution of velocities for 1996-bin5

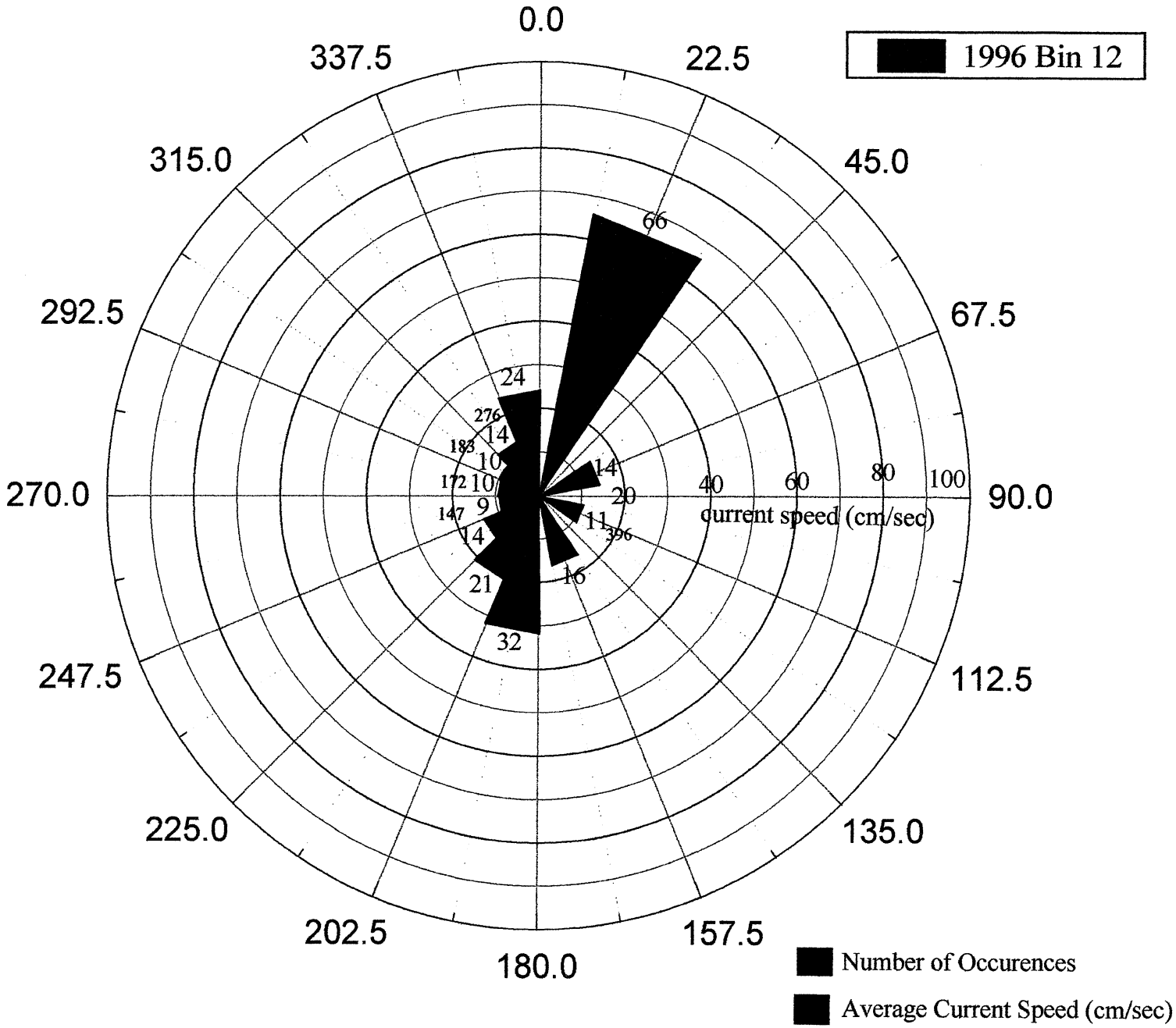


Figure 18. Directional distribution of velocities for 1996-bin 12

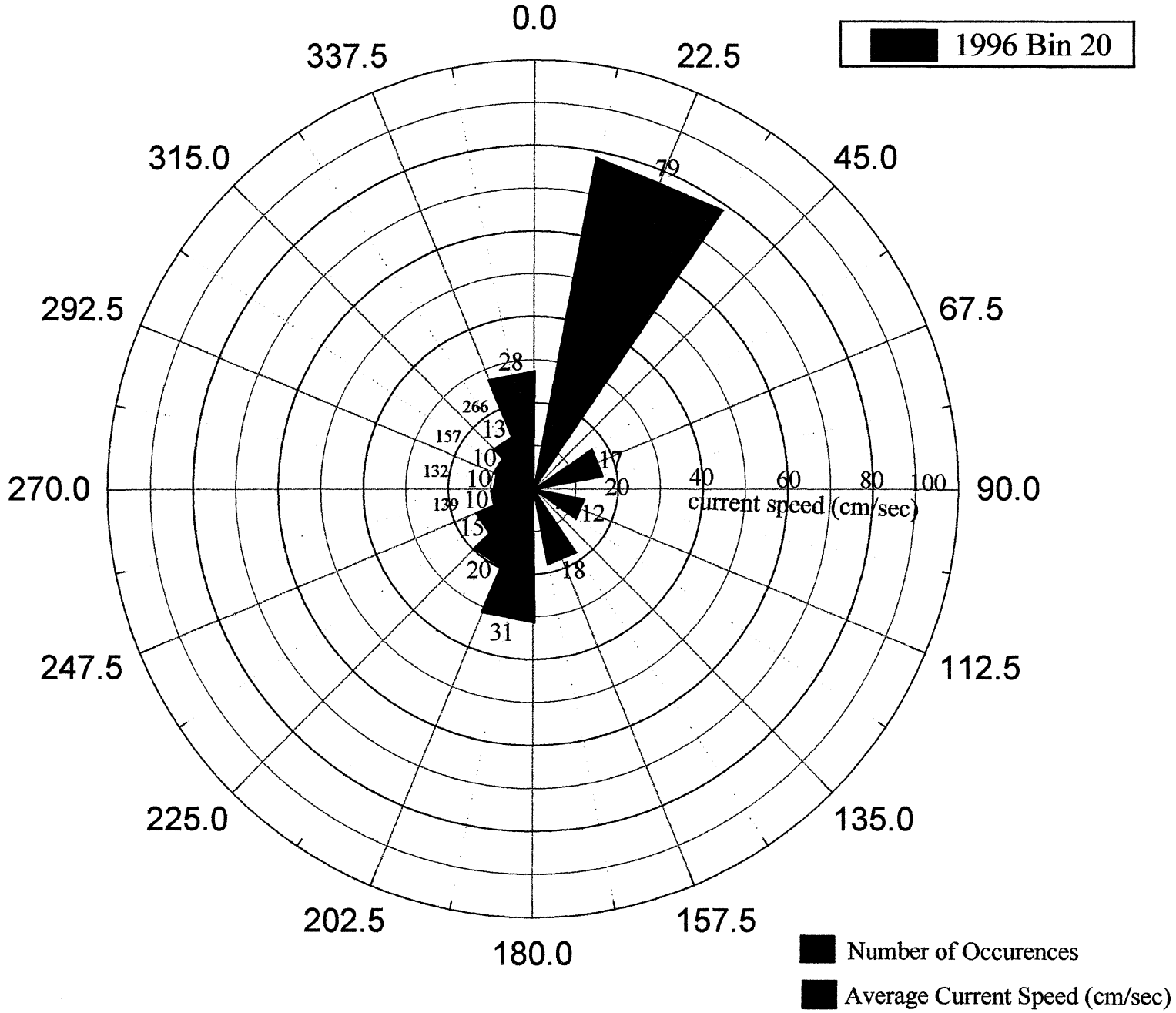


Figure 19. Directional distribution of velocities for 1996-bin 20

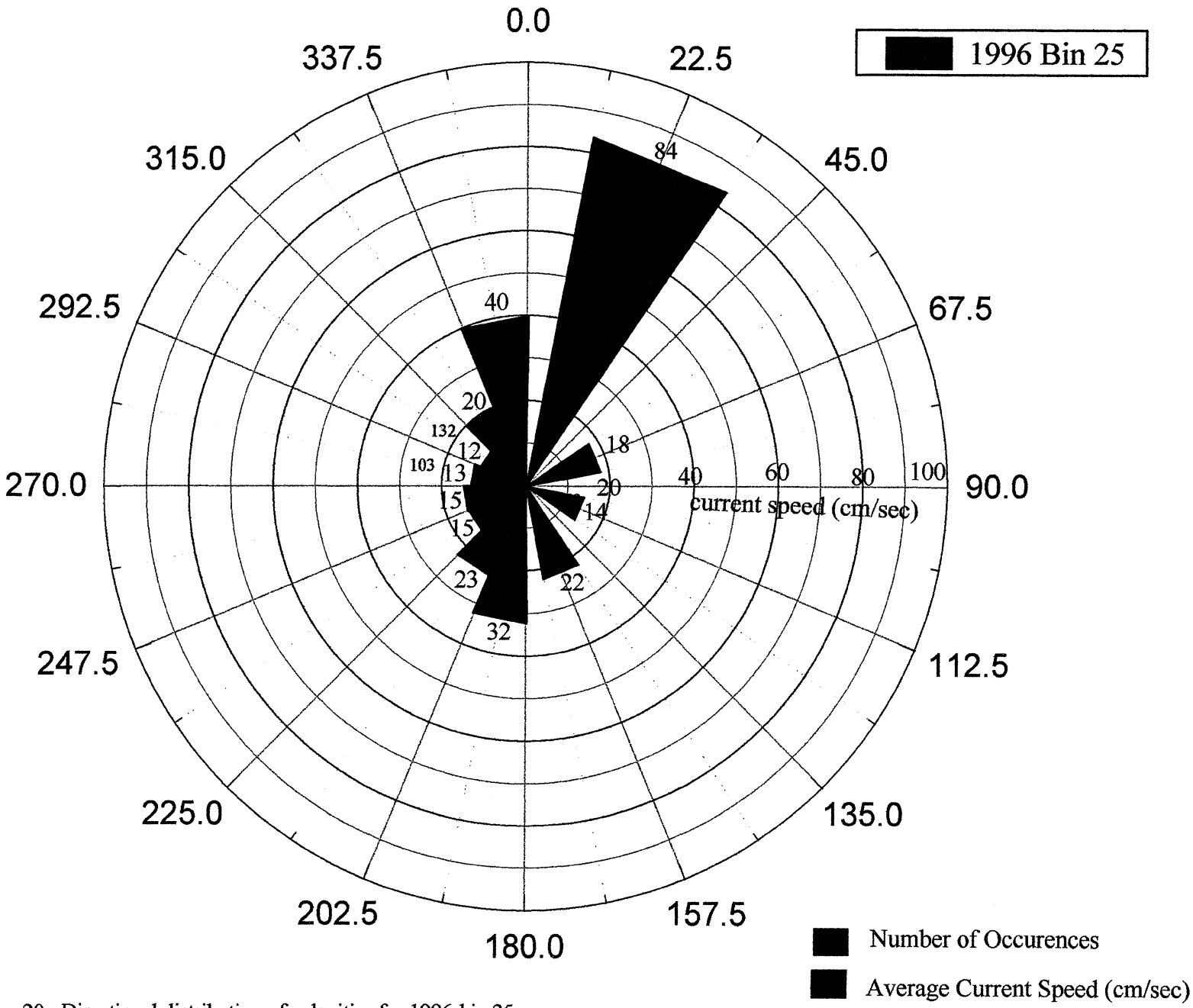


Figure 20. Directional distribution of velocities for 1996-bin 25

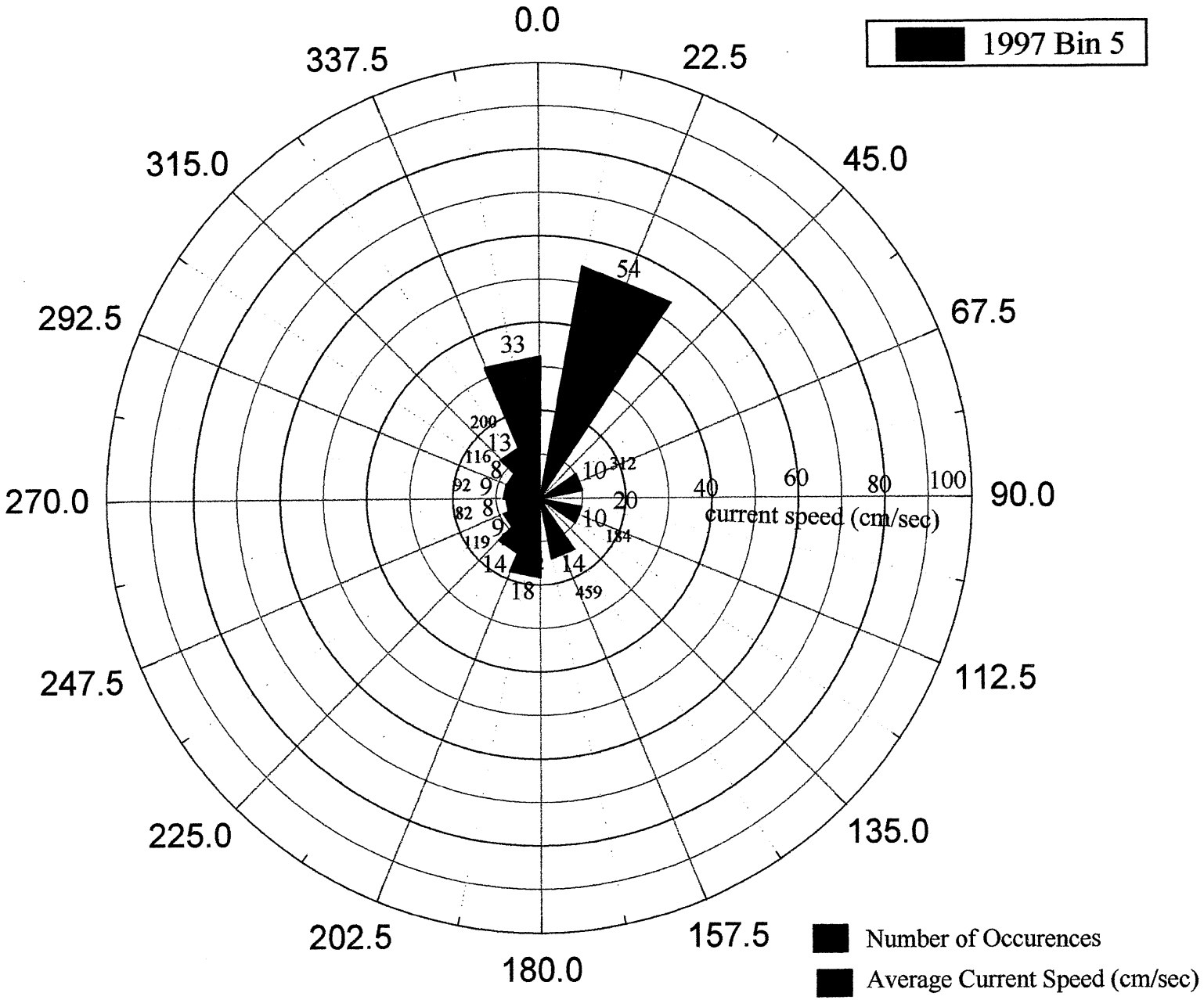


Figure 21. Directional distribution of velocities for 1997-bin 5

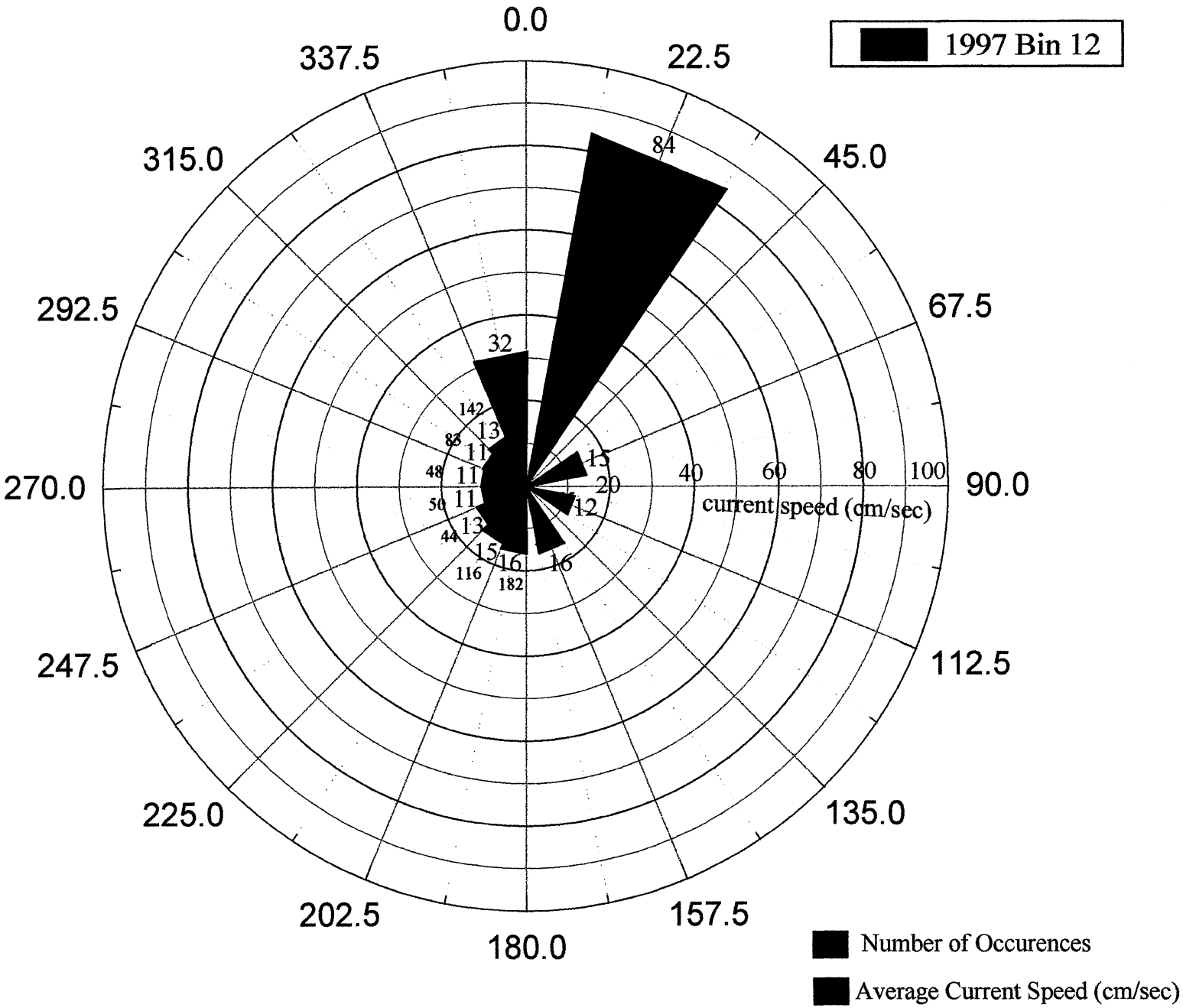


Figure 22. Directional distribution of velocities for 1997-bin 12

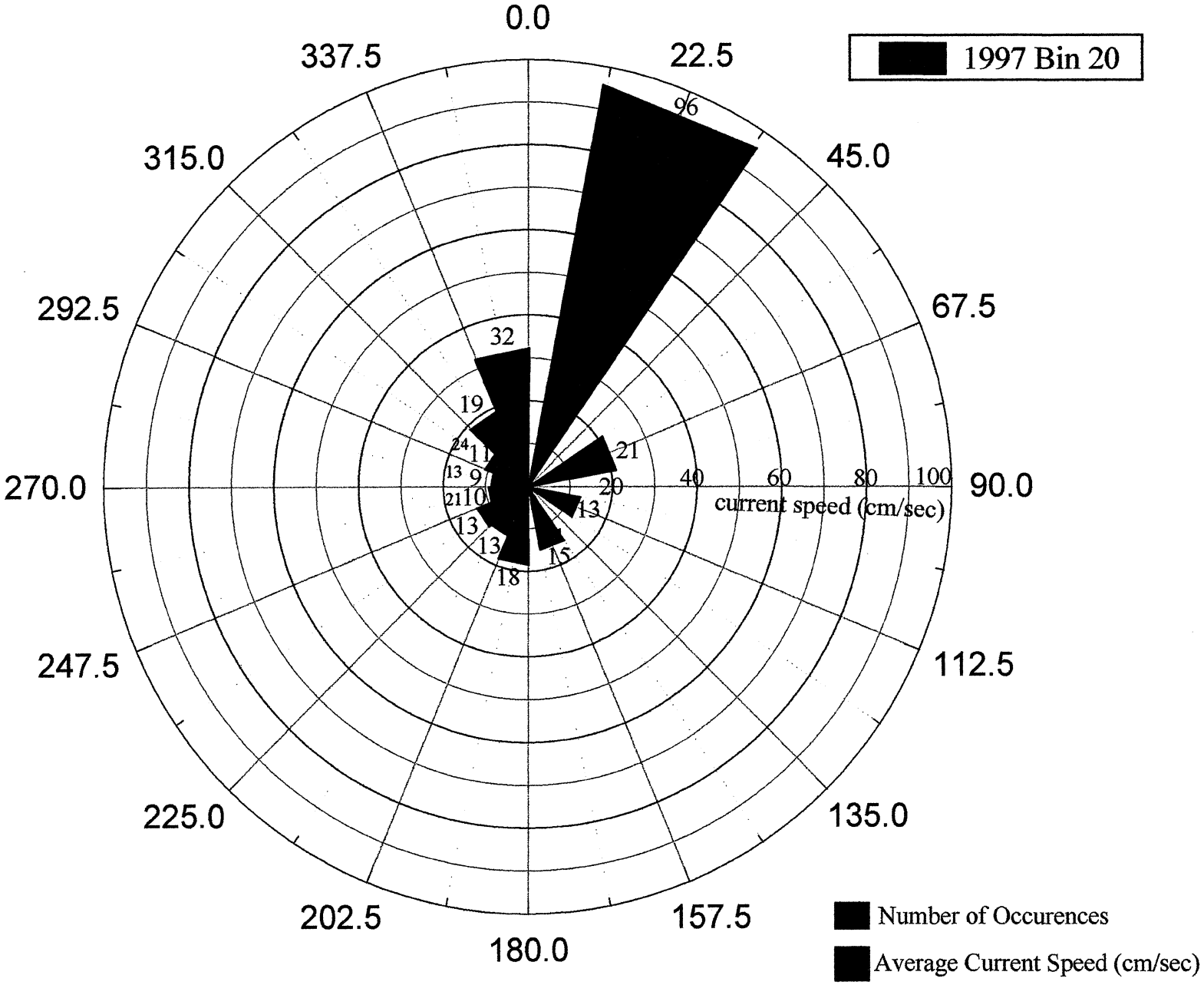


Figure 23. Directional distribution of velocities for 1997-bin 20

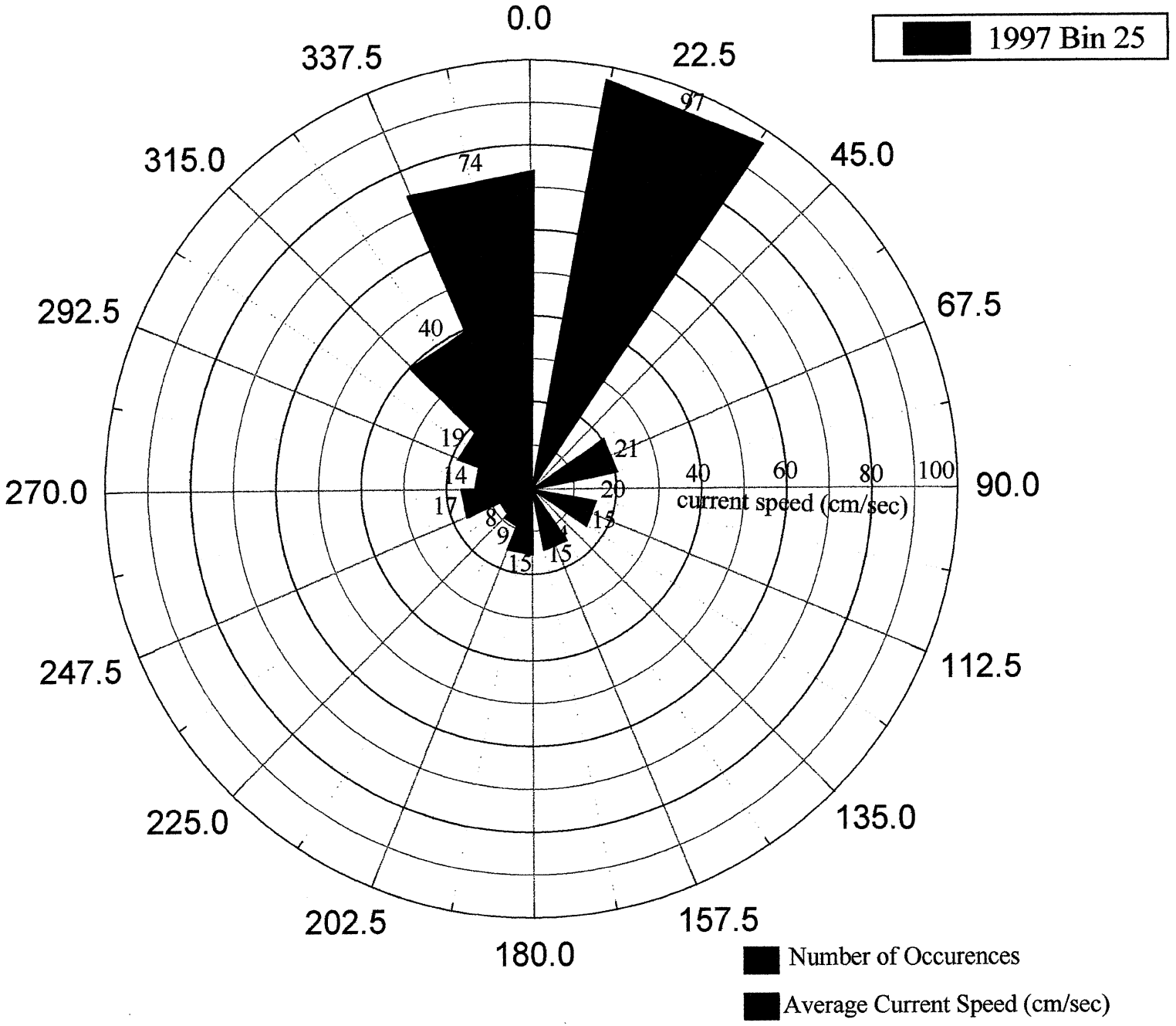


Figure 24. Directional distribution of velocities for 1997-bin 25

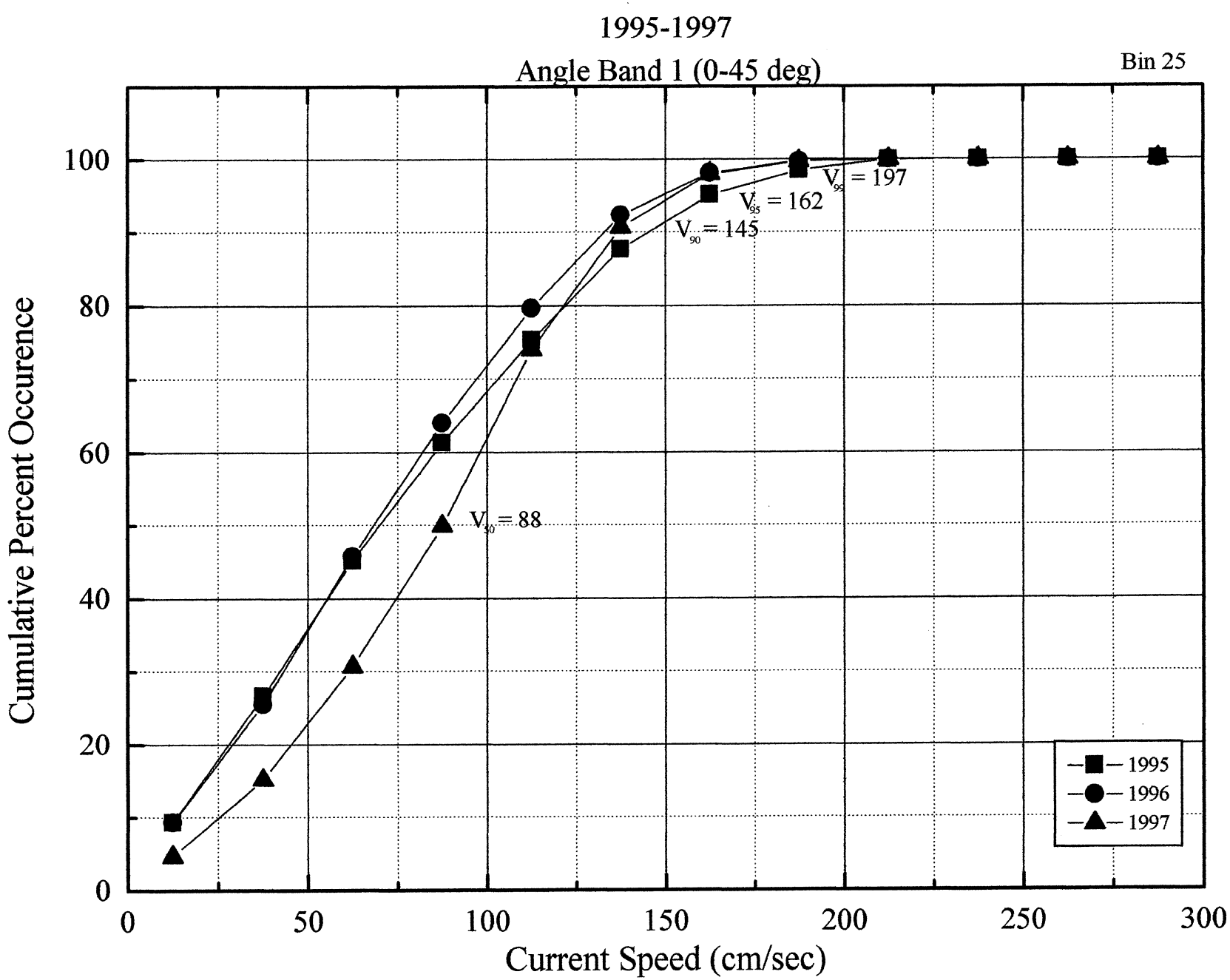


Figure 25. Cumulative probability distribution for Angle Band 1

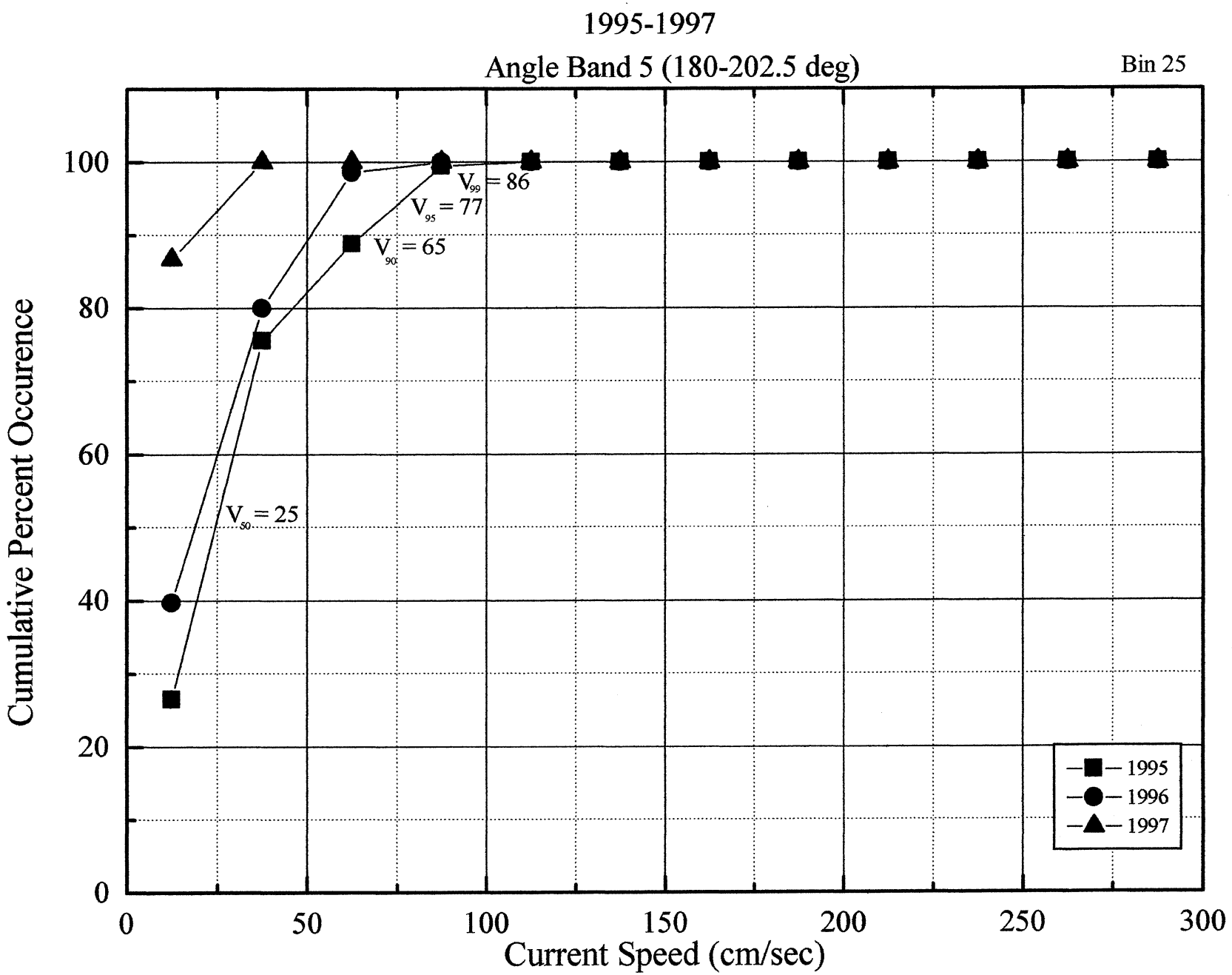
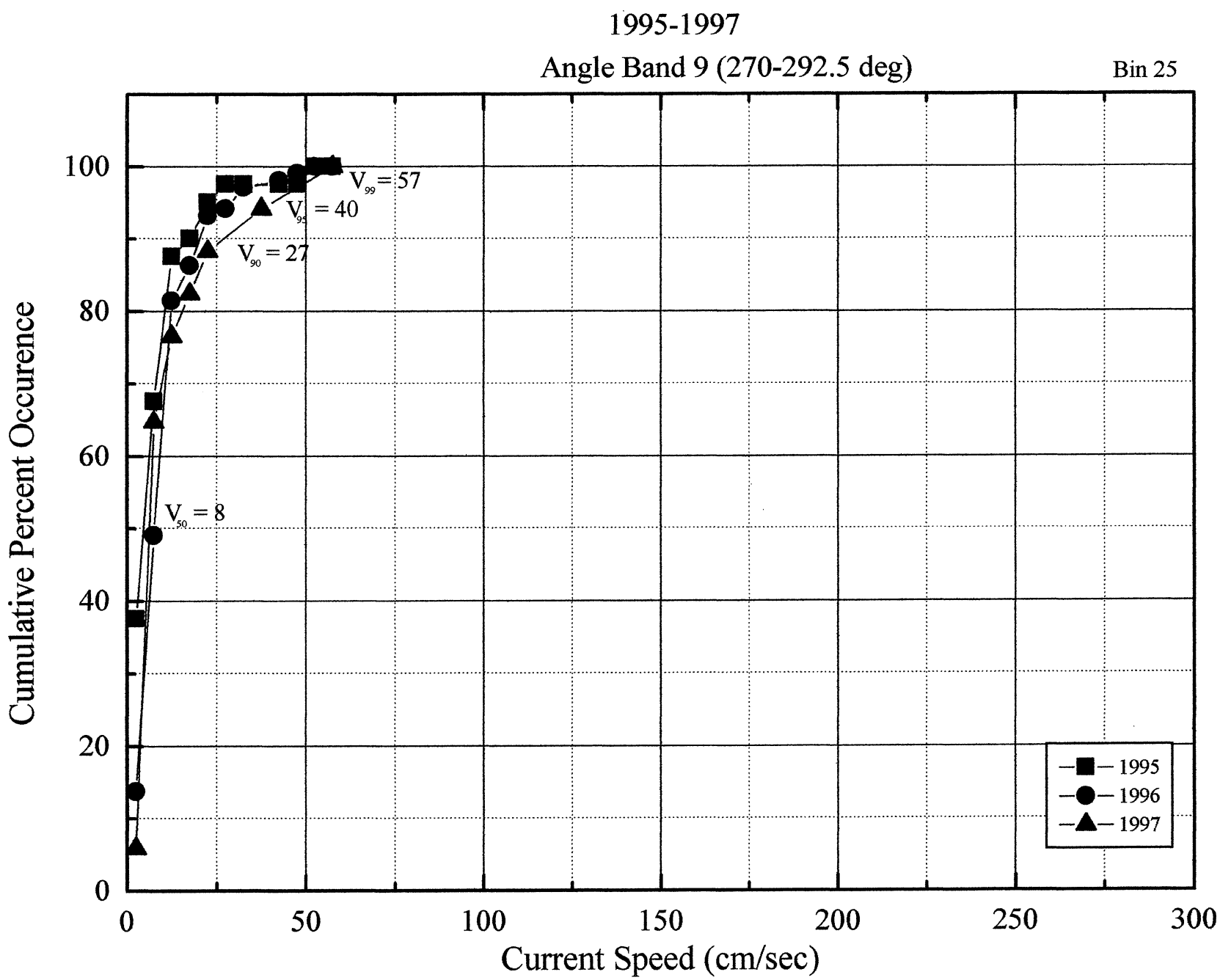


Figure 26. Cumulative probability distribution for Angle Band 5


1995-1997
Angle Band 9 (270-292.5 deg)
Bin 25
Cumulative Percent Occurence
Current Speed (cm/sec)
0
20
40
60
80
100
0
50
100
150
200
250
300
V99 = 57
V95 = 40
V90 = 27
V50 = 8
1995
1996
1997

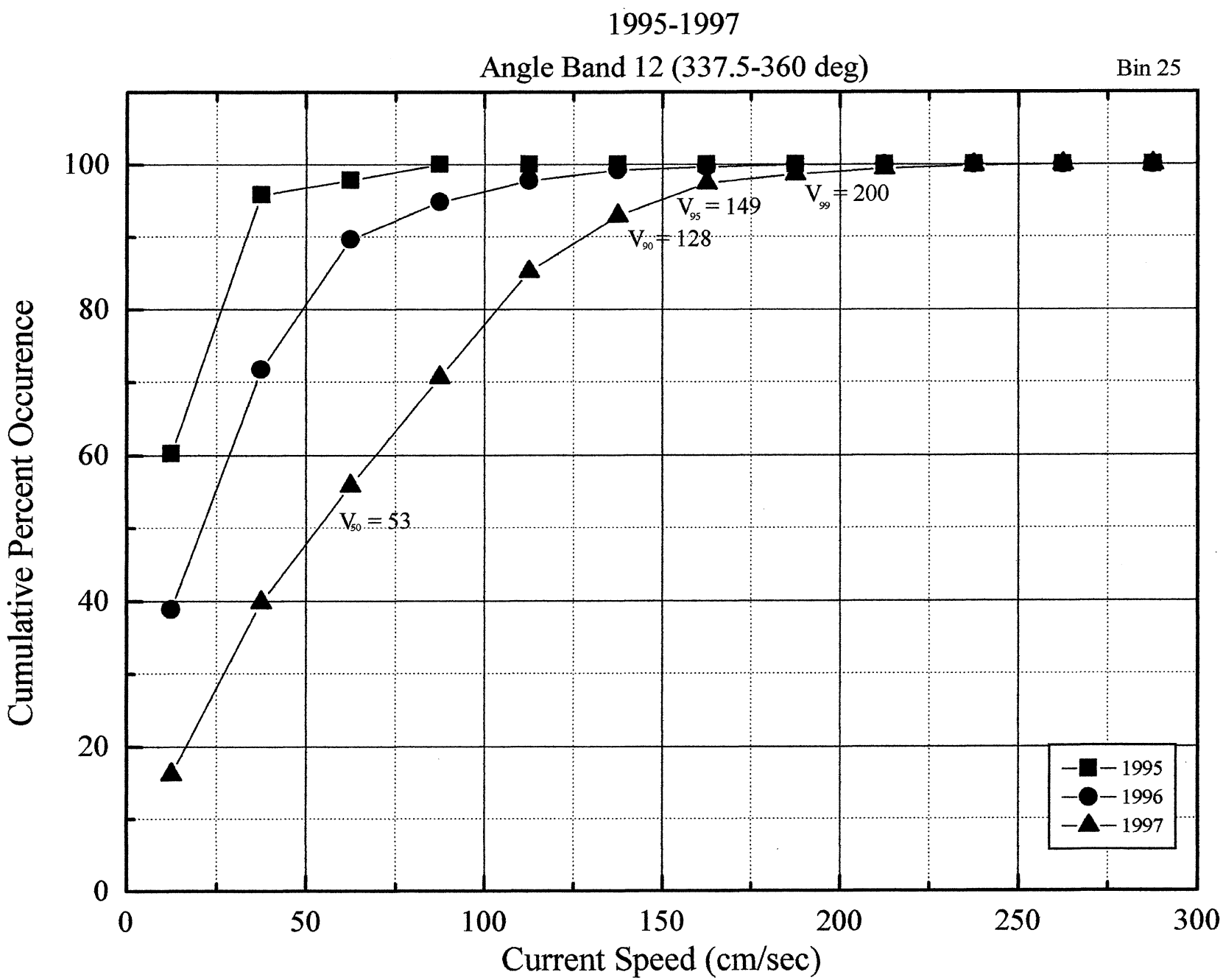


Figure 28. Cumulative probability distribution for Angle Band 12

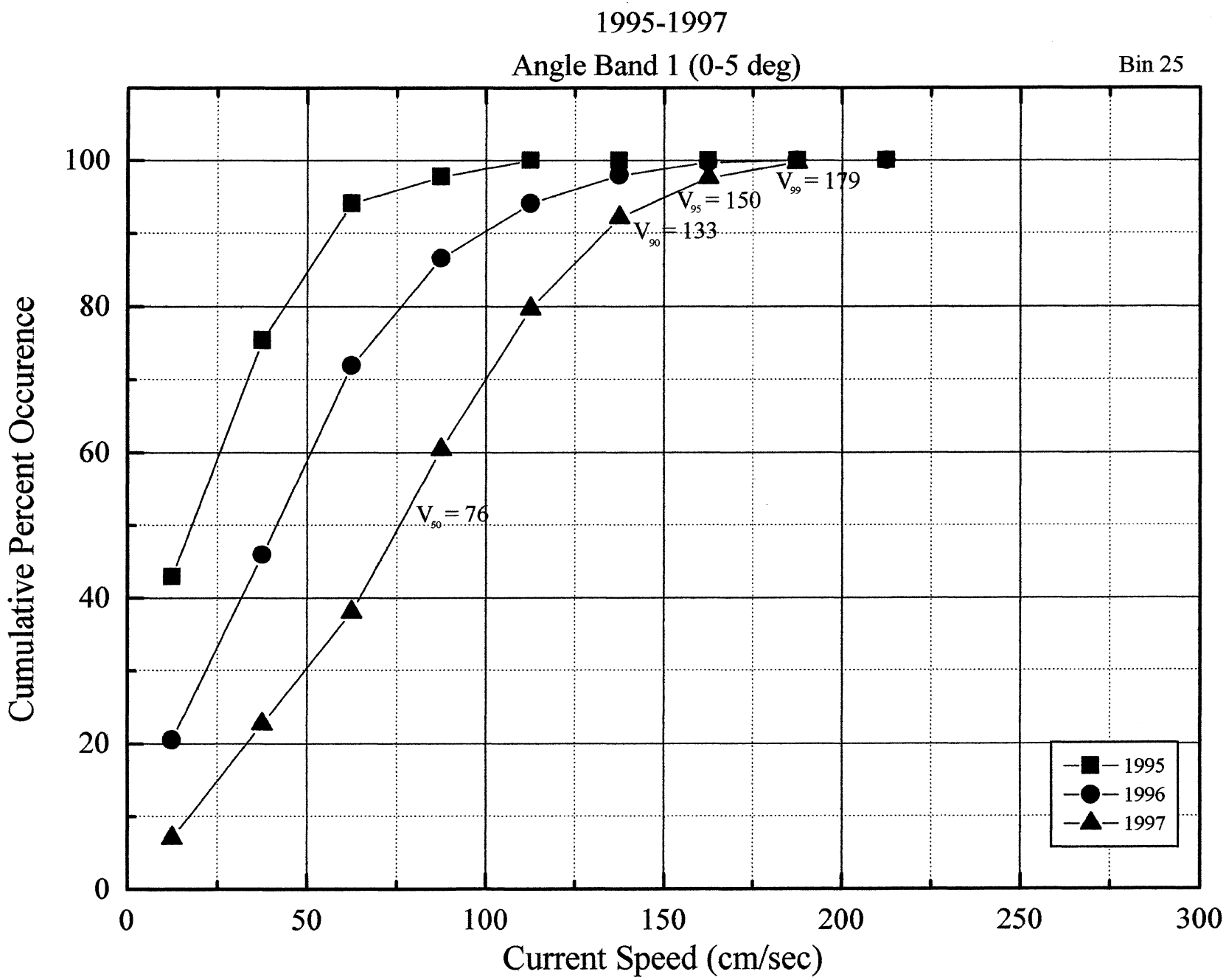


Figure 29. Cumulative probability distribution for Angle Band 1 (0-5 deg)

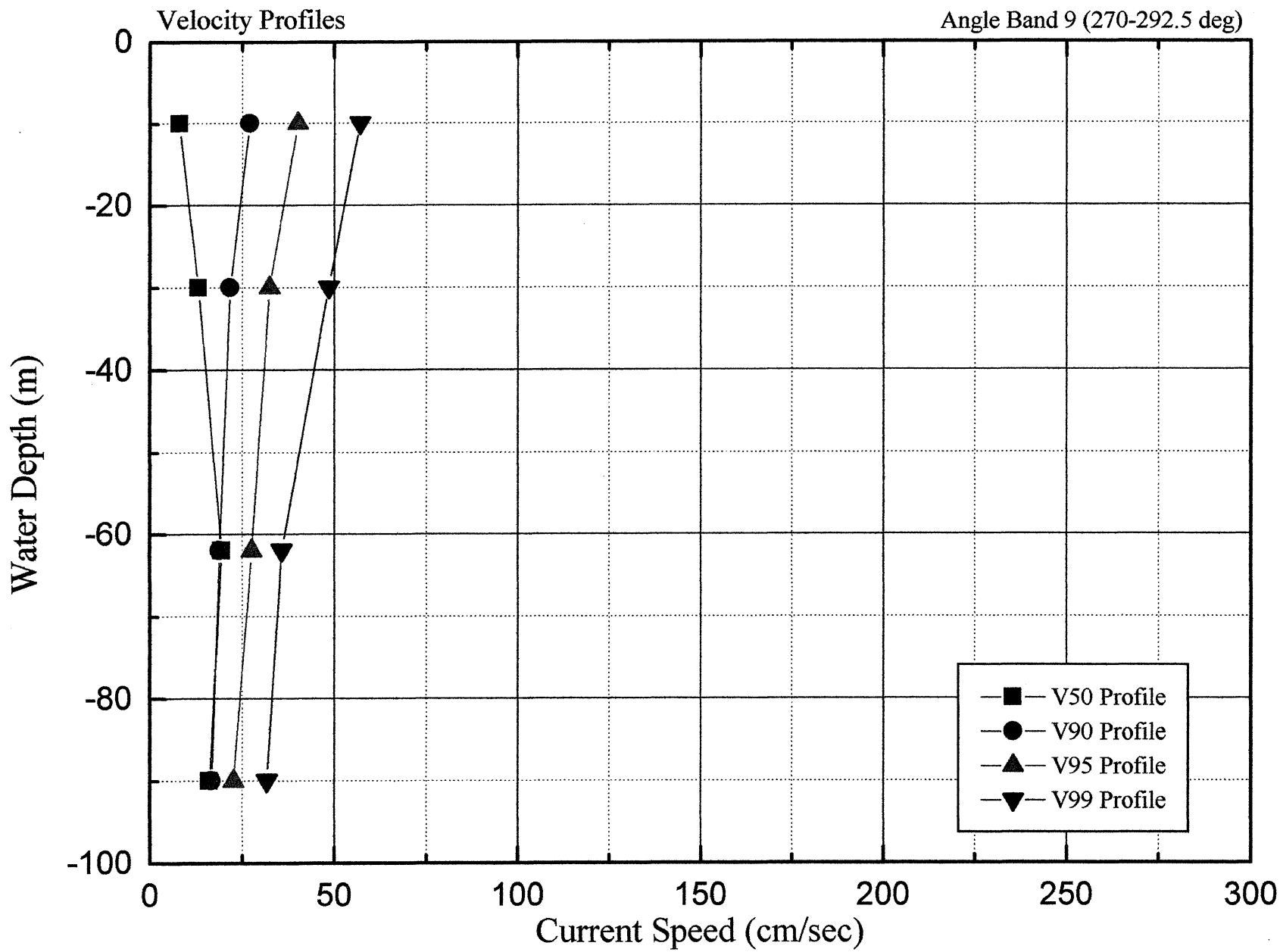


Figure 30. Velocity profiles for Angle Band 9

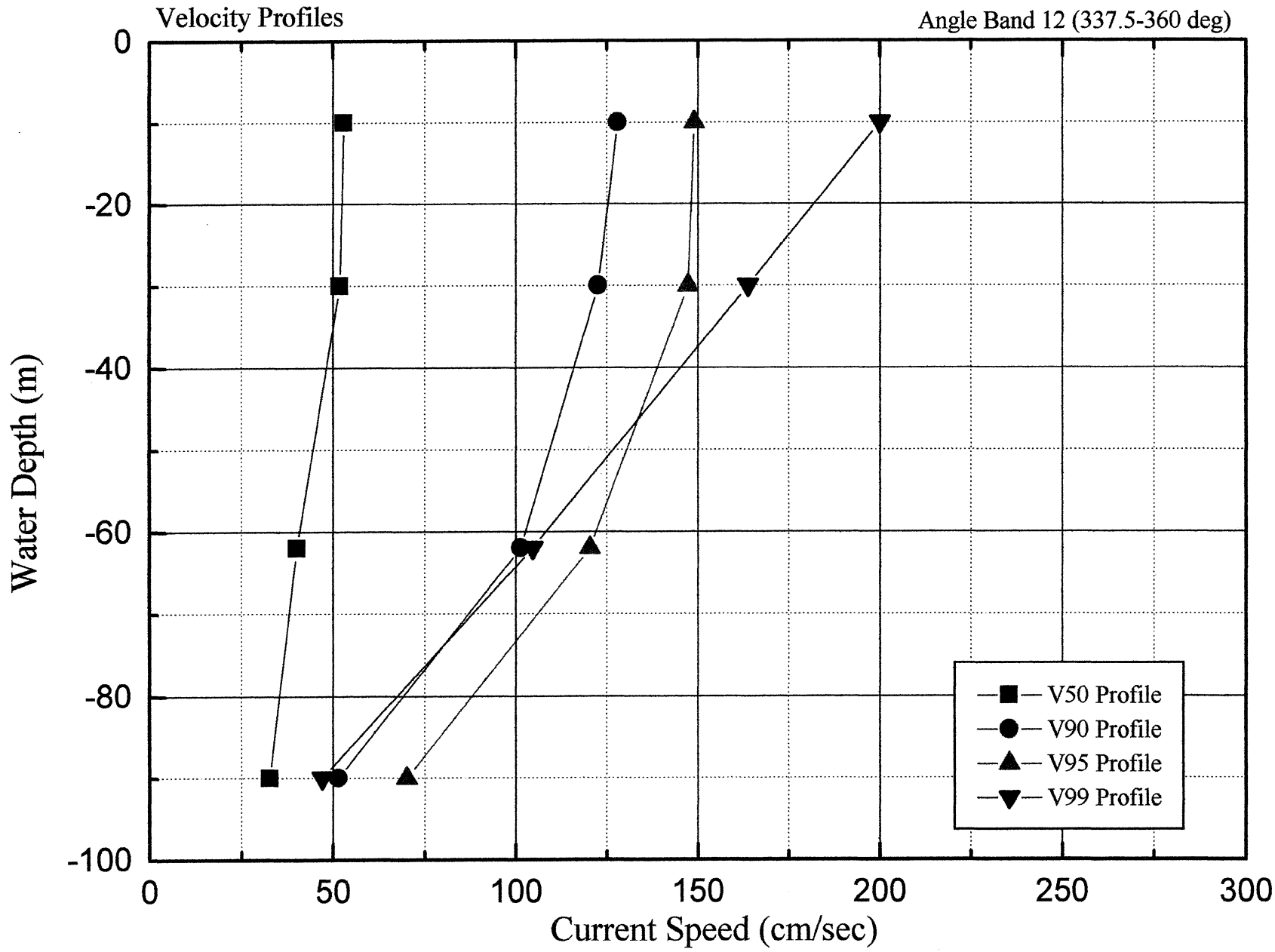


Figure 31. Velocity profiles for Angle Band 12

Note that the selected velocity profiles also reflect conservative estimates of current profiles occurring at the study site. First, the highest value from the cumulative distribution curves (usually 1997) was selected to represent V_{50}, V_{90}, V_{95}, and V_{99}. The 1995 and 1996 cumulative distribution velocity curves show values on the order of 50% lower than the extreme year. Again, one should keep in mind that velocities in these angle bands occur infrequently. For example, velocities in Angle Band 12 occurred only 5-6% of the data collection time period. Only half of that time (3% or approximately 260 hrs per year), would it be likely for velocities in Bin 25 (near the surface) to exceed 53 cm/sec. A velocity with 1% exceedance (200 cm/sec) would most likely occur only 0.06% of a given year, or approximately 4-5 hours per year near the water surface.

Simulated Velocity Values. The STFATE model can accommodate the velocity profiles described above for a single water-depth, but uses a single (depth-integrated) velocity for varying bathymetry. In order to simulate the potential movement of material into the shallower regions of the reefs, an extreme value for the depth-integrated velocity was selected (Table 1). That is, the maximum value for a given velocity profile was used in each simulation (usually the Bin 25 (surface) value).

Table 1. Velocities simulated

Direction and Percentile	Velocity Magnitude (cm/sec)
W50	20
W90	27
W95	40
W99	57
N50	53
N90	128
N95	149
N99	200

Sediment Characteristics. The dredged material composition consists of a solid fraction (rock, sand, silt-clay, etc.) and a fluid component. Each component must be defined according to its density, concentration by volume (percentage of total load volume), fall velocity, and void ratio (volume of water to volume of solids ratio).

Ten sediment samples were collected on 17-18 September 1997 at Port Everglades. Upon examination of the data, samples 1-8 located in the bay had 38% fines whereas the 2 samples taken from the inlet had only 5% fines. Bay samples had approximately 60% solids by weight whereas the inlet samples were approximately 70% solids by weight. The great difference in sediment characteristics from the two locations suggested that both conditions should be simulated. Volume fractions of sand and silt were determined and are given in Table 2.

Table 2. Port Everglades sediment characteristics			
% solids by weight	% fines	Volume fraction fines	Volume fraction sand
60	38	.1401	.2247
70	5	.0239	.4460

In June 1997, fifteen core borings were taken in the Palm Beach turning basin. From these borings the Jacksonville District provided eleven gradation curves. Analysis showed that the samples contained approximately 6% fines by weight and the percent solids ranged from 77 to 85% with an average percent solids of 80%. Two conditions selected for simulation were as shown in Table 3.

Table 3. Palm Beach sediment characteristics			
% solids by weight	% fines	Volume fraction fines	Volume fraction sand
80	6	.0368	.5664
85	6	.0417	.6426

Other sediment properties used in model simulations are as shown in Table 4.

Table 4. Sediment properties used in STFATE simulations						
Sediment	Specific Gravity	Fall Velocity (fps)	Void Ratio	Critical Shear Stress (lbs/ft^2)	Cohesive /Non-cohesive behavior	Stripped During Descent?
Sand	2.70	0.04660	0.700	0.030	N	Y
Silt-Clay	2.65	0.00256	4.000	0.007	Y	Y

Temperature and Salinity. A field survey off of Palm Beach Harbor, Florida conducted by Continental Shelf Associates included measurements of temperature and salinity in and around the Palm Beach ODMDS in February and April, 1988. Stations 4-7 were within the limits of the ODMDS and were used in this analysis (Figures 32-35) . Temperature and salinity profiles for the four stations were averaged to determine conditions to use in model simulations. Conditions shown in Table 5 were used for both project sites.

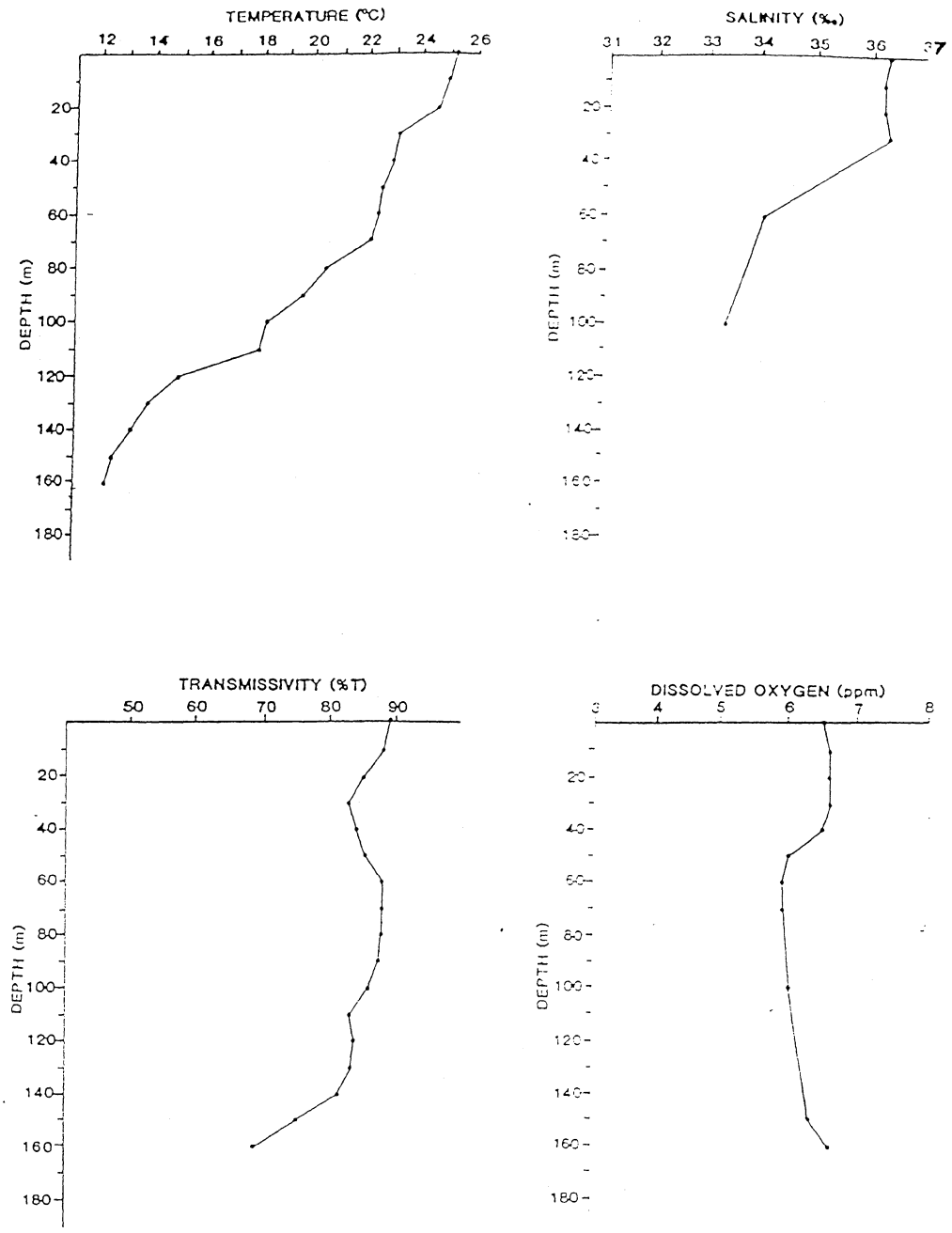


Figure 32. Hydrographic measurements of salinity and temperature at Station 4 (from Continental Shelf Associates, Inc.)

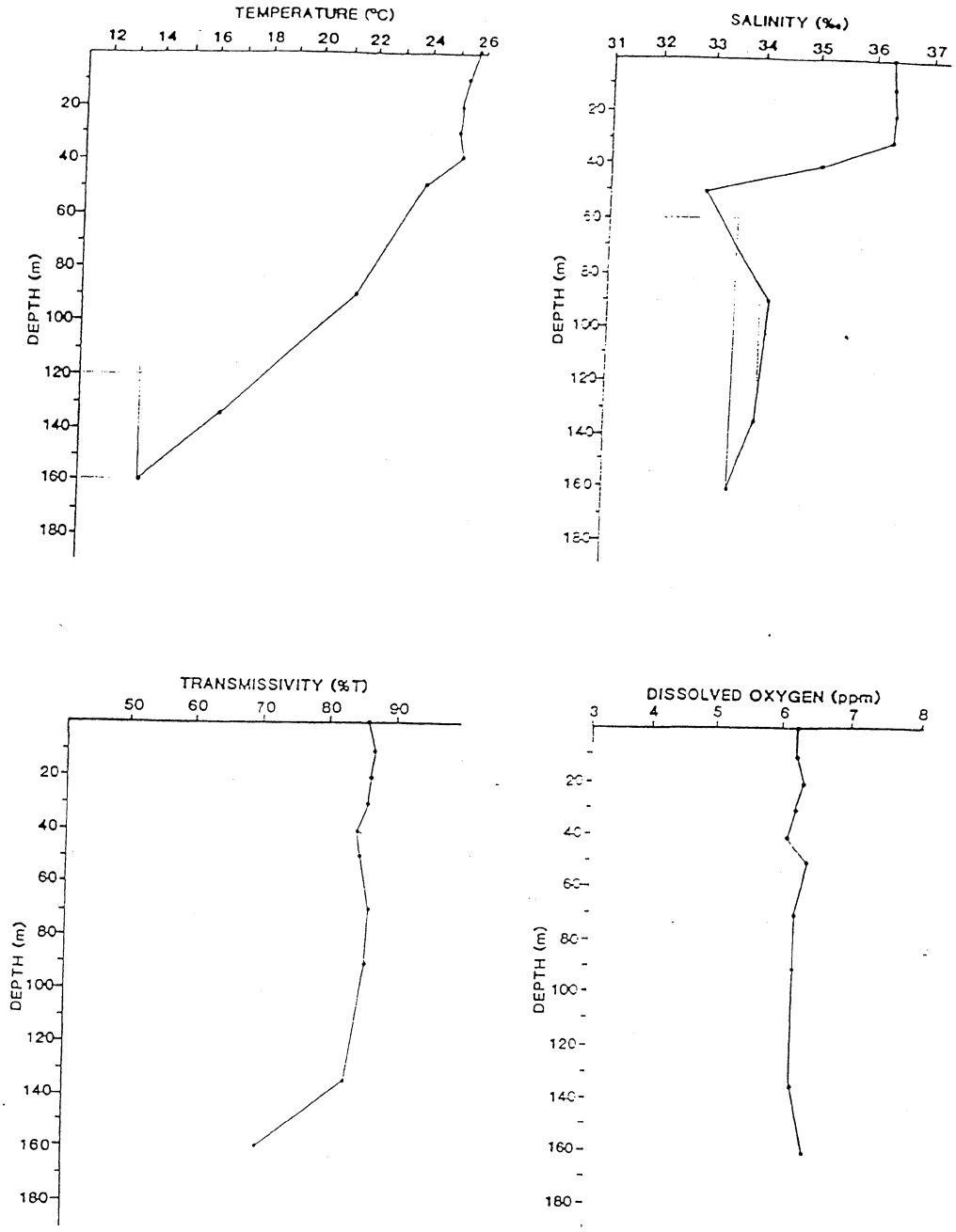


Figure 33. Hydrographic measurements of salinity and temperature at Station 5 (from Continental Shelf Associates, Inc.)

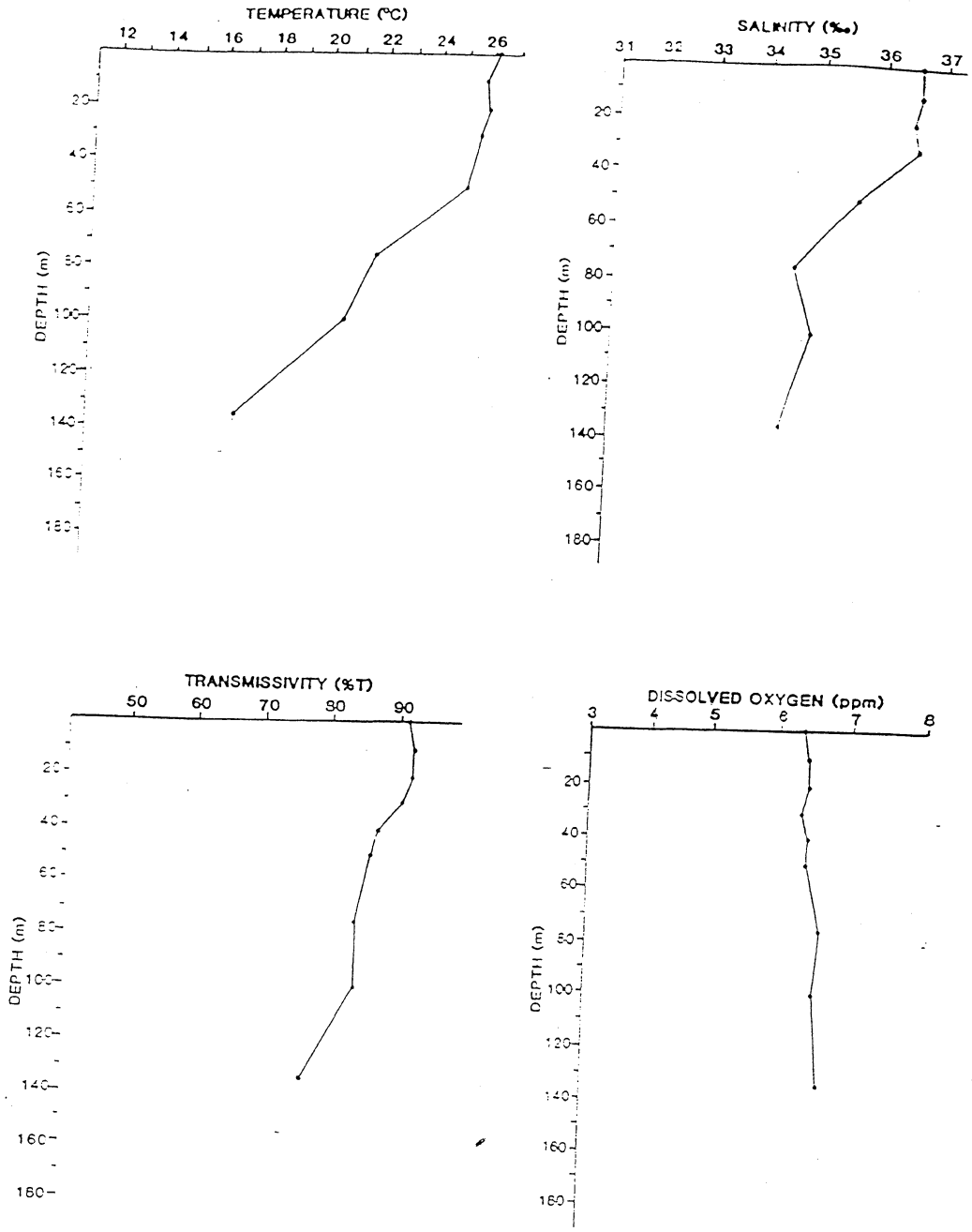


Figure 34. Hydrographic measurements of salinity and temperature at Station 6 (from Continental Shelf Associates, Inc.)

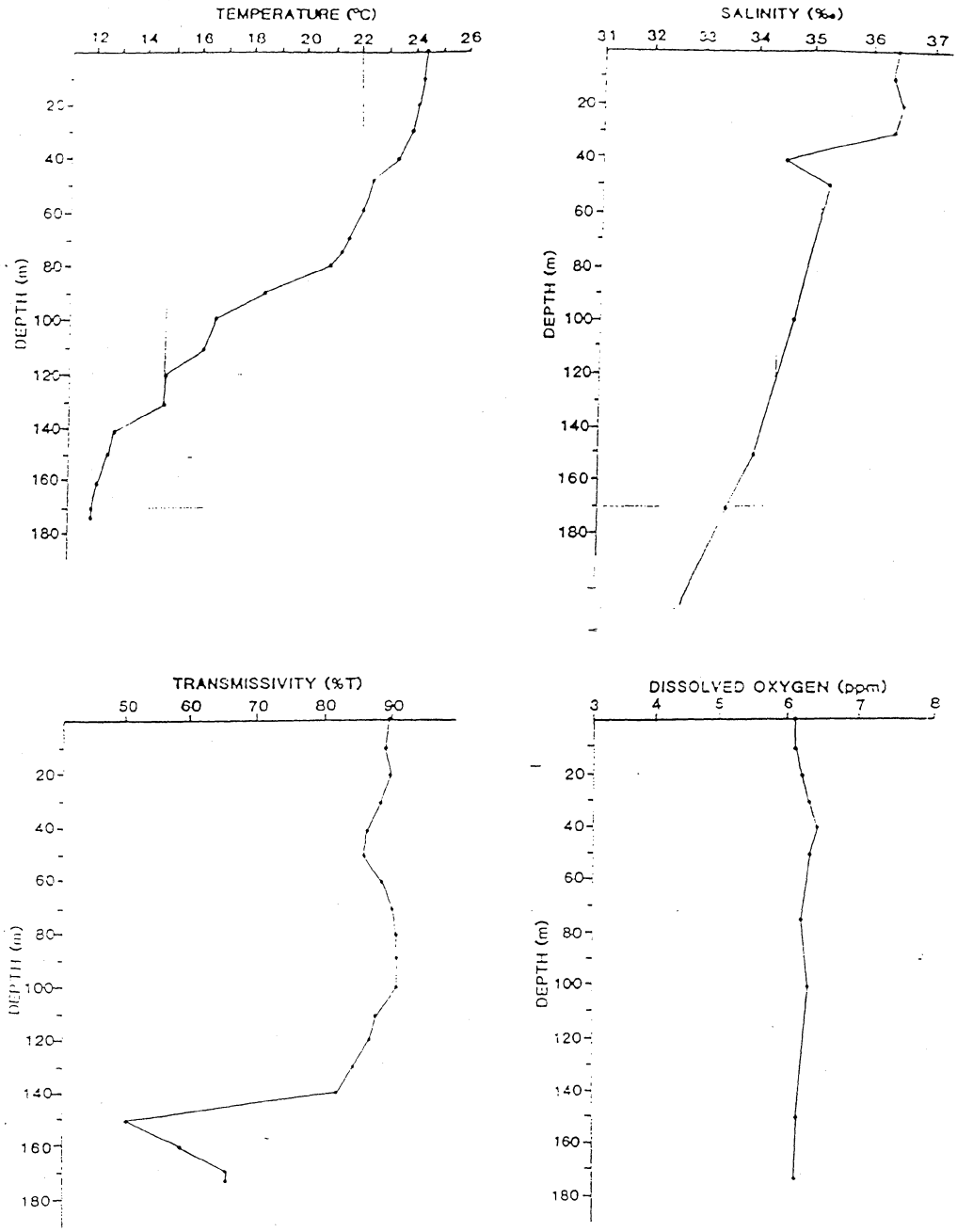


Figure 35. Hydrographic measurements of salinity and temperature at Station 7 (from Continental Shelf Associates, Inc.)

Table 5. Temperature and salinity values used in STFATE simulations		
Depth (m)	Temperature (deg C)	Salinity (ppt)
0	25.4	36.4
60	22.8	34.5
120	16.5	34.3
Max	12.0	33.5

Density Profile. Temperature and salinity profiles given above resulted in the following density profiles computed by the STFATE model:

Table 6. Density profile	
Depth (m)	Density (g/cm^3)
0	1.0243
60	1.0243
120	1.0258
Max	1.0265

Dredge Dimensions and Disposal Operations. The objective of the short-term modeling effort was to determine the fate of disposed material at the two ODMDSs and the likelihood of material transport in the direction of the shore-parallel reefs. A large capacity, split-hull dredge was specified in STFATE model simulations because it was anticipated that a large volume of disposed material would be placed in the water column at one time. The disposal vessel bin length and width were 100 and 16 m (300 and 50 ft), respectively. STFATE model simulations were for 2750 m^3 of material in a single disposal. The pre-disposal draft was 18 ft and the post-disposal draft was 4 ft. The time to empty was 5 sec. ~3,560 yd³

Model Parameters and Coefficients. Model parameters (time step, grid spacing, etc.) used for STFATE simulations were selected based on required overall grid dimensions, ambient velocities, and required model duration (Table 7). Model coefficients were selected based on recommended default values and values more appropriate for the study area (Norman Scheffner and Paul Schroeder, personal communications).

Table 7. Model coefficients		
Variable	**Palm Beach**	**Port Everglades**
Grid size (m)	150	150
Number cells: cross-shore alongshore	45 45	45 45
Time step (sec)	375-750	300-600
Simulation Duration (hrs)	1-5	3-6
Maximum Velocity (cm/sec)	200	200
Density (g/cm^3)	1.0247	1.0247
CSTRIP	0.003	0.003
ALPHA0	0.235	0.235
BETA	0.000	0.000
CM	1.000	1.000
CD	0.500	0.500
GAMA	0.250	0.250
CDRAG	1.000	1.000
CFRIC	0.010	0.010
CD3	0.100	0.100
CD4	1.000	1.000
ALPHAC	0.100	0.100
FRICTN	0.010	0.010
ALAMDA (m$^{(2/3)}$/sec)	0.005	0.005
AKY0 (m^2/sec	0.025	0.025

Model Simulations

All variables and model parameters discussed above were used to simulate the short-term fate of dredged material disposed of at the Palm Beach or Port Everglades ODMDSs. Final results for westerly and northwesterly directed sets of velocities for the four selected velocity magnitudes and two sediment compositions resulted in 16 simulations for each ODMDS. The length of each simulation was a function of the ambient velocity, with slower current speeds requiring longer simulation times.

Port Everglades. STFATE modeling results for Port Everglades are presented in Figures 36-43. In all Port Everglades applications sediment was disposed 6100 m (20,000 ft) from the grid origin (reef location). Note that westerly-directed and northwesterly-directed velocities are denoted in the figures with a W and N, respectively. Velocities with exceedances of 50% (V_{50}), 10% (V_{90}), 5% (V_{95}), and 1% (V_{99}) were identified in the figures with 50, 90, 95, and 99, respectively.

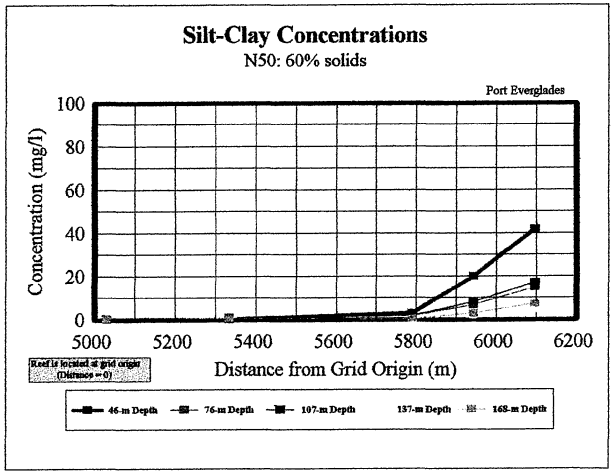
Results indicate silt-clay concentrations diminish to approximately 1 mg/l or less within 1500 m (5000 ft) of the disposal location (4500 m (15,000 ft) from the reef location). Higher current speeds carry sediment from the disposal location more rapidly, but silt-clay concentrations still drop below about 1 mg/l within 1500 m (5000 ft) of the disposal location. A major portion of the dredged material is sand. Sand concentrations diminish to 1 mg/l or less within 2440 m (8000 ft) of the disposal location (3660 m (12,000 ft) from reef location)even under the most severe velocity conditions. The majority of the sand in the dredged material settles rapidly, but some of the sand that is stripped during descent remains in the water column for longer time/distances as indicated by these results.

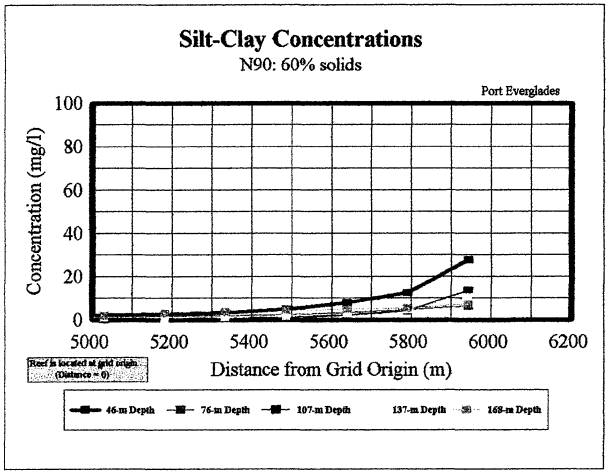
Palm Beach. STFATE modeling results for Palm Beach are presented in Figures 44-51. In all Palm Beach applications sediment was disposed 5300 m (17,500 ft) from the grid origin (reef location). Two sediment compositions were simulated, 80% and 85% solids by weight, with 6% fines.

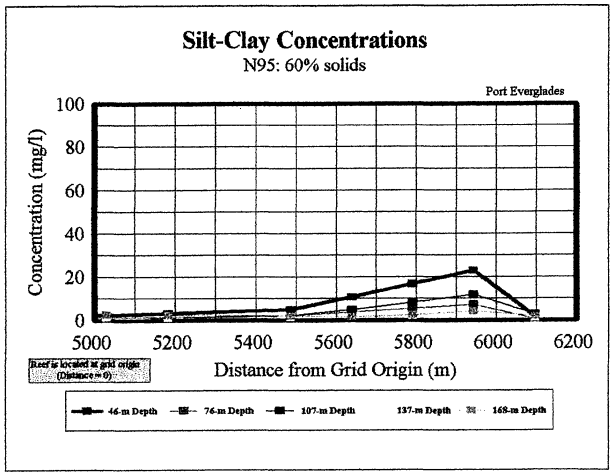
Silt-clay concentrations diminish rapidly to 1 mg/l or less within 1500 m (5000 ft) of the disposal location (12500 ft from the reef location) under all flow conditions. Higher current speeds carry sediment from the disposal location more rapidly, but the concentration of fines remains low (less than 1 mg/l within 1500 m (5000 ft) of the disposal location). A major portion of the dredged material is sand. Sand concentrations diminish to 1 mg/l or less within 2400 m (8000 ft) of the disposal location (2900 m (9500 ft) from reef location). The majority of the sand in the dredged material settles rapidly, but some remains in the water column for longer time/distances as indicated by these results.

In summary, conservative estimates of flow conditions were identified and used to model the short-term fate of dredged material. Even under the most severe flow conditions, the impact on the reefs is negligible. As a most conservative estimate one might limit disposal operations to periods when velocities are less than V_{90}.

Would be nice to see plots with [illegible]







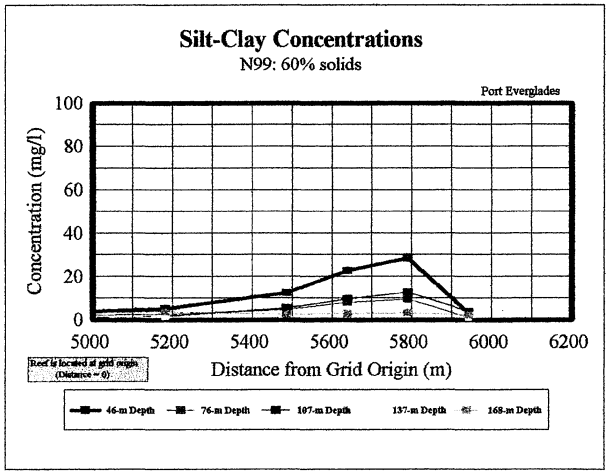
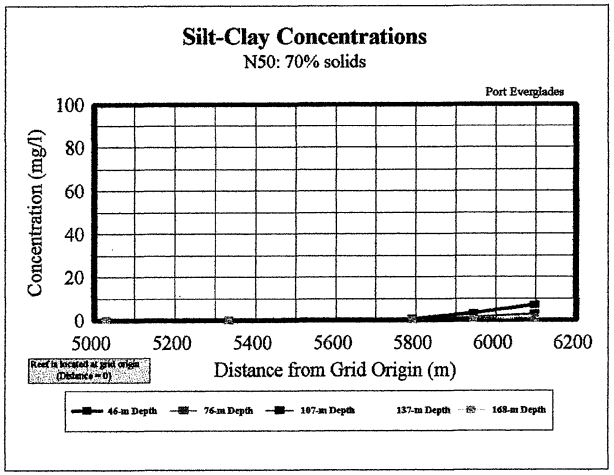
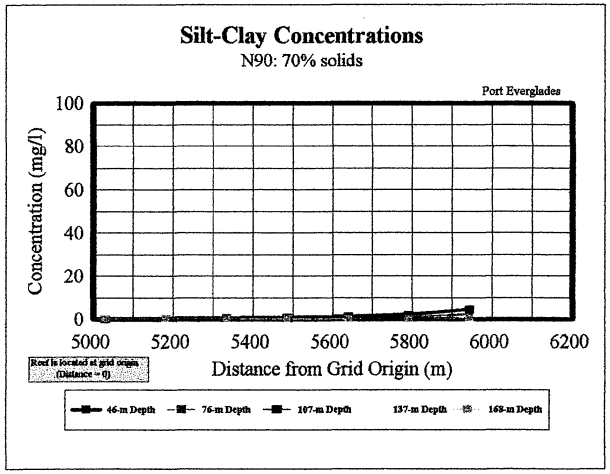
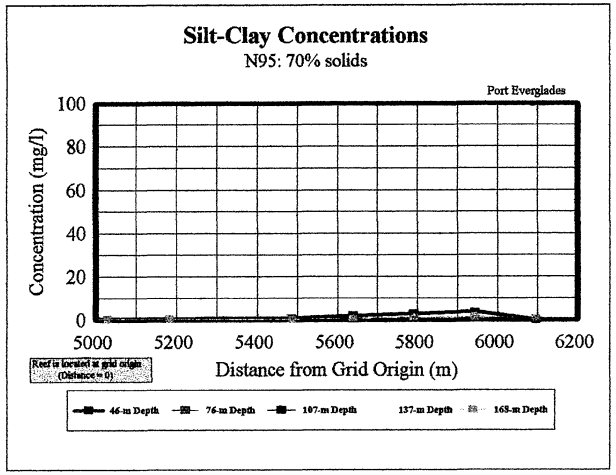


Figure 36. Port Everglades silt-clay concentrations for northwesterly-directed velocities and 60% solids







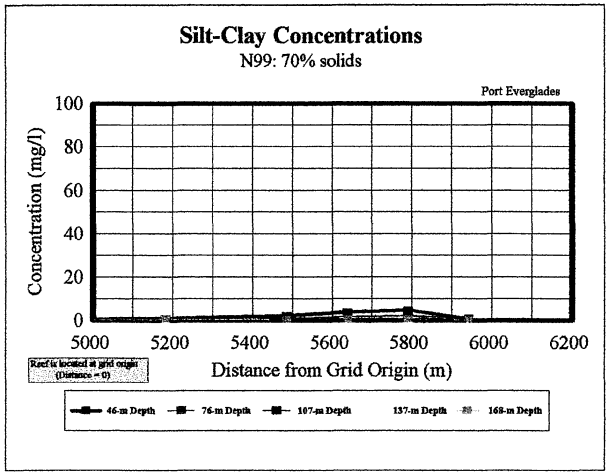
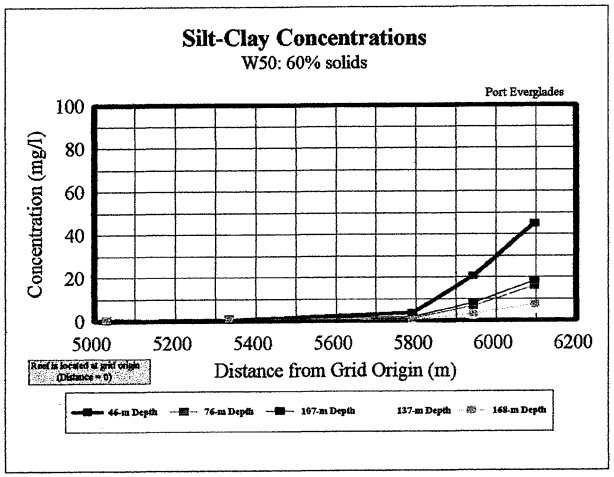
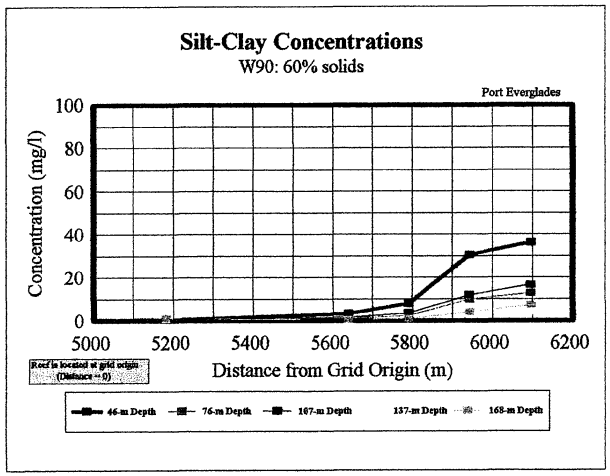
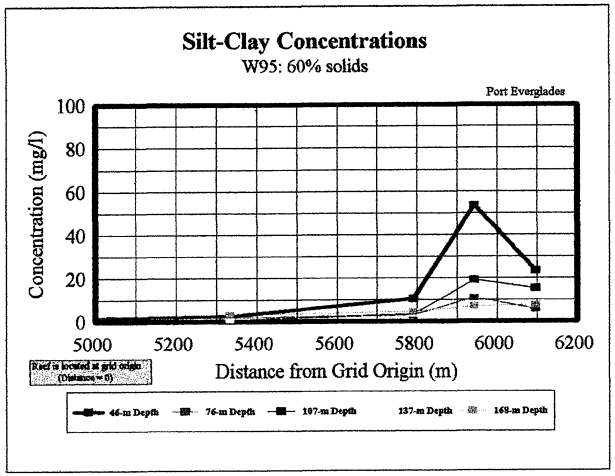


Figure 37. Port Everglades silt-clay concentrations for northwesterly-directed velocities and 70% solids







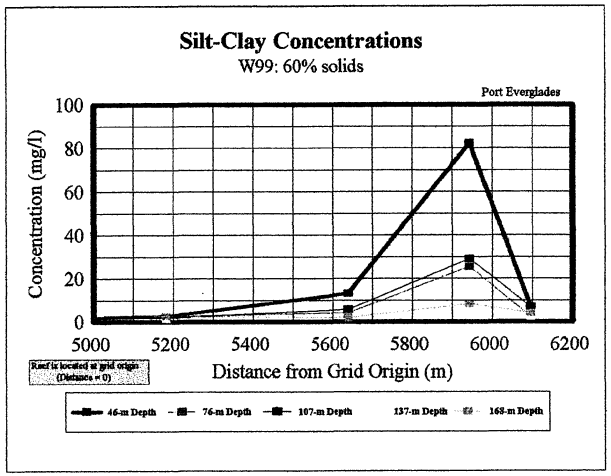


Figure 38. Port Everglades silt-clay concentrations for westerly-directed velocities and 60% solids

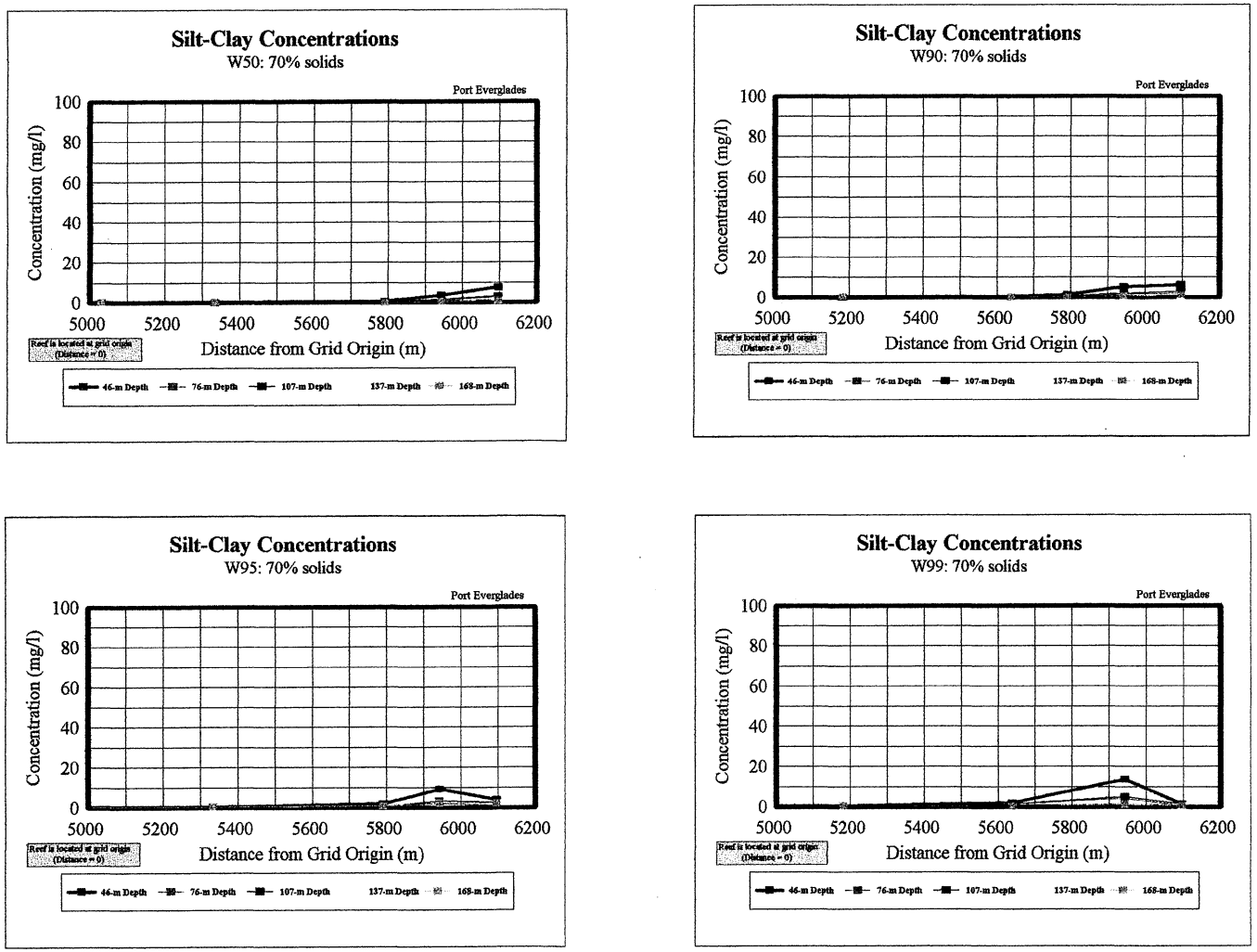
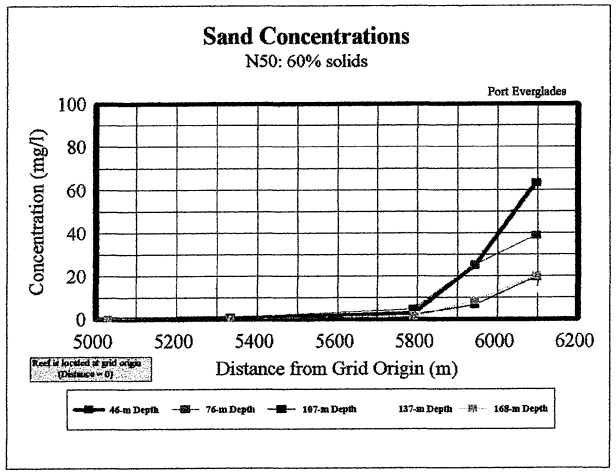
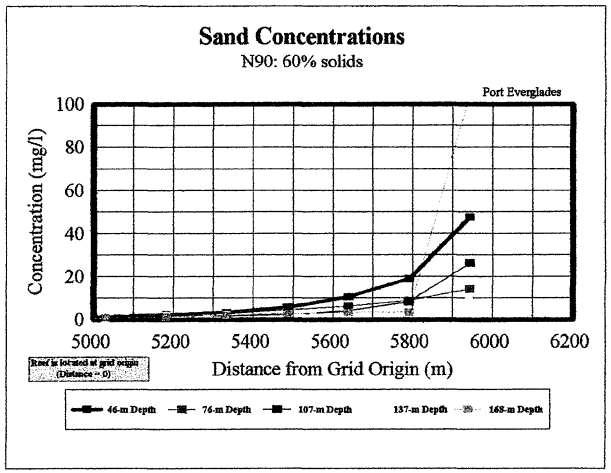
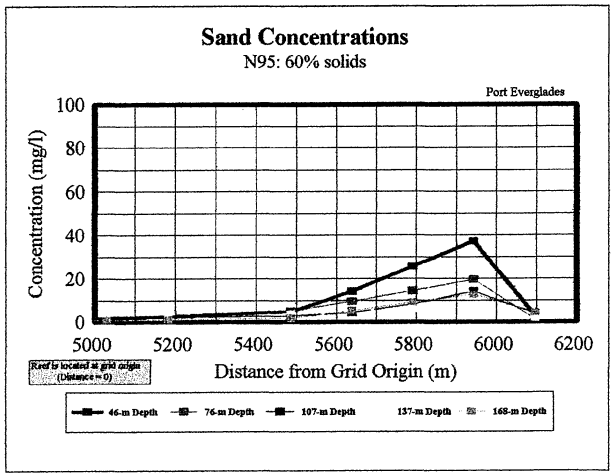


Figure 39. Port Everglades silt-clay concentrations for westerly-directed velocities and 70% solids







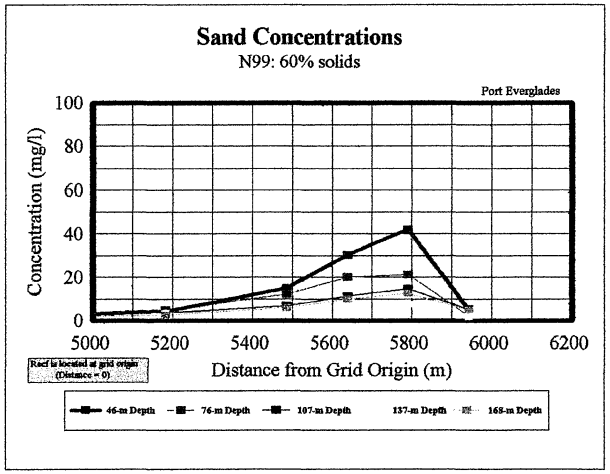


Figure 40. Port Everglades sand concentrations for northwesterly-directed velocities and 60% solids

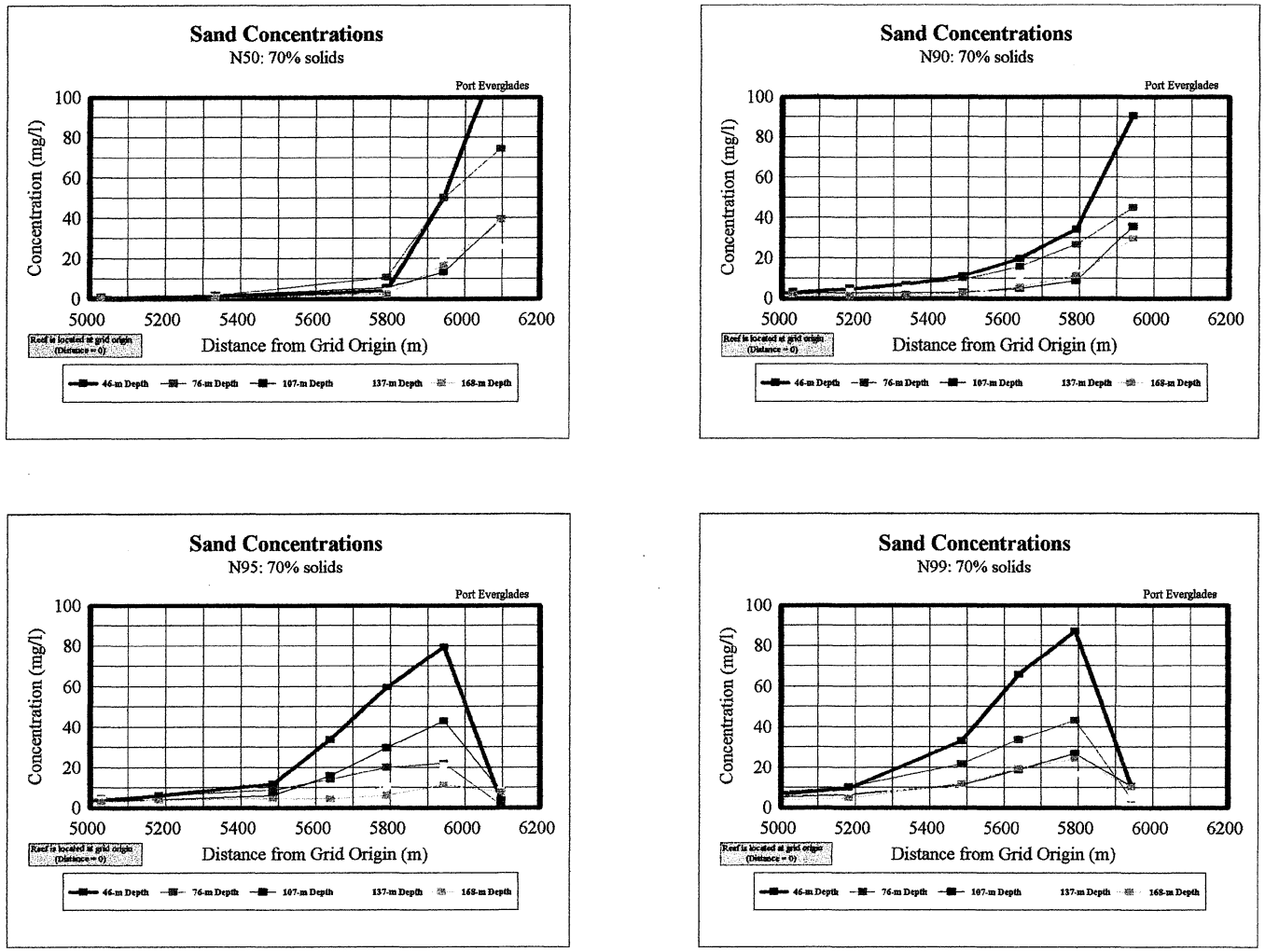
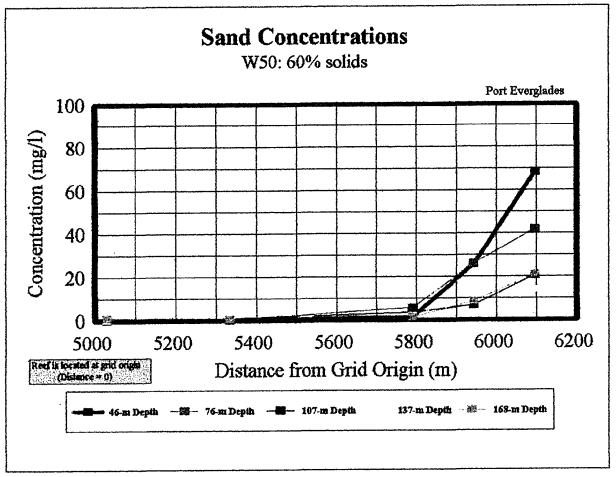
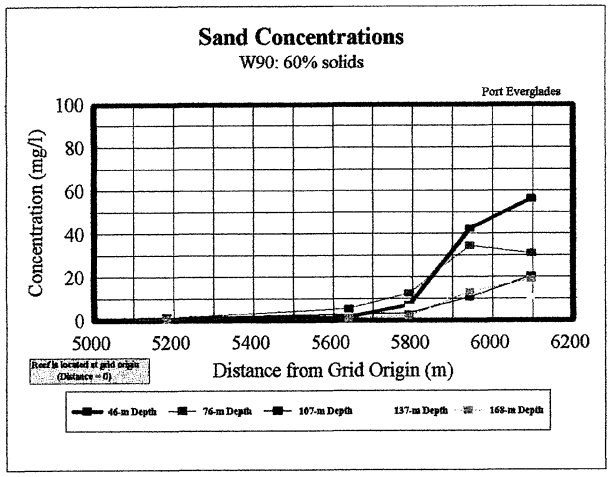
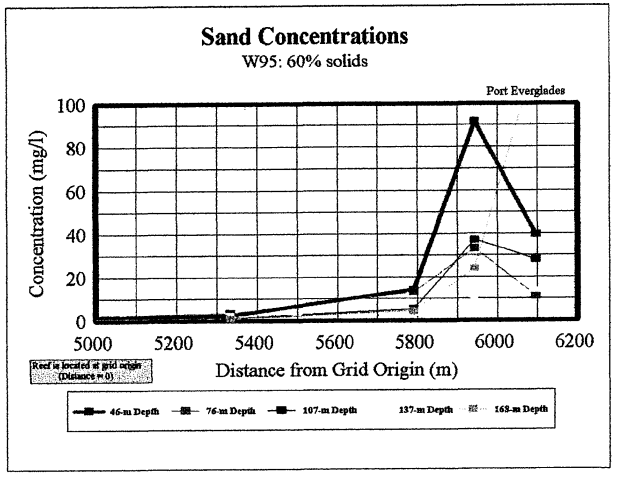


Figure 41. Port Everglades sand concentrations for northwesterly-directed velocities and 70% solids







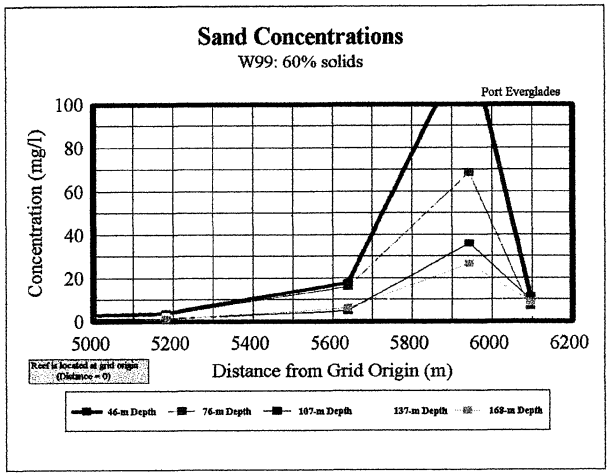


Figure 42. Port Everglades sand concentrations for westerly-directed velocities and 60% solids

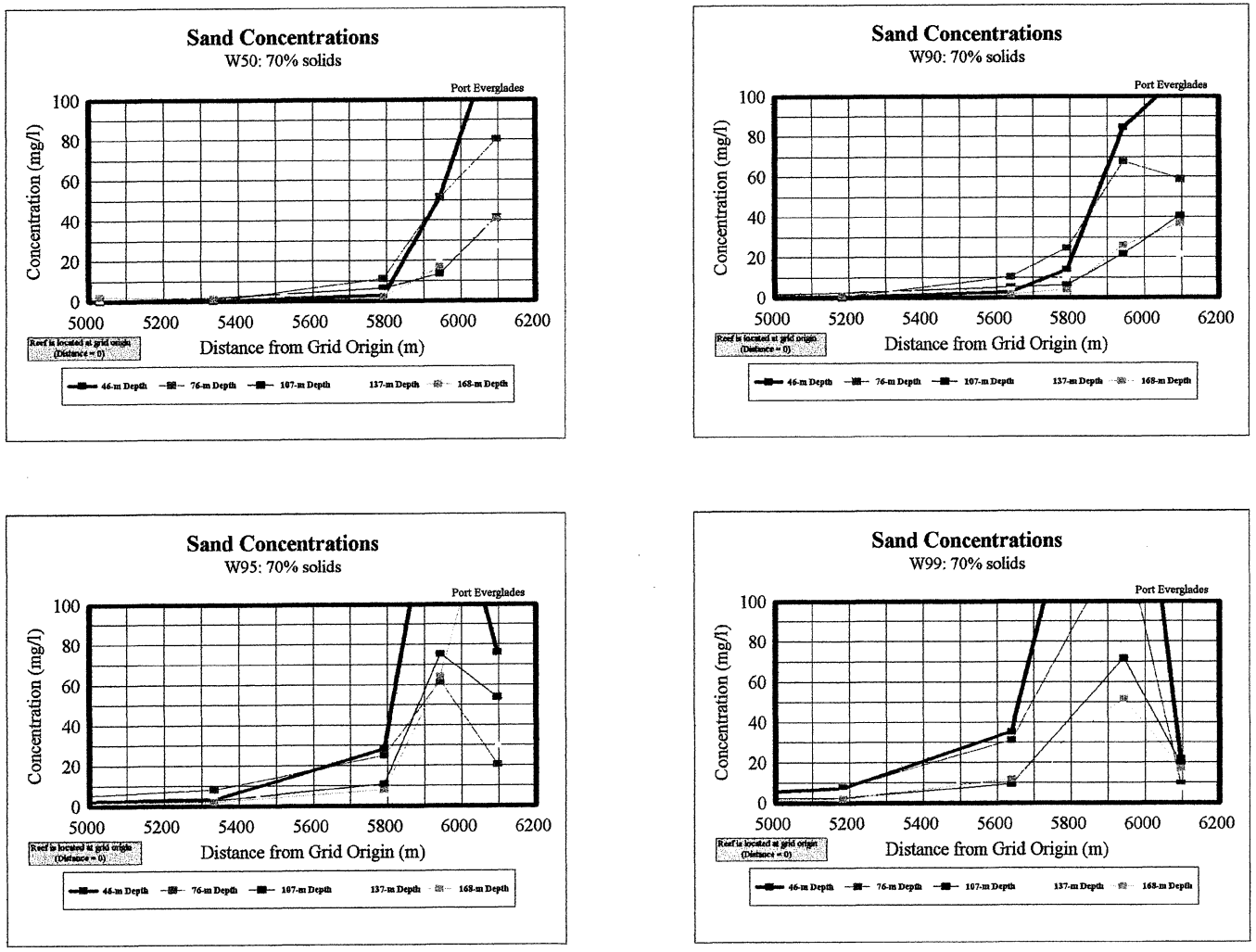
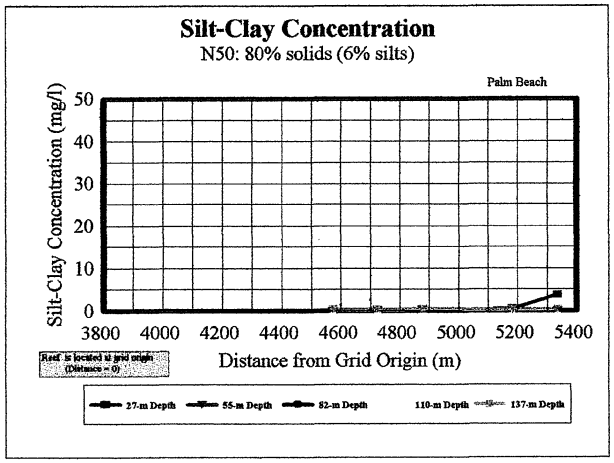
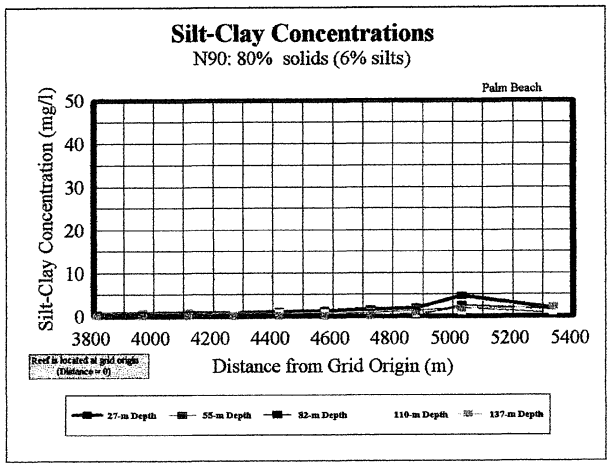
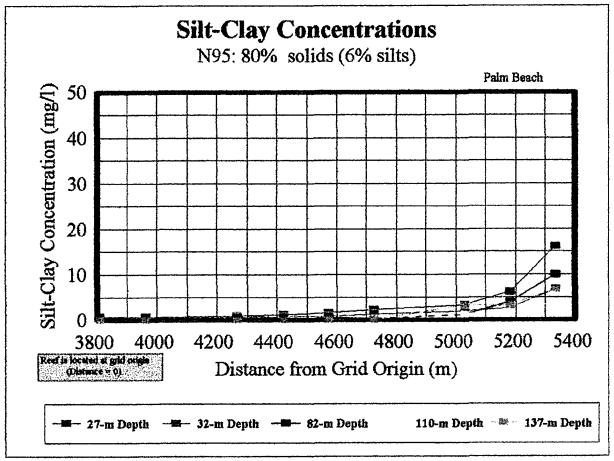


Figure 43. Port Everglades sand concentrations for westerly-directed velocities and 70% solids







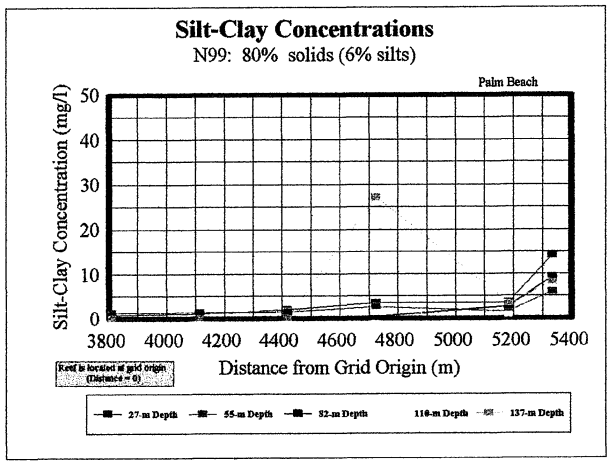
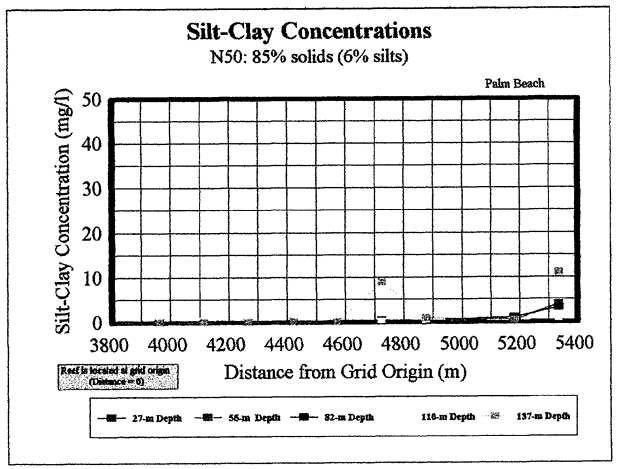
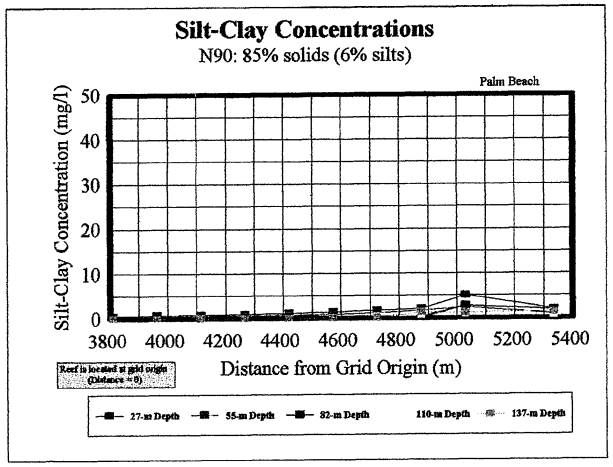
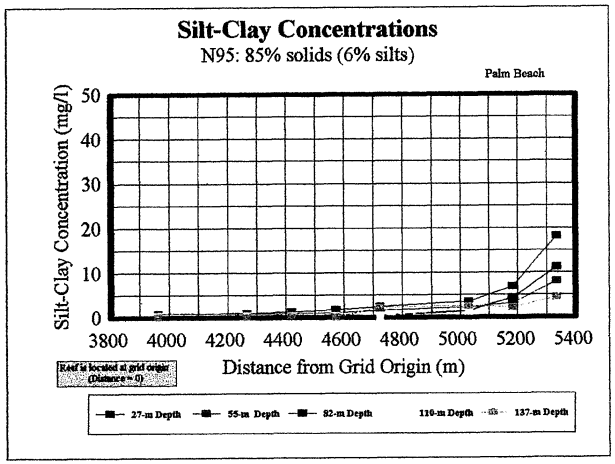


Figure 44. Palm Beach silt-clay concentrations for northwesterly-directed velocities and 80% solids







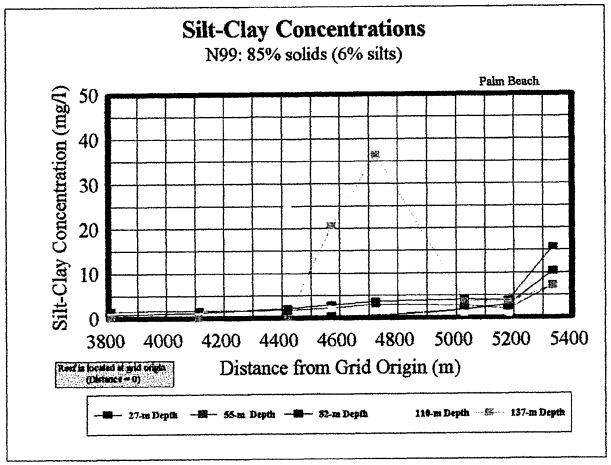
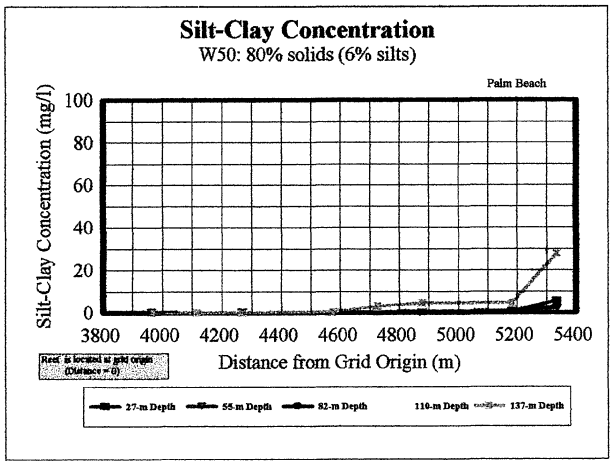
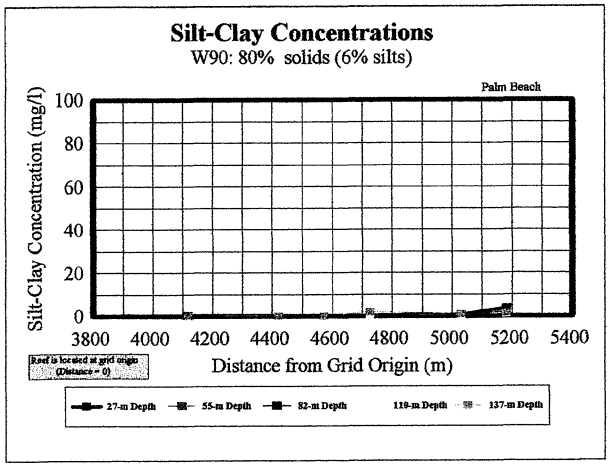
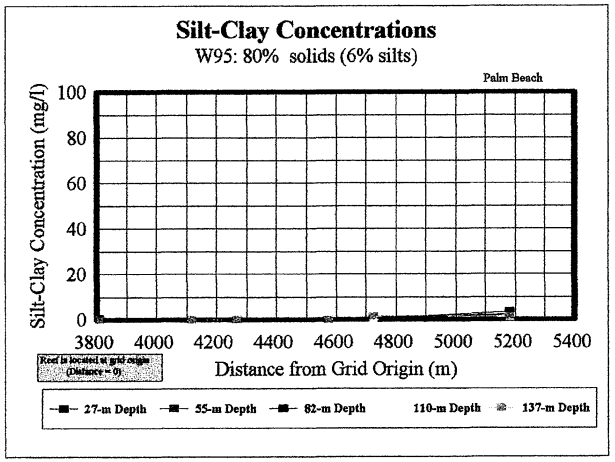


Figure 45. Palm Beach silt-clay concentrations for northwesterly-directed velocities and 85% solids







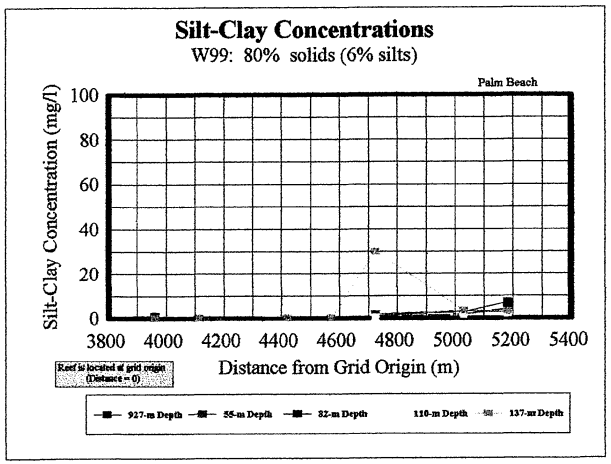
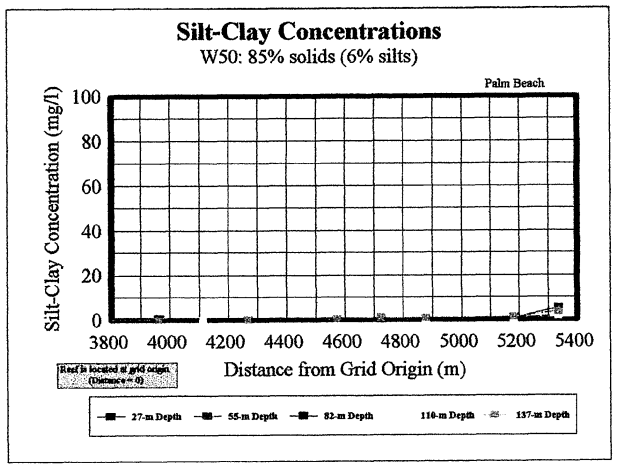
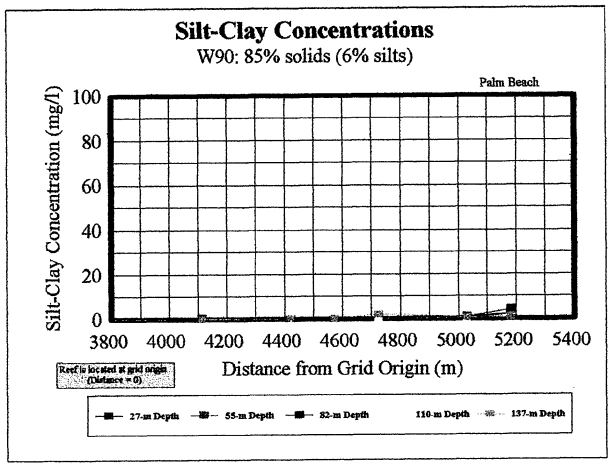
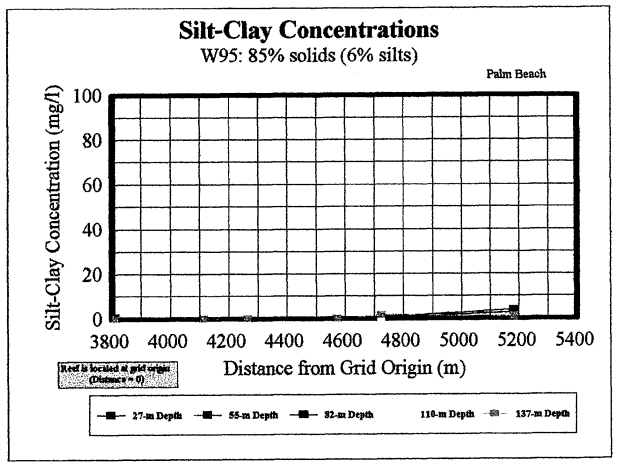


Figure 46. Palm Beach silt-clay concentrations for westerly-directed velocities and 80% solids







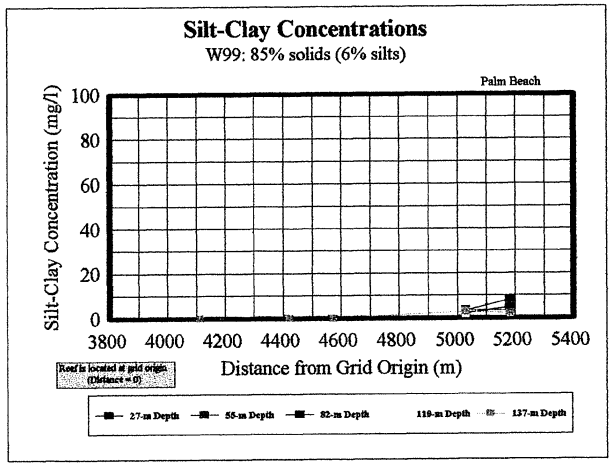
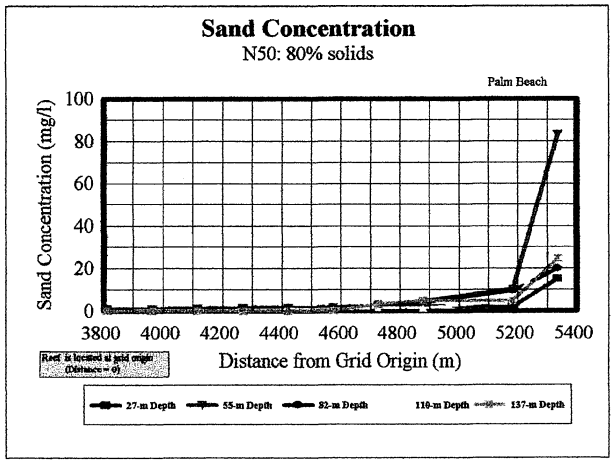
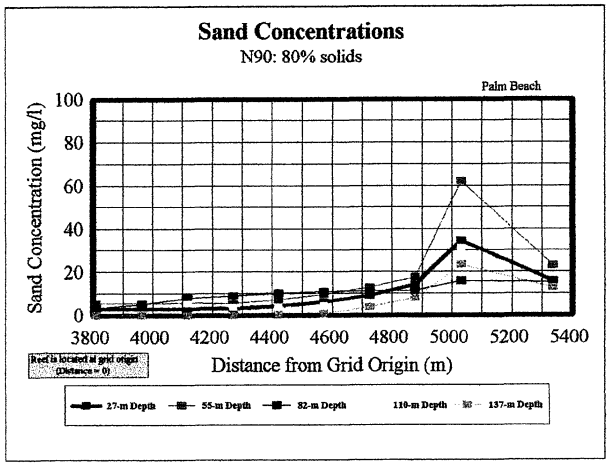
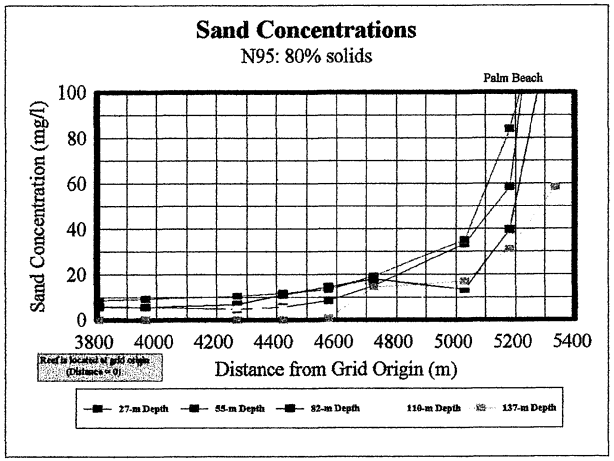


Figure 47. Palm Beach silt-clay concentrations for westerly-directed velocities and 85% solids







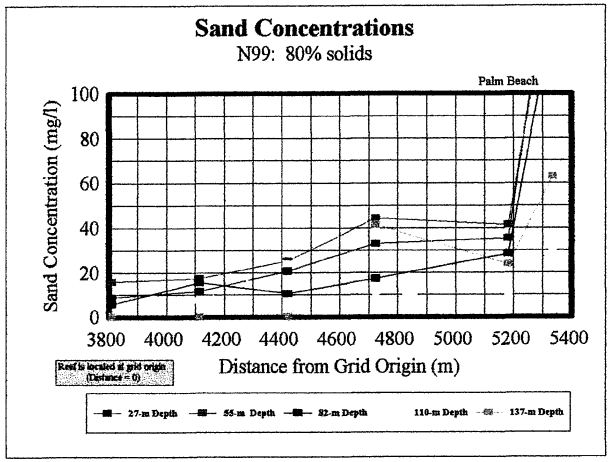


Figure 48. Palm Beach sand concentrations for northwesterly-directed velocities and 80% solids

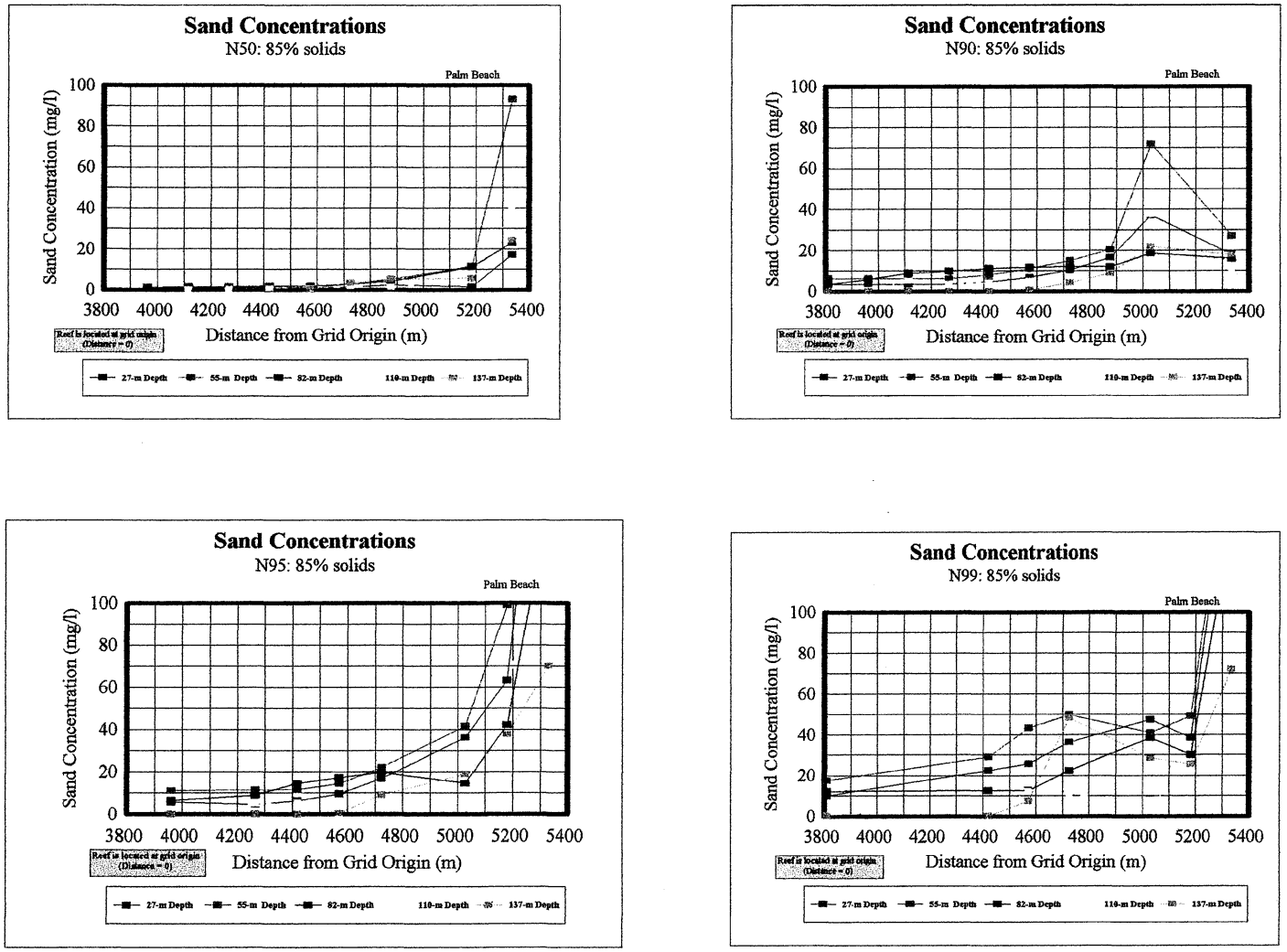
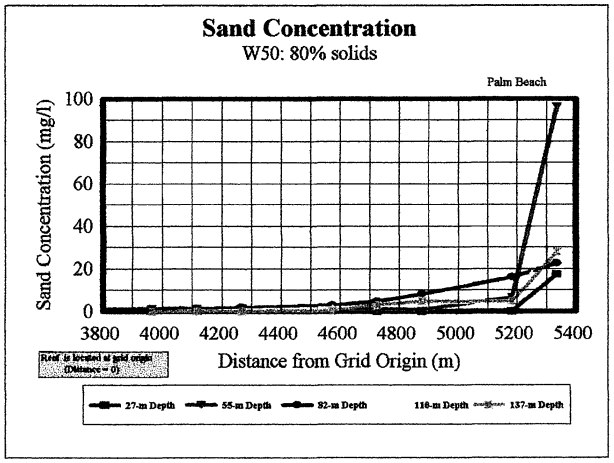
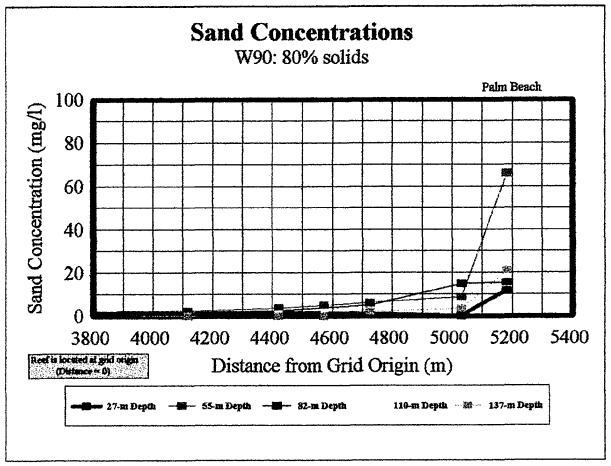
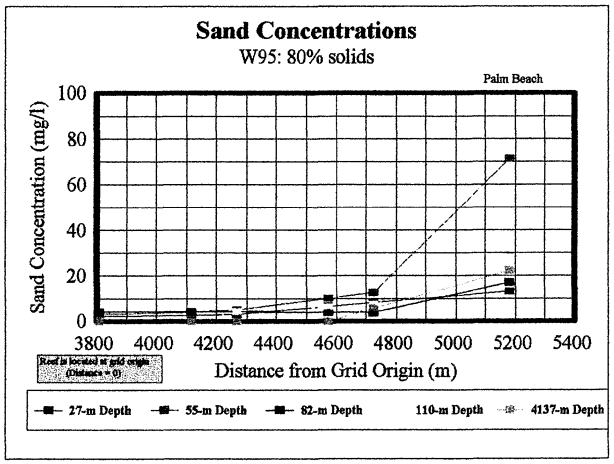


Figure 49. Palm Beach sand concentrations for northwesterly-directed velocities and 85% solids







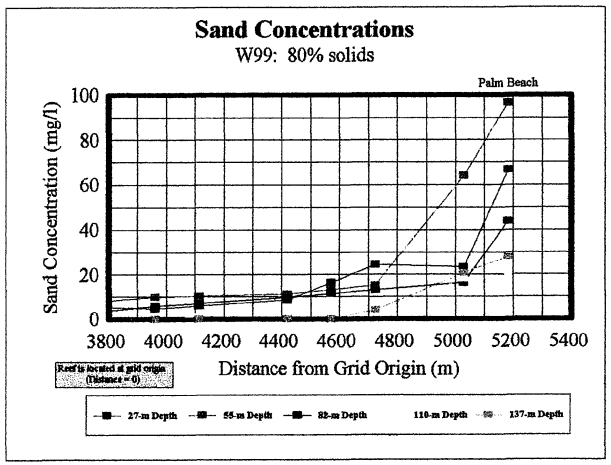
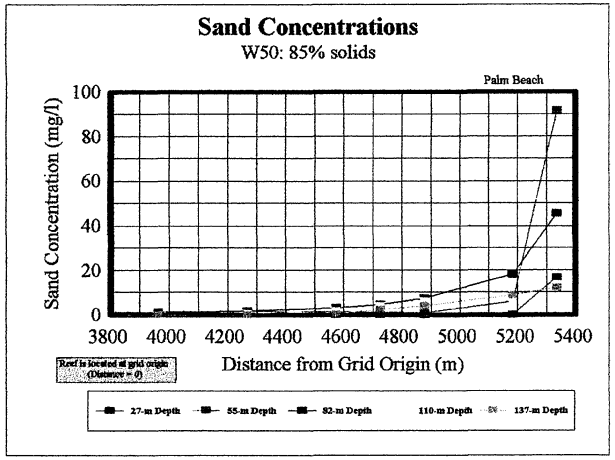
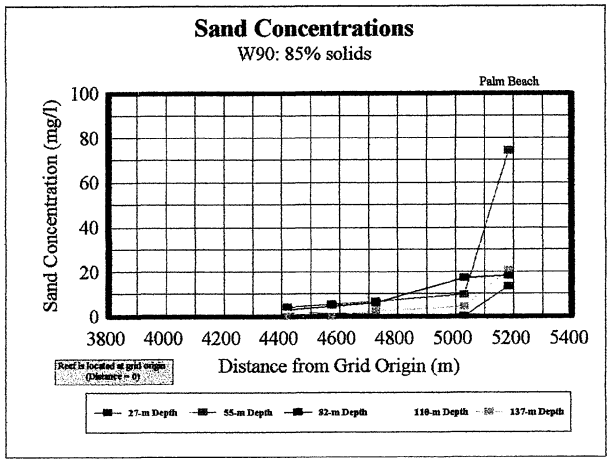
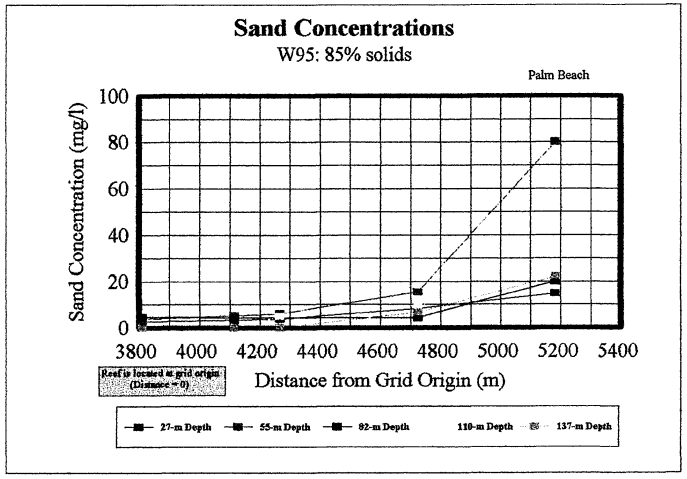


Figure 50. Palm Beach sand concentrations for westerly-directed velocities and 80% solids







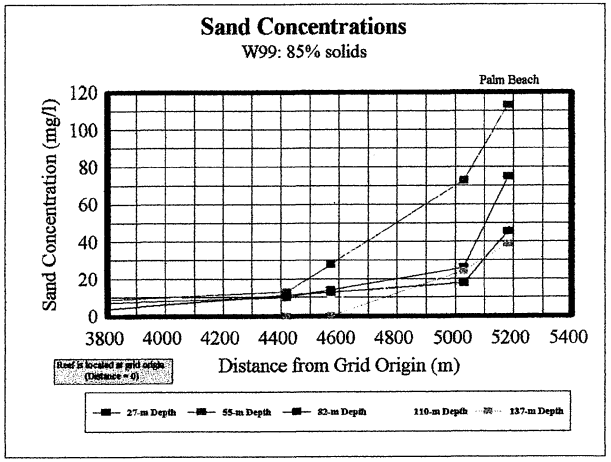


Figure 51. Palm Beach sand concentrations for westerly-directed velocities and 85% solids

3 Long-term Fate Modeling

LTFATE is a site-analysis program that uses coupled hydrodynamic, sediment transport, and bathymetry change sub-models to compute site stability over time as a function of local waves, currents, bathymetry, and sediment characteristics (Scheffner et al., 1995). LTFATE was developed to simulate the long-term fate and stability of dredged material placed in open water with an initial intended use for classifying existing or proposed disposal sites as dispersive or nondispersive. The model estimates the stability of a site for time periods ranging from days (for storm events) to years (for ambient conditions). If the site is demonstrated to be dispersive, model output will provide an estimate of the temporal and spatial fate of the eroded cohesionless material. Sediment movement is estimated as a function of not only the local bathymetry and sediment characteristics, but also the time varying wave and current conditions. LTFATE uses an information database to provide design wave and current time series boundary conditions that realistically represent conditions at the candidate disposal site. The user can also specify conditions for specific storms , if desired.

The wave simulation methodology and the water surface elevation and current databases referenced in this report were developed through the Dredging Research Program (DRP) (Hales, 1995) at WES. The database of tidal elevations and currents for the study area was from DRP tidal constituent database. Wave data necessary for these applications is derived from the Wave Information Study (WIS) hindcast for the Atlantic Coast (Brooks and Brandon, 1995). These sources are used to generate wave, water surface elevation and current condition data for use as input to LTFATE for evaluating mound stability.

cohesive for?

LTFATE has the capability of simulating both non-cohesive and cohesive sediment transport. In addition, consolidation of cohesive sediments are accounted for to more accurately predict physical processes which occur at the site. Many sediment transport equations require near bottom velocities, but the methods incorporated in LTFATE were developed and work well using mean velocity of flow reflective of conditions outside the wave and current boundary layers. Unlike near-bottom velocities, these velocities are not significantly effected by bottom roughness. This is an advantage in regions where bottom roughness is unknown or continually changing. A screening level erosion model was used initially to determine if LTFATE level modeling was necessary. The screening level erosion uses the same basic equations as LTFATE, but the solution is at a point rather than over a grid mesh. If the sediment fluxes determined from the point model prove to be sufficiently large, than the LTFATE model would be used. Following are sections describing the effects of waves on the sediment/water interface and non-cohesive sediment transport. What about cohesive sediments?

Effect of Waves at Sediment/Water Interface. Most non-cohesive sediment transport equations are developed for a current only environment. Areas of interest where LTFATE or the screening level erosion model is applied normally include bottom stresses due to both currents and waves. Therefore the effects of waves must be included in estimating sediment transport. A modification of the transport equations proposed by Bijker (1967) is incorporated into LTFATE and the screening level erosion model to reflect an increase in the transport rate if the ambient currents are accompanied by surface waves. The modification, in the form of an effective increase in the near-bottom velocity outside the wave and current boundary layers used to compute sediment transport, is based on equations reported by Swart (1976). This increased velocity can be thought of as the current velocity that would produce a bottom stress equivalent to the stress due to the combined effects of ambient currents and waves. The effective increase in velocity for currents accompanied by waves V_{wc}, is written as a function of the current velocity V_c in the absence of waves as follows:

$$V_{wc} = V_c \left[1.0 + \frac{1}{2} \left(\xi \frac{\hat{u}_0}{V} \right)^2 \right]^{1/2} \tag{1}$$

where:

$$\xi = \hat{C} \left(\frac{f_w}{2g} \right)^{1/2} \tag{2}$$

$$\hat{C} = 18 \log \left(\frac{12d}{r} \right) \tag{3}$$

$$f_w = \exp \left[-5.977 + 5.213 \left(\frac{r}{a_0} \right)^{0.194} \right] \tag{4}$$

(if $f_w > 0.3$, $f_w = 0.3$)

$$\hat{u}_0 = \frac{Hgk}{2\sigma} \frac{1}{\cosh(kd)} = \frac{HgkT}{4\pi} \frac{1}{\cosh(kd)} \tag{5}$$

$$a_0 = \frac{Hgk}{2\sigma^2} \frac{1}{\cosh(kd)} = \frac{H}{2} \frac{1}{\sinh(kd)} \tag{6}$$

where $\hat{u}_0$ is the amplitude of the orbital velocity at the bed (Van De Graff and Van Overeem 1979), computed according to linear wave theory (Ippen 1966, p 28) and a_0 is defined as the orbital excursion (amplitude) at the bed (Swart 1976), computed from linear wave theory (Ippen 1966, p 29). In the above, the parameter f_w is defined as the bottom friction coefficient (Jonsson 1966). The parameter r is the hydraulic bed roughness and taken to be 0.197 ft (0.06 m), (Van De Graff and Van Overeem 1979). The terms H, k, σ, and T represent wave height (ft), wave number (ft^{-1}), angular frequency (sec^{-1}) and period (sec) respectively. The terms d and g represent water depth (ft) and acceleration of gravity (ft sec^{-2}) respectively.

Non-Cohesive Sediment Transport Model Component. The equations reported by Ackers and White (1973) were selected as the basis for the non-cohesive sediment transport modeling component. These relationships predict sediment transport as a primary function of sediment grain size, depth, and depth averaged velocity (here the depth averaged velocity is assumed to be V_{wc}). The equations are applicable to uniformly graded noncohesive sediment with a grain diameter in the range of 0.04 mm to 4.0 mm (White 1972).

The Ackers-White transport equations relate sediment transport to three dimensionless quantities. The first, a nondimensional grain size D_{gr}, is defined as a function of the ratio of the immersed particle weight to the viscous forces acting on the grain. The value is defined as:

$$D_{gr} = D\left[\frac{g(s-1)}{\nu^2}\right]^{1/3} \qquad \textbf{(7)}$$

where:

D = sediment diameter (i.e., D_{50}), ft
g = acceleration of gravity, ft/sec^2
s = sediment specific gravity
ν = fluid kinematic viscosity, ft^2/sec

The value of D_{gr} is used to categorize the sediment as coarse or transitional, with the following coefficients defined for the two sediment classifications:

a. Coarse sediments: $D_{gr} > 60$.
n = 0.0
m = 1.50
A = 0.17
C = 0.025

b. Transition sediments: $1.0 < D_{gr} \leq 60.0$

$$n = 1.00 - 0.56 \log(D_{gr}) \qquad \textbf{(8)}$$

$$m = \frac{9.66}{D_{gr}} + 1.34 \tag{9}$$

$$A = \frac{0.23}{\sqrt{D_{gr}}} + 0.14 \tag{10}$$

$$\log C = 2.86 \log D_{gr} - (\log D_{gr})^2 - 3.53 \tag{11}$$

The second nondimensional parameter, F_{gr}, represents particle mobility defined as the ratio of shear forces to the immersed sediment weight. The general form of the relationship is

$$F_{gr} = \frac{v_*^n}{\sqrt{gD(s-1)}} \left[\frac{V_{wc}}{\sqrt{32}\log(10\frac{d}{D})} \right]^{1-n} \tag{12}$$

where V is the depth averaged velocity determined from the above described modification to the current velocity to account for the effect of waves (ft/sec), d is the mean depth of flow (ft), and v_* is the shear velocity (ft/sec) which can be defined from Chow (1959, p 204) as:

$$v_* = \frac{\sqrt{g}V_{wc}}{C_z} \tag{13}$$

where C_z is the Chezy coefficient.

The third nondimensional parameter, G_{gr}, defines a sediment transport rate as a ratio of shear forces to the immersed weight multiplied by the efficiency of transport. The efficiency term is based on work needed to move the material per unit time and the total fluid power. The transport rate is written as

$$G_{gr} = \frac{Xd}{sD}\left(\frac{v_*}{V_{wc}}\right)^n \tag{14}$$

where X is a nondimensional sediment transport function in the form of mass flux per unit mass flow rate. The sediment transport rate G_{gr} can be related to the mobility function F_{gr} through the following relationship:

$$G_{gr} = C\left(\frac{F_{gr}}{A} - 1.0\right)^m \tag{15}$$

Equations 14 and 15 are used to solve for X as:

$$X = C\left(\frac{F_{gr}}{A} - 1.0\right)^{m} \frac{sD}{d}\left(\frac{V_{wc}}{v_*}\right)^{n} \qquad \textbf{(16)}$$

A dimensional sediment load transport rate Q_b, defined in cubic feet of sediment (solids) per second per unit width can be written as:

$$Q_b = XVd \qquad \textbf{(17)}$$

Therefore, the total sediment mixture transport, i.e., solids plus voids, is written as:

$$Q_b = \frac{Q_b}{(1-n)} \qquad \textbf{(18)}$$

where n is the porosity (ratio of void volume to total volume).

A dimensional sediment transport magnitude in volume (ft^3) of sediment mixture per second per unit width (ft) is finally written in the following form:

$$Q = C\left[\frac{F_{gr}}{A} - 1.0\right]^{m} \frac{sD}{(1-e)}\left(\frac{V_{wc}}{v_*}\right)^{n} V_c \qquad \textbf{(19)}$$

Equation 19 represents sediment transport as a primary function of depth, sediment grain size, and depth-averaged velocity.

LTFATE was applied to a site just south of Mobile Bay (Alabama) and successfully predicted the movement of the Sand Island disposal mound over a 30-month period from March 1987 through August 1989 (Scheffner 1996). Mound movement was tracked using six bathymetric surveys (Hands and Allison 1991). LTFATE predictions compared favorably to these bathymetry data, offering partial verification of the methods incorporated in the model.

Screening Level Erosion Model

As a preliminary to performing LTFATE simulations, a screening level erosion model is run to address the potential for sediment transport from the dredged material mound. If the screening level erosion model indicates little to no potential for sediment movement, then LTFATE model simulations would be purely academic. In the screening level erosion model the total load of sediment is assumed to move as bed load. The method followed for this application is based on Ackers and White (1973). This work is well accepted as one of the best methods for estimating non-cohesive sediment transport and compares favorably to multiple

datasets collected under varied hydrodynamic conditions (Brownlie, 1981). The application for this project is similar to the application of the Ackers and White method to the LTFATE model (Scheffner, 1996). The Ackers and White formula for bed load transport were originally developed for streams, as were most commonly used non-cohesive formulas. Therefore, the formulas are generally for current dominated environments. The same method was used to solve for this shortcoming as was used in LTFATE. A coefficient is determined based on current velocity, wave height, wave period, bottom roughness and water depth. This current velocity is then multiplied by this coefficient to determine a new 'perceived bottom velocity', which is a velocity that would produce the same shear as the combined current and wave motions. Derivation of the coefficient and the application to calculation of shear stress can be found in Bijker (1971), Swart (1976) and Scheffner (1996). It should be noted, however, that the strength of orbital velocities in the large water depths at the ODMDSs would be minimal except for the longest period waves experienced at each site.

Approximations used in estimating the sediment erosion from the ODMDSs are as follows: All sediment was assumed to move as bed load. Because bed load is calculated as a flux across a boundary, a cell size estimate was necessary. For these calculations, the cells were set to 305x305 m^2 with the flow moving perpendicular to one of the faces. The mound height was assumed to be small relative to the total water depth. Outside the mound, the sediment type was assumed to be identical to that of the mound, with a median grain size of 0.12 mm. With these assumptions, calculation of sediment flux was determined.

In all likelihood, placement of material in 170-220 m depths will not lead to resuspension of material. If in fact, no mound movement occurs for severe storms, then simulation of long-term average conditions would not be needed.

Input Data Requirements

All data for the long-term fate and stability of dredged material disposal site modeling were assembled for the Palm Beach and Port Everglades ODMDSs. These data include bathymetry and tidal conditions at the disposal site, sediment characteristics, storm surges and velocities at Wave Information Study (WIS) Stations 9 (for Port Everglades) and 10 (for Palm Beach), and wave conditions at WIS Stations 9 and 10.

Bathymetry. A 305x305 m square mound configuration (41 cm high) was assumed as a reasonable first estimate for model simulations. These dimensions achieve a 38,230 m^3 (50,000 c.y.) mound volume, which is the annual amount that each disposal site is expected to accommodate.

Tidal Conditions. Tidal constituent data from the Dredging Research Program (DRP) tidal constituent database were used to generate tidal elevations and tidal velocity time series at the two ODMDSs. Maximum velocities at the Port Everglades ODMDS were approximately 10 cm/sec in the direction of maximum storm velocities. Maximum velocities at the Palm Beach ODMDS were approximately 7 cm/sec in the direction of maximum storm velocities.

Sediment Characteristics. A mean grain size of 0.12 mm was used for initial screening level erosion modeling at both ODMDSs.

Storm Conditions. Severe (storm) conditions were simulated to determine the "worst case" scenario. If movement was minimal for storm conditions, then simulating average conditions would be unnecessary. Thirteen tropical storms were selected from the 104-year period covered in the National Hurricane Center's HURDAT database. HURDAT includes storm parameters for all hurricanes, tropical storms, and severe depressions that impacted the east coast, Gulf of Mexico, and Caribbean from 1896 to 1989. These data were used as input to the ADCIRC model to compute depth-averaged velocities and water surface elevation data (which are saved in the DRP Hurricane Database).

Storm Velocities. Depth-averaged velocities and water surface elevation data (Figure 52) for the largest three storms were selected from the DRP Hurricane Database for the initial screening level modeling at the ODMDS sites. Based on current measurements near the ODMDSs, depth-averaged velocities are probably not representative of bottom velocities in 170-200 m of water. Evaluation of the ADCP velocity profile data was used to determine a more realistic estimate of near-bottom velocities to use in the evaluation of long-term fate of dredged material at the two sites (Figure 53). This figure shows that if the depth-averaged velocity is 1.0 m/sec, one could expect the velocity at the 90-m depth to be approximately 50% of the depth-averaged value, or 0.5 m/sec. Near-bottom velocities in 200-m of water would be somewhat less and 40% of the depth-averaged value was considered a conservative estimate.

Storm Waves. No database of wave conditions exists for the 104-year period from which the tropical storms were selected. Therefore, the Planetary Boundary Layer (PBL) model was used to generate each hurricane wind and pressure field. The PBL model output was then used as input to the WISWAVE ocean hindcast model to generate wave conditions for the entire east coast. Wave conditions at WIS Station 9, corresponding to the Port Everglades ODMDS are shown in Figure 54. (Wave conditions at WIS Station 10 correspond to the Palm Beach ODMDS.)

Model Simulations

Screening level erosion modeling was completed for the three largest storms selected from the National Hurricane Center's HURDAT database. This model was used to estimate the peak sediment flux and total sediment loss caused by the three severe tropical storms. Tables 8 and 9 summarize the input data, the resulting sediment flux, and an estimate of the total sediment loss for each storm, in which the peak flux was assumed to occur for four hours across one side of a 305 X 305 m disposal site for each of the disposal sites. Computed total sediment losses were zero for two of the three most severe tropical storms, and rather small (less than 3%) for even the most severe historical hurricane to occur during the 100+ years of the HURDAT database.

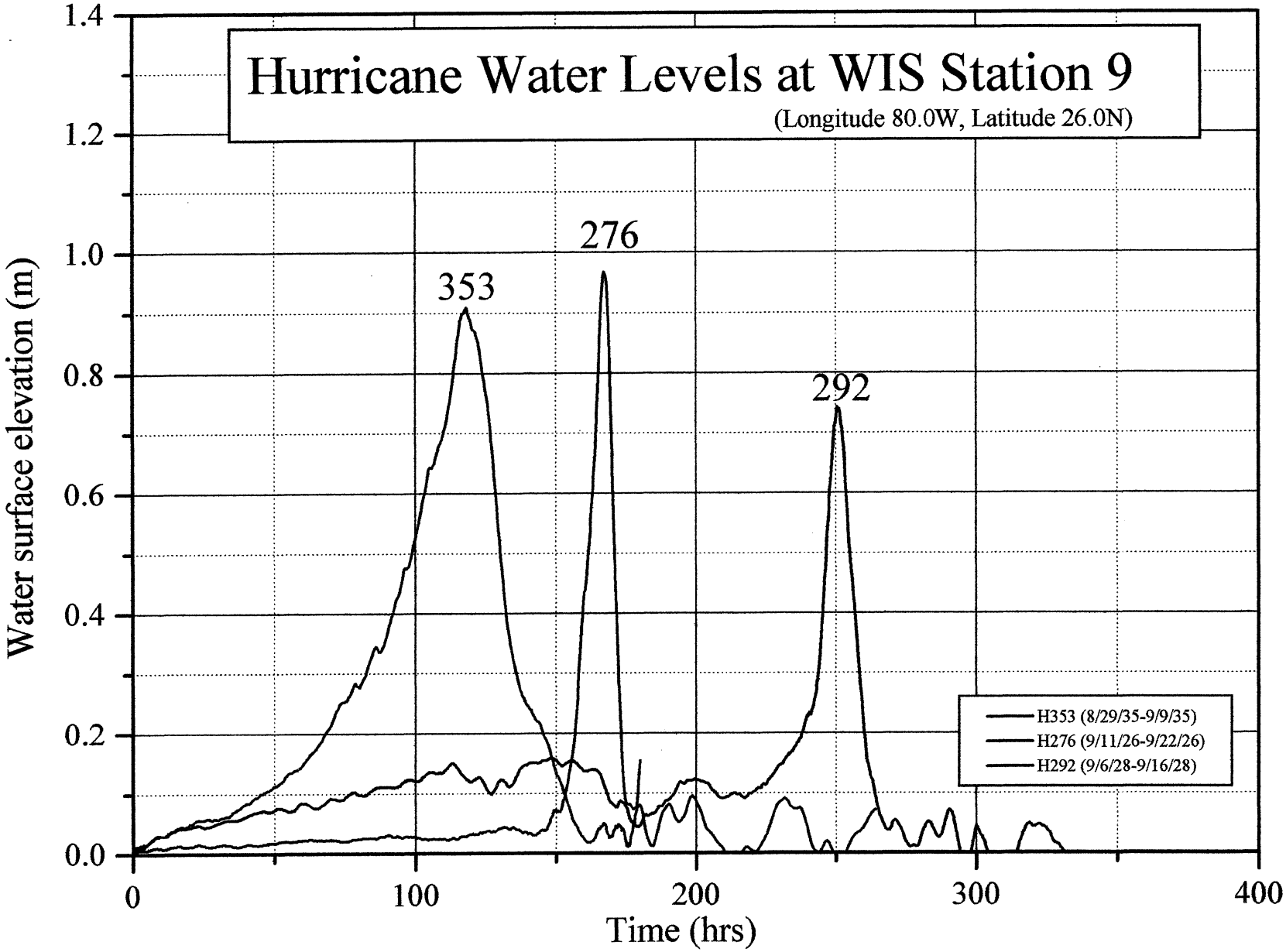


Figure 52. Water surface elevations for three largest storms at WIS Station 9

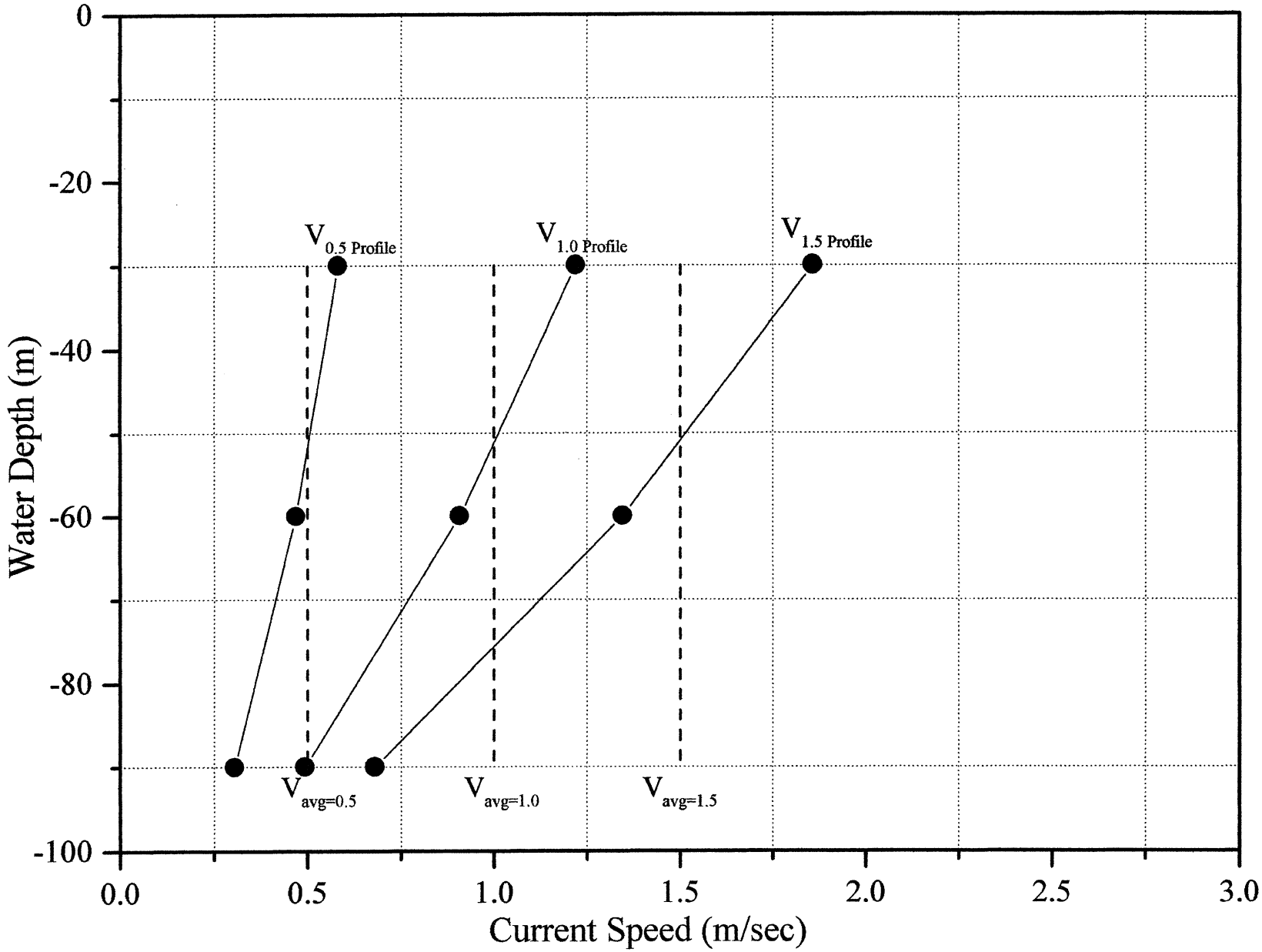


Figure 53. Relationship between depth-averaged velocities and near-bottom velocities

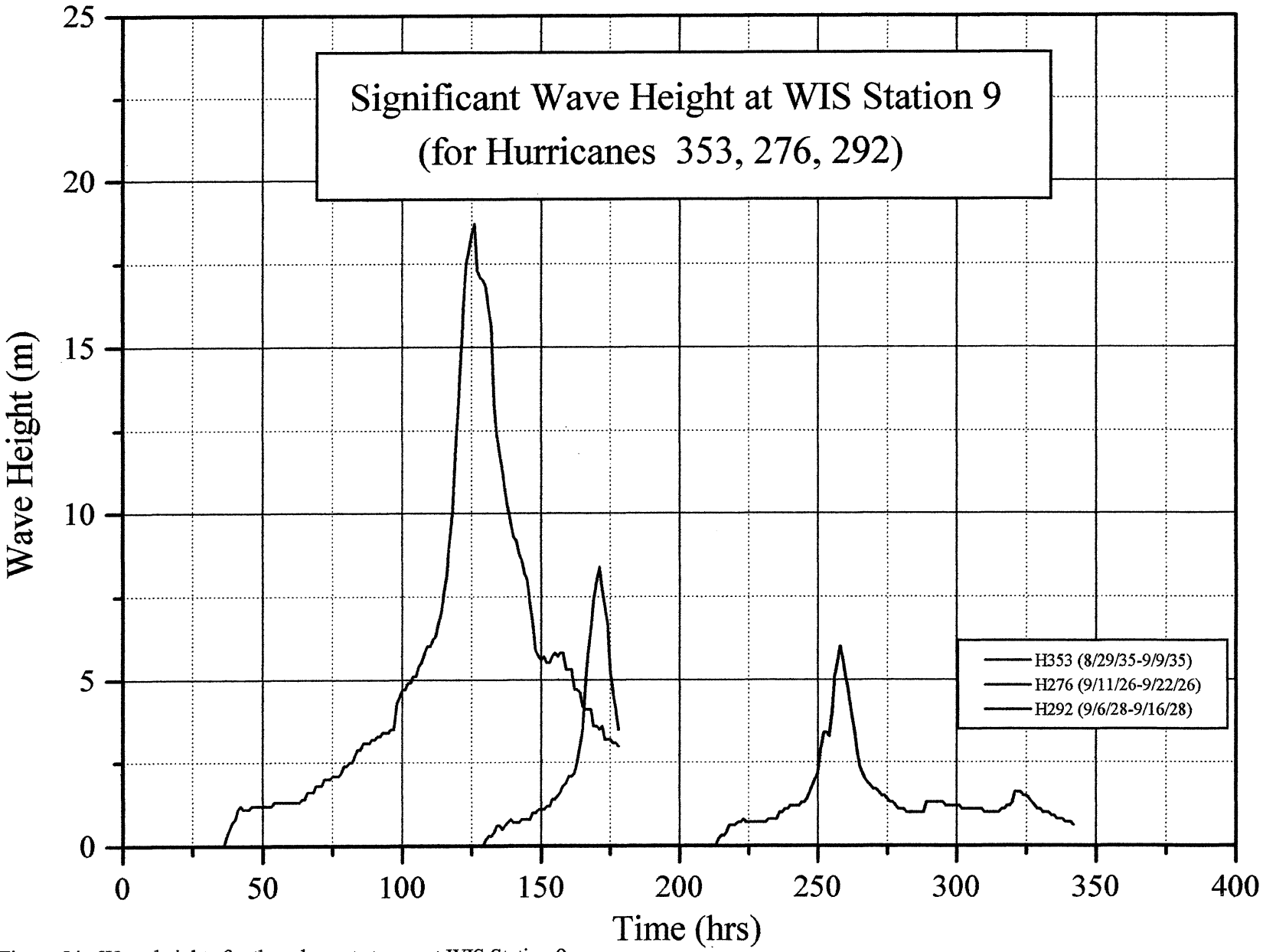


Figure 54. Wave heights for three largest storms at WIS Station 9

Extratropical Storm Simulation. An additional case was simulated for the Port Everglades site using the screening level erosion model. An estimate of conditions for a severe extratropical storm were made using available data. The maximum bottom velocity recorded by the ADCP over the three year period, 1995-1997, was linearly-extrapolated from a depth of 100 m to a depth of 200 m using the trend for the maximum velocity to decrease with depth that was evident in the measured data (Figure 55). The maximum measured velocity at the 100-m depth was 1.3 m/sec. Extrapolating to a 200-m depth would result in a bottom velocity of 0.5 m/sec. Assuming these conditions are associated with a extratropical storm of duration 24 hrs, maximum wave height of 10 m, peak period of 11 sec, and grain size of 0.12 mm results in a sediment flux of 5.1×10^{-8} $m^3/m/sec$ or a total volume loss of 410 m^3 over the 305 m by 305 m mound area. This loss is an estimate of what might be experienced during a very severe extratropical storm event, and is an order of magnitude less than the loss associated with the most severe tropical storm. Assessment of these results indicates that even the most severe storms will not significantly erode the mound. Therefore, LTFATE modeling will not be undertaken.

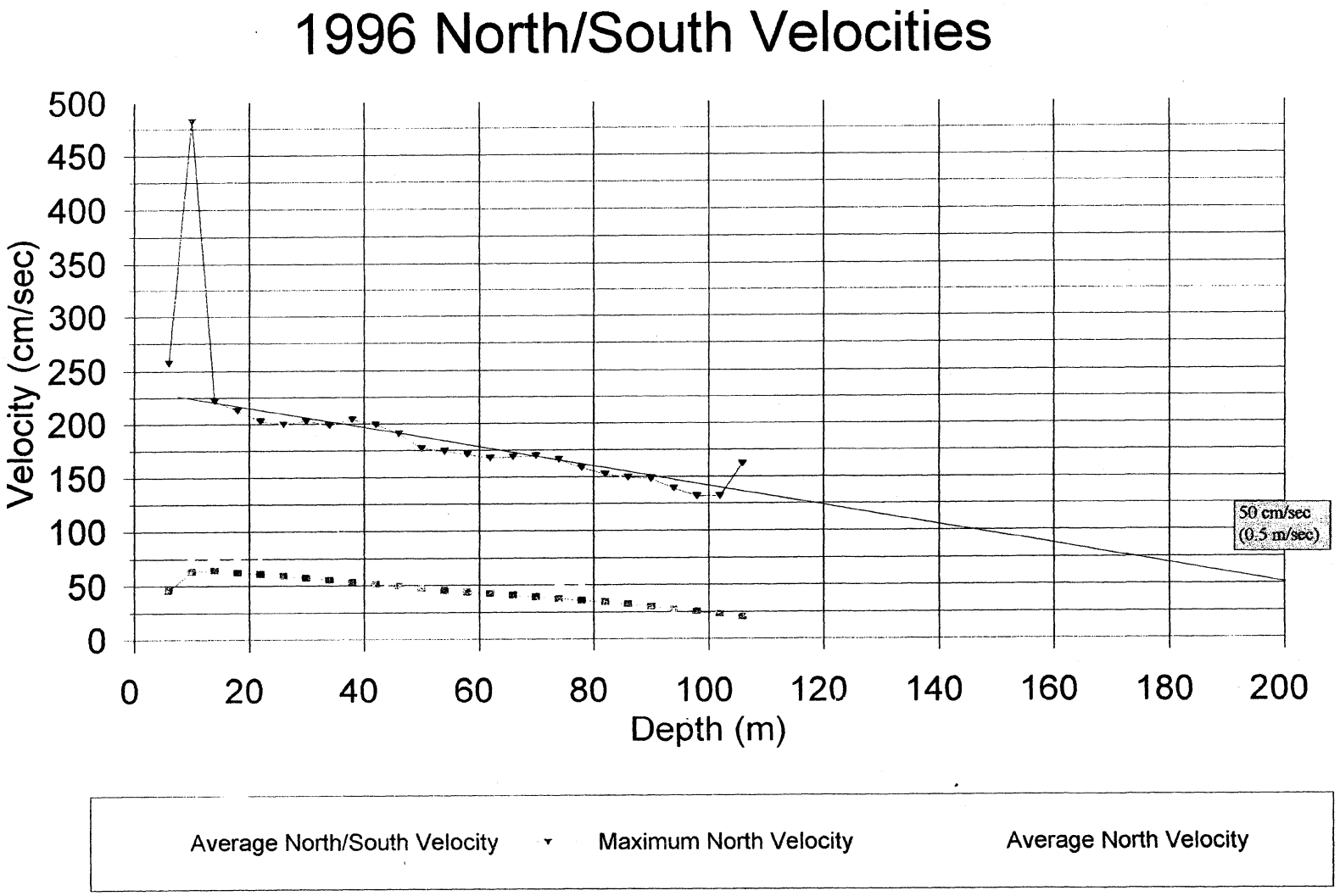


Figure 55. Extrapolated maximum near-bottom velocity from ADCP data

Table 8. Screening level erosion model inputs and results for Port Everglades			
	Storm 276	**Storm 292**	**Storm 353**
H_s (m)	8.4	6.0	18.7
T (sec)	11	11	17
D (m, msl)	-200	-200	-200
Z_{storm} (m, msl)	0.97	0.74	0.91
U_{storm} (m/sec)	0.082	0.035	0.199
V_{storm} (m/sec)	0.601	0.706	1.125
Z_{tidal} (m, msl)	0.45	0.45	0.45
U_{tidal} (m/sec)	.003	.003	.003
V_{tidal} (m/sec)	.09	.09	.09
d_{50} (mm)	0.12	0.12	0.12
V_{total} (m/sec)	0.70	0.80	1.2
$V_{reduced}$ (m/sec)	0.35	0.40	0.6
Flux (m^3/m/sec)	--0--	--0--	7.98×10^{-7}
Vol (m^3)	--0--	--0--	1069

Variable definitions:

H_s - significant wave height at peak of the storm
T - period associated with peak wave height
D - water depth
$\acute{\eta}_{storm}$ - water surface elevation at peak of storm
U_{storm} - east/west depth-averaged velocity component due to storm
V_{storm} - north/south depth-averaged velocity component due to storm
$\acute{\eta}_{tidal}$ - tidal elevation at ODMDS
U_{tidal} - east/west depth-averaged velocity component due to tides
V_{tidal} - north/south depth-averaged velocity component due to tides
d_{50} (mm) - median grain size
V_{total} (m/sec) - resultant velocity $((U_{storm}+U_{tidal})^2+(V_{storm}+V_{tidal})^2)^{1/2}$
$V_{reduced}$ (m/sec) - reduced velocity due to greater water depth
Flux (m^3/m/sec) - amount of sediment moving passed a 1-m segment in 1 sec at the peak of the storm
Volume Loss (m^3) - total volume eroded from a 305 m x 305 m mound, assuming the peak flux persists for a 4-hr storm duration

Table 9. Screening level erosion model inputs and results for Palm Beach			
	Storm 276	**Storm 292**	**Storm 353**
H_s (m)	8.0	6.5	16.7
T (sec)	11	11	17
D (m, msl)	-179	-170	-170
Z_{storm} (m, msl)	0.87	0.85	0.84
U_{storm} (m/sec)	0.095	0.077	0.202
V_{storm} (m/sec)	0.552	0.953	0.992
Z_{tidal} (m, msl)	0.51	0.51	0.51
U_{tidal} (m/sec)	.01	.01	.01
V_{tidal} (m/sec)	.066	.066	.066
d_{50} (mm)	0.12	0.12	0.12
V_{total} (m/sec)	0.63	1.02	1.08
$V_{reduced}$ (m/sec)	0.25	0.41	0.43
Flux (m^3/m/sec)	--0--	1.27×10^{-10}	6.92×10^{-7}
Vol (m^3)	--0--	--0--	927

4 Conclusions

The evaluation of ODMDSs located 7.4-8.3 km off of Port Everglades and Palm Beach Harbors was accomplished by numerically simulating the disposal, descent, and collapse of the dredged material plume as well as the long-term fate of the disposal mound. Of primary concern was the possible movement of material in the direction of environmentally-sensitive reefs located approximately 1-3 km offshore (5.3-6.1 km from the disposal sites). Results indicate that the potential for sediment movement onto the reefs is remote.

STFATE was used to estimate the dynamics of the sediment cloud following its release from the dredge. The model computes the time-history of a single disposal operation from the time the dredged material is released from the barge until it reaches equilibrium. In all Port Everglades applications sediment was disposed 6100 m (20,000 ft) from the grid origin (reef location). Two sediment compositions were simulated, 60% and 70% solids by weight, with 38% and 5% fines, respectively. Results indicate silt-clay concentrations diminish to approximately 1 mg/l or less within 1500 m (5000 ft) of the disposal location (4500 m (15,000 ft) from the reef location). Higher current speeds carry sediment from the disposal location more rapidly, but silt-clay concentrations still drop below about 1 mg/l within 1500 m (5000 ft) of the disposal location. A major portion of the dredged material is sand. Sand concentrations diminish to 1 mg/l or less within 2440 m (8000 ft) of the disposal location (3660 m (12,000 ft) from reef location). The majority of the sand in the dredged material settles rapidly, but some remains in the water column for longer time/distances as indicated by these results.

In all Palm Beach applications sediment was disposed 5300 m (17,500 ft) from the grid origin (reef location). Two sediment compositions were simulated, 80% and 85% solids by weight, with 6% fines. Silt-clay concentrations diminish rapidly to 1 mg/l or less within 1500 m (5000 ft) of the disposal location (12500 ft from the reef location). Higher current speeds carry sediment from the disposal location more rapidly, but silt-clay concentrations still drop below 1 mg/l within 1500 m (5000 ft) of the disposal location. A major portion of the dredged material is sand. Sand concentrations diminish to 1 mg/l or less within 2400 m (8000 ft) of the disposal location (2900 m (9500 ft) from reef location). The majority of the sand in the dredged material settles rapidly, but some remains in the water column for longer time/distances as indicated by these results.

A screening level erosion model is the site evaluation tool used to estimate the long-term response of the dredged material mounds at the Port Everglades and Palm Beach ODMDSs to local environmental forcing functions. The model simulates the dispersion characteristics (or conversely, site stability) of a dredged material mound over time periods of days for storms to years for ambient conditions using coupled hydrodynamic, sediment transport, and bathymetric change submodels. A screening level erosion model was run to address the potential for sediment transport from the dredged material mound. The screening level erosion

model indicated little (less than 3%) to no potential for sediment movement for the most severe storms to impact the area in 100+ years. Therefore, these sites can be considered stable and the reef will not be adversely affected by up to 100-year return period events.

5 References

Ackers, P. and White, W.R. 1973. "Sediment Transport: New Approach and Analysis," ASCE Journal of the Hydraulics Division, Vol 99, No. HY11, pp 2041-2060.

Bane, J.M. and Brooks, D.A. 1979. "Gulf Stream Meanders Along the Continental Margin from the Florida Straits to Cape Hatteras," Geophysical Research Letters, No. 6, pp 280-282.

Bijker, E.W. 1967. "Some considerations about scales foe coastal models with moveable beds," Publication no. 50, Delft Hydraulics Laboratory, Delft, The Netherlands.

Bijker, E.W. 1971. "Longshore Transport Computations," Journal of Waterways, Harbors, and Coastal Engineering Division, ASCE, Vol 97 (WW4), pp 687-701.

Brandsma, M.G. and Divorky, D.J. 1976. "Development of Models for Prediction of Short-term Fate of Dredged Material Discharged in the Estuarine Environment," Technical Report D-76-5, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brooks, R. and Brandon, W.A. 1995. "Hindcast Wave Information for the U.S. Atlantic Coast: Update 1976-1993 with Hurricanes," WIS Report 33, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brownlie, W.R. 1981. "Prediction of Flow Depth and Sediment Discharge in Open Channels," Report No. KH-R-43A, W.M. Keck Laboratory of Hydraulics and Water Resources, California Institute of Technology, Pasadena, CA.

Chow, V.T. 1959. *Open Channel Hydraulics*. McGraw-Hill Book Co, Inc., New York, NY.

Johnson, B.H., McComas, D.N., McVan, D.C., and Trawle, J.J. 1993. "Development and verification of numerical models for predicting the initial fate of dredged material disposed in open water," Technical Report DRP-93-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Jonsson, I.J. 1966. "Wave boundary layers and friction factors," Proceedings of the 10th Coastal Engineering Conference, Tokyo, Japan.

Hales, L. 1995. "Accomplishments of the Corps of Engineers Dredging Research Program," U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hands, E.B. and Allison, M.C. 1991. "Mound Migration in Deeper Water and Methods of Categorizing Active and Stable Depths," Proceeding of Coastal Sediments 91, pp 1985-1999.

Ippen, A.T. (ed.) 1966. *Estuarine and coastline hydrodynamics*. McGraw-Hill Book Co, Inc., New York, NY.

Lee, T.N., Brooks, I., and Duing, W. 1977. "The Florida Current: Its Structure and Variability," Technical Report UM-RSMAS No. 77003, University of Miami, Rosenstiel School of Marine and Atmospheric Sciences, Miami, FL.

Maritimes , 1991. "Focus on the Gulf Stream," Feb Issue, Vol 35, No 1.

Proni, J.R., Tsai, J.J., Dammann, W.P., 1991, "Miami Harbor Dredged Material Disposal Project," Draft Report, National Oceanic and Atmospheric Administration, Miami, FL.

Scheffner, N.W. 1996. "Systematic Analysis of Long-term Fate of Disposed Dredged Material," Journal of Waterways, Ports, Coastal, and Ocean Engineering, Vol. 122, No. 3, pp 127-133.

Scheffner, N.W. and Swain, A. 1989. "Evaluation of the Dispersion Characteristics of the Miami and Fort Pierce Dredged Material Disposal Sites," Draft Report, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Scheffner, N.W., Thevenot, M.M., Tallent, J.R., Mason, J.M., "LTFATE: A Model to Investigate the Long-Term Fate and Stability of Dredged Material Disposal Sites; User's Guide," Instruction Report, DRP-95-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Swart, D.H. 1976. "Predictive Equations Regarding Coastal Transports," Proceedings of the 15th Coastal Engineering Conference, Honolulu, HI.

Thevenot, M.M. and Johnson, B.H. 1994. "Verification of Numerical Modeling of the Fate of Disposed Dredged Material," Proceeding of the Second International Conference on Dredging and Dredged Material Placement," Vol 1, pp 180-189.

Tsai, J.J., Proni, J.R., Dammann, P.W., and Kraus, N.C. 1992. "Dredged Material Disposal at the Edge of the Florida Current," Chemistry and Ecology, Vol 6, pp 169-187.

Van De Graff, J. and VanOvereem, J. 1979. "Evaluation of sediment transport formulae in coastal engineering practice," Coastal Engineering, Vol 3, pp 1-32, Amsterdam, The Netherlands,

White, W.R. 1972. "Sediment transport in channels: a general function," INT 104, Wallingford Hydraulics Research Station, Wallingford, UK.

Williams, E. and Lee, T.N. 1987. "FLEX 1987 Current Meter Mooring Array, Preliminary Data Report," University of Miami, Miami, FL.