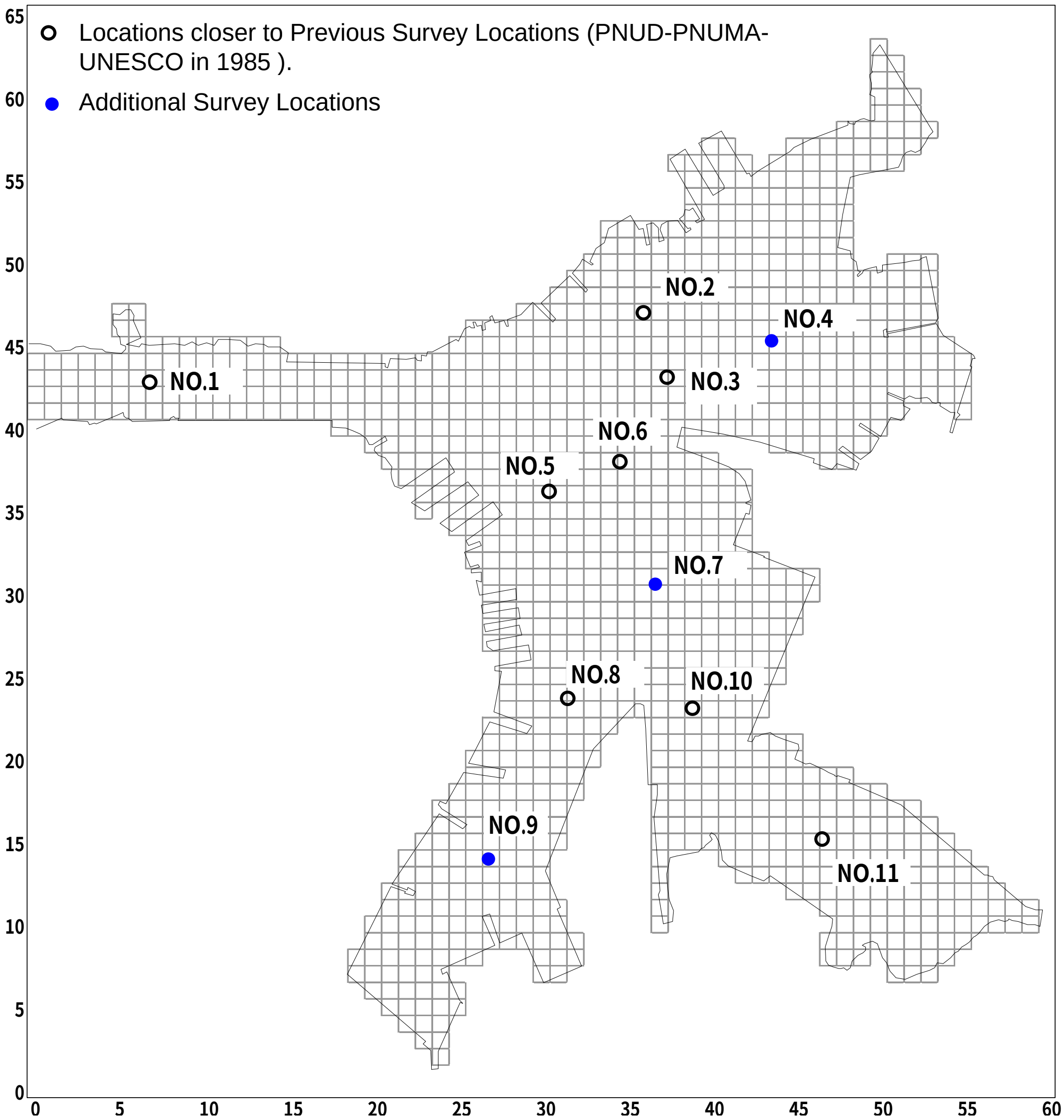


Location No. 12 is approximately 500 m from the mouth of the bay and is used as a reference location

THE DEVELOPMENT STUDY ON THE IMPROVEMENT OF SEWERAGE AND DRAINAGE SYSTEM FOR THE HAVANA BAY	Figure 4.25 Location Map for Tidal Current Survey in This Study
JAPAN INTERNATIONAL COOPERATION AGENCY	

4.4.1 RESULTS OF TIDAL CURRENT SURVEY

(1) Temperature

Figure 4.26 shows vertical variation of temperature (and salinity) during flood tide in October 2002. It shows the typical characteristics of Havana Bay which is that surface layer has significant variation of temperature (and salinity) at different points in the bay whereas middle and bottom layers have uniform temperature (and salinity) throughout the bay. Temperature decrease with depth.

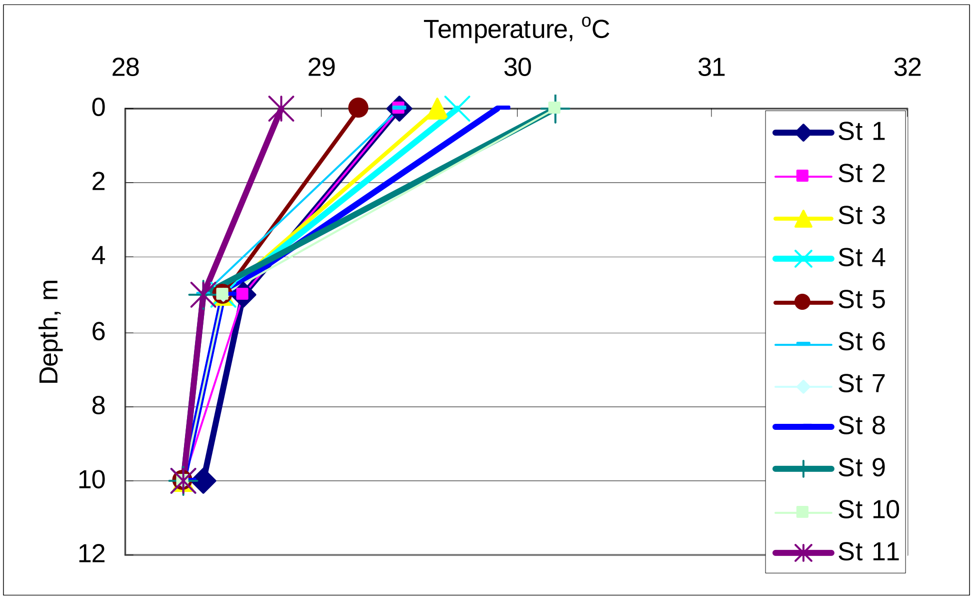
(2) Salinity

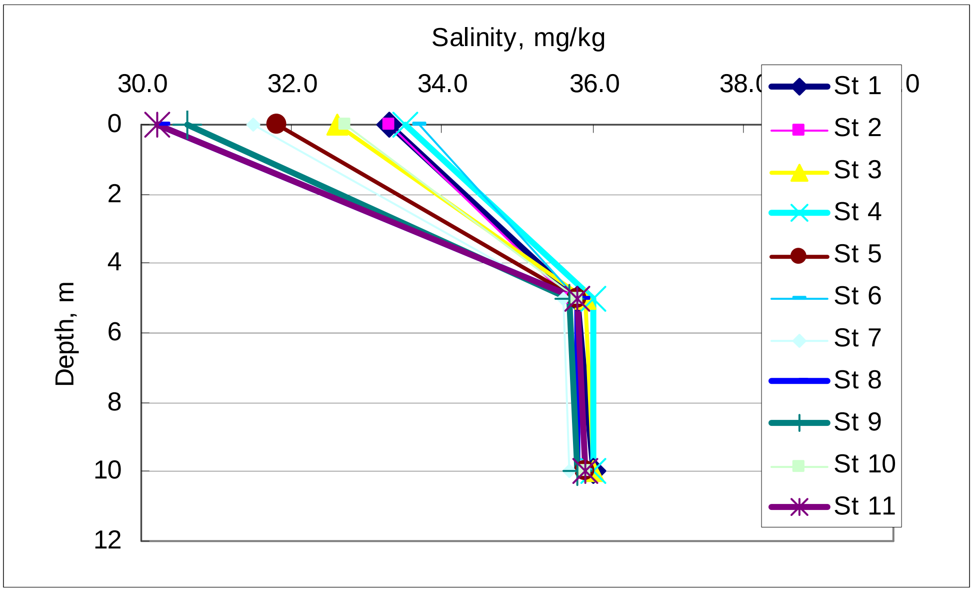
Table 4.19 shows the summary of salinity measured and calculated mean values. Vertical variation is as discussed above in temperature as evidenced by the standard deviation which is much lower (±0.1 to ±0.3) for middle and bottom layer compared to that of surface layer (±0.9 to ±3.5). However, salinity increases with depth as opposed to temperature.

Table 4.19 Salinity of Havana Bay in October and December 2002

Item	Unit	October, 2002	December, 2002
Surface Layer- flood tide			
Minimum salinity	mg/kg	30.2	31.4
Maximum salinity	mg/kg	34.8	34.3
Mean salinity	mg/kg	32.4±1.5	32.2±1.0
Surface Layer- ebb tide			
Minimum salinity	mg/kg	32.0	23.1
Maximum salinity	mg/kg	35.2	34.0
Mean salinity - ebb tide	mg/kg	33.3±0.9	30.3±3.5
Middle Layer (5 m) - flood tide			
Mean salinity	mg/kg	35.8±0.1	35.7±0.2
Middle Layer (5 m) - ebb tide			
Mean salinity	mg/kg	35.9±0.1	35.5±0.3
Bottom Layer (10 m) - flood tide			
Mean salinity	mg/kg	35.9±0.1	35.9±0.1
Middle Layer (10 m) - ebb tide			
Mean salinity	mg/kg	36.0±0.1	35.8±0.1

Figure 4.27 and Figure 4.28 show the variation of salinity in the surface layer for flood and ebb tides for October 2002 and December 2002. In December 2002 observation, decrease of salinity towards Guasabacoa was more marked due to the rains experienced in the previous week following the on-set of cold-fronts.





Date : 7 October 2002

THE DEVELOPMENT STUDY ON THE IMPROVEMENT OF SEWERAGE AND DRAINAGE SYSTEM FOR THE HAVANA BAY	Figure 4.26 Vertical Variation of Temperature and Salinity during Flood Tide - October 2002
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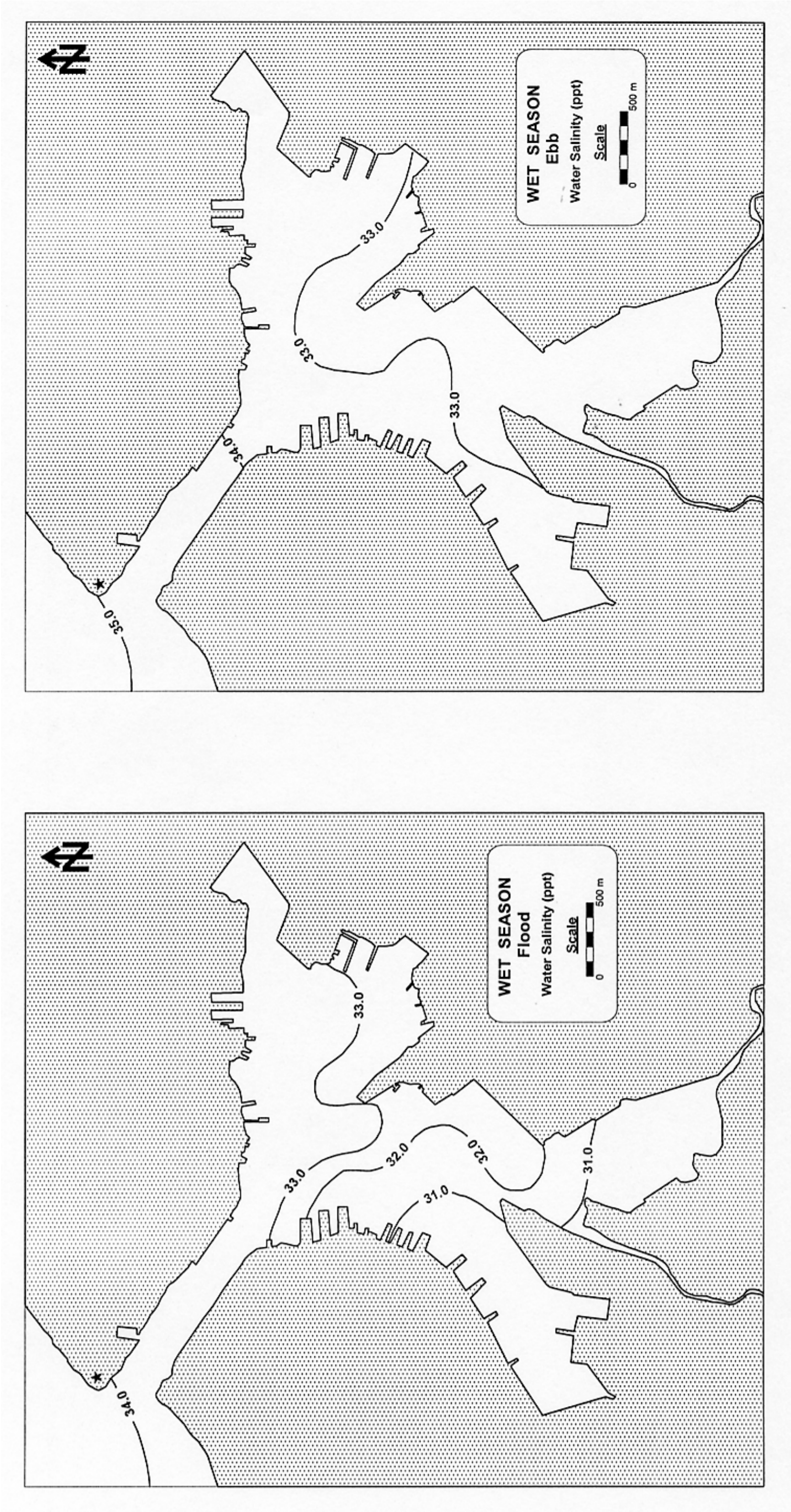

THE DEVELOPMENT STUDY ON THE IMPROVEMENT OF SEWERAGE AND DRAINAGE SYSTEM FOR THE HAVANA BAY	Figure 4.27 Variation of Surface Water Salinity in Havana Bay (October 2002-wet season)
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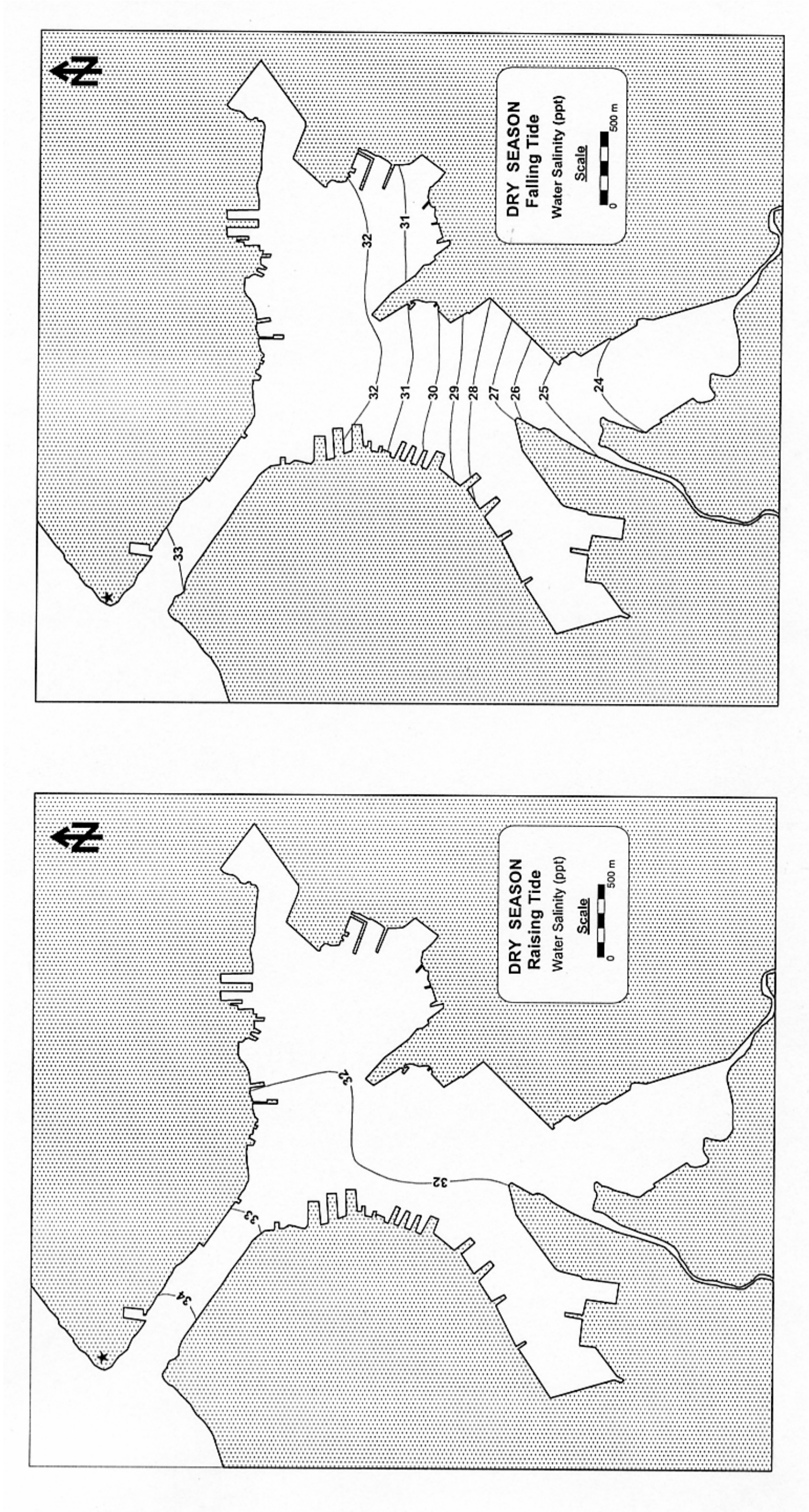
4.4 TIDAL CURRENT SURVEY

To confirm the tidal current characteristics in the Havana Bay, a survey was carried out during flood and ebb tide, twice in November 2002 and December 2002 as specified in Table 4.18. The work was subcontracted to CIMAB.

Table 4.18 Specification for the Tidal Current Survey

No.	Items	Specification	Note
1	Survey Locations	Twelve locations in horizontal direction (refer to Figure 4.25)	
		At three levels in vertical direction shown as follows o Surface level (0.5m under the surface) o Middle level o Bottom level (1.0 m above the bottom)	
2	Observation parameters	o Velocity and direction of currents (Location No.1 to No.11) o Water temperature (Location No.1 to No.12) o Salinity (Location No.1 to No.12) o Density (Location No.1 to No.11) o Transparency (Location No.1 to No.11) o Color (Location No.1 to No.11) o Meteorological parameters including velocity and direction of wind, air temperature, atmospheric pressure and relative humidity (Location No.1 to No.11)	
3	Frequency of observation (interval of data)	o Observations taken out every 2 hrs during 25 hrs for the locations No.1, No. 3, and No.5. o For the other locations, 2 observations taken out both in ebb tide and flood tide (4 hrs interval for each observation) o 12 hours for the other locations	Frequency of measurement of transparency and color is the same with the other locations described in second line for the locations of No.1, No.3 and No.5.
4	Number of campaigns	Twice in October 2002 and in December 2002	



THE DEVELOPMENT STUDY ON THE IMPROVEMENT OF SEWERAGE AND DRAINAGE SYSTEM FOR THE HAVANA BAY	Figure 4.28 Variation of Surface Water Salinity in Havana Bay (December 2002-dry season)
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(1) Currents

Figure 4.29 through 4.32 show the direction and magnitude of current observed during flood tide and ebb tide in October 2002 and in December 2002.

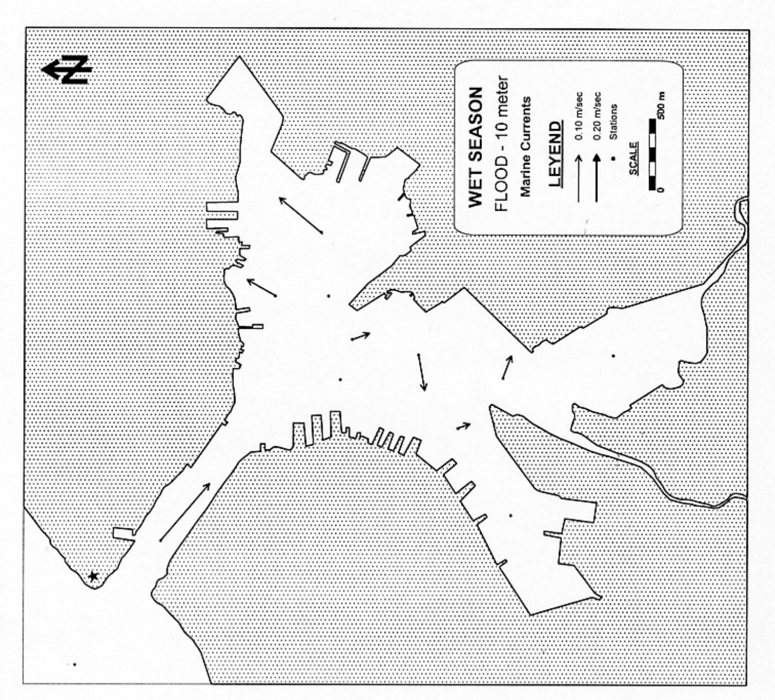
Table 4.20 shows the summary of results of current velocity.

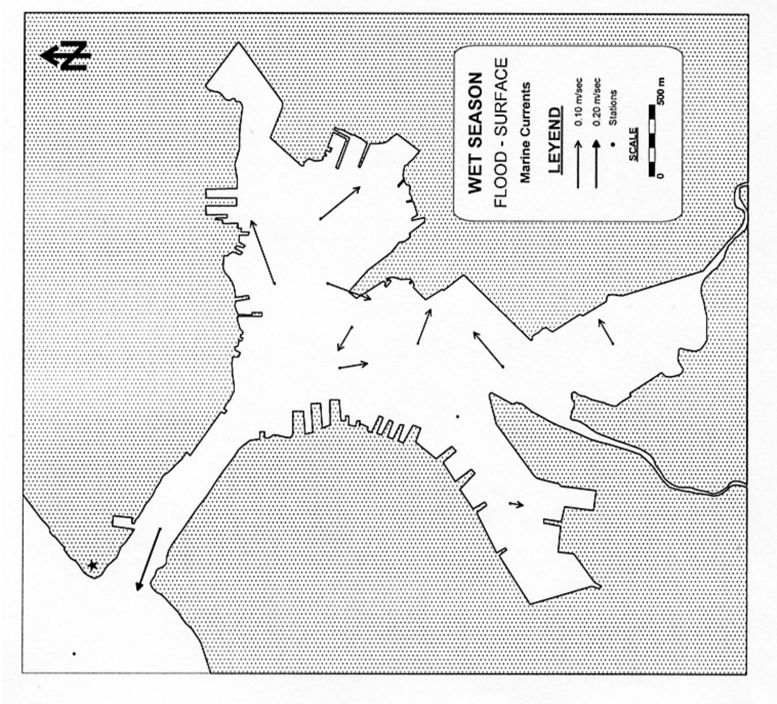
Table 4.20 Current Velocity in October and December 2002

Item	Unit	October, 2002	December, 2002
Flood tide			
Mean velocity of surface currents	cm/s	8.6±6.5	4.5±2.0
Mean velocity at 5m depth	cm/s	7.2±6.6	8.4±4.8
Mean velocity at 10 m depth	cm/s	5.0±5.0	5.3±2.7
Ebb tide			
Mean velocity of surface currents	cm/s	5.2±3.4	8.7±3.7
Mean velocity at 5m depth	cm/s	4.5±2.4	6.2±2.3
Mean velocity at 10 m depth	cm/s	2.5±1.8	4.8±3.3
24-hour Survey			
Station 1			
Mean velocity of surface currents	cm/s	11.5±5.2	15.9±7.8
Mean velocity at 5m depth	cm/s	11.0±7.3	16.3±5.6
Mean velocity at 10 m depth	cm/s	11.2±6.6	17.1±7.0
Station 3			
Mean velocity of surface currents	cm/s	6.7±2.3	5.2±2.2
Mean velocity at 5m depth	cm/s	4.1±1.3	6.5±5.9
Mean velocity at 10 m depth	cm/s	4.5±1.7	3.6±4.3
Station 5			
Mean velocity of surface currents	cm/s	8.2±4.9	5.6±2.0
Mean velocity at 5m depth	cm/s	7.9±5.1	5.8±5.2
Mean velocity at 10 m depth	cm/s	7.7±5.0	3.9±4.3

In general, circulation of the water in the bay showed a net circulation towards the open sea in the surface layer and net circulation towards the bay in the bottom layer which was first established during the UNDP study in 1982-83. Further, the bay was characterized as having that between a partially-mixed and mixed estuary behavior in that study (classification for estuaries based on Hansen and Rattray, 1966) owing to extremely high rainfall during that year of observation. In this Study, the behavior of the bay was determined to be that of a well mixed estuary (type 2a) in both October 2002 and in December 2002.

The results above are used in the hydrodynamic simulation.





THE DEVELOPMENT STUDY ON THE IMPROVEMENT OF SEWERAGE AND DRAINAGE SYSTEM FOR THE HAVANA BAY	Figure 4.29 Current Pattern in Havana Bay during Flood Tide (October 2002- wet season)
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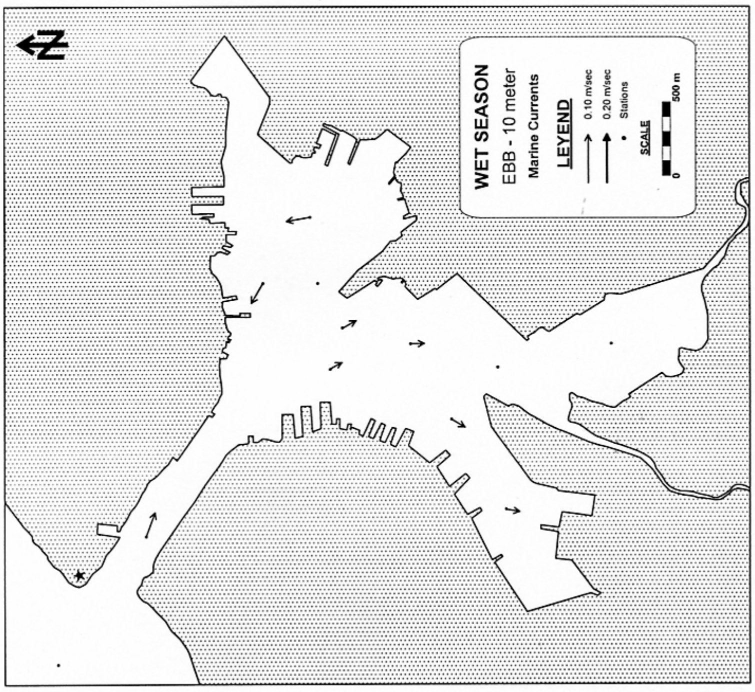
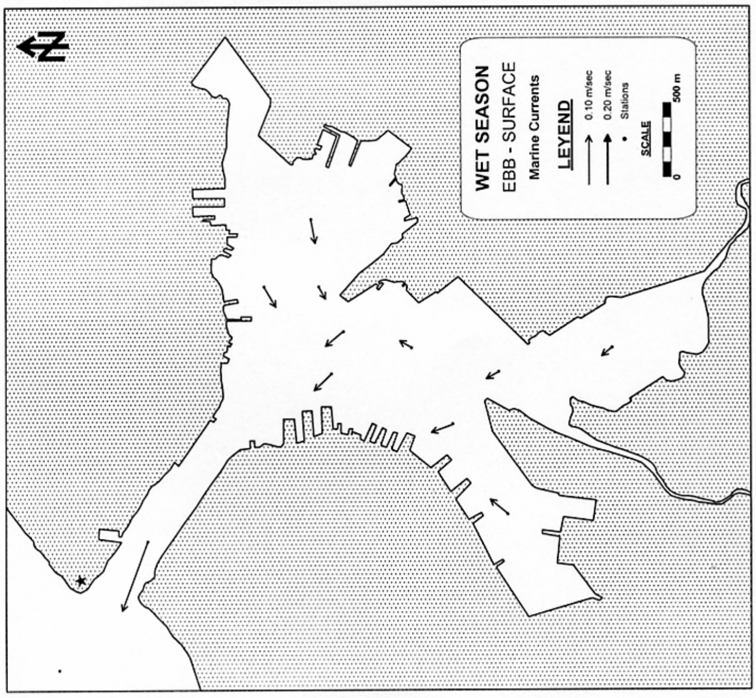
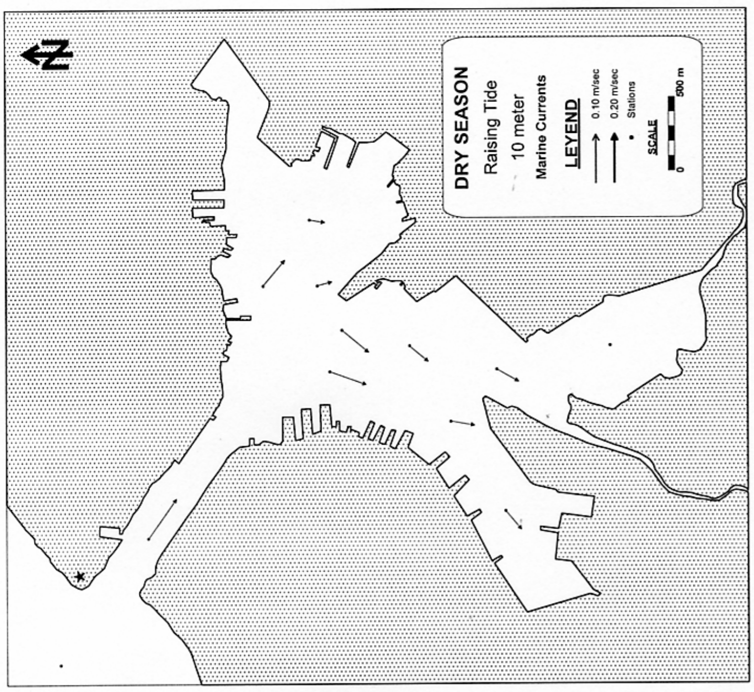
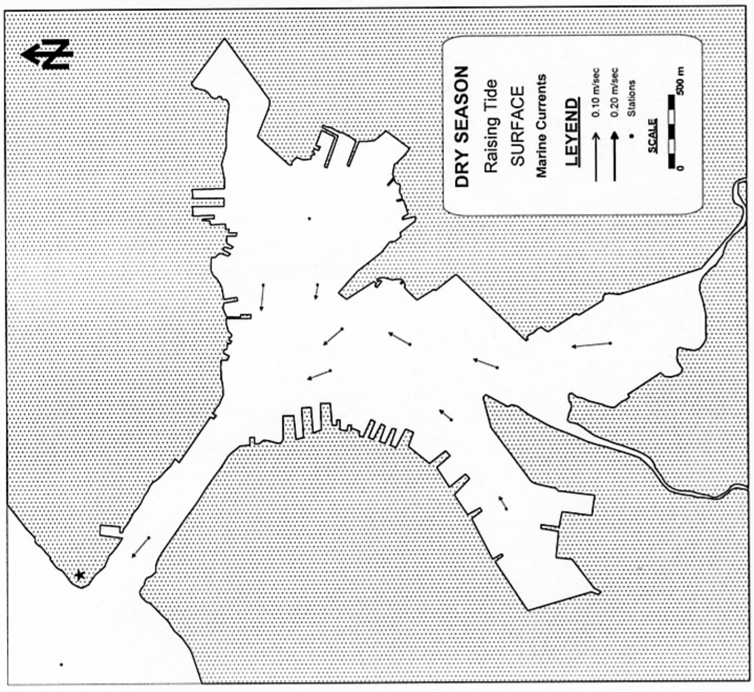


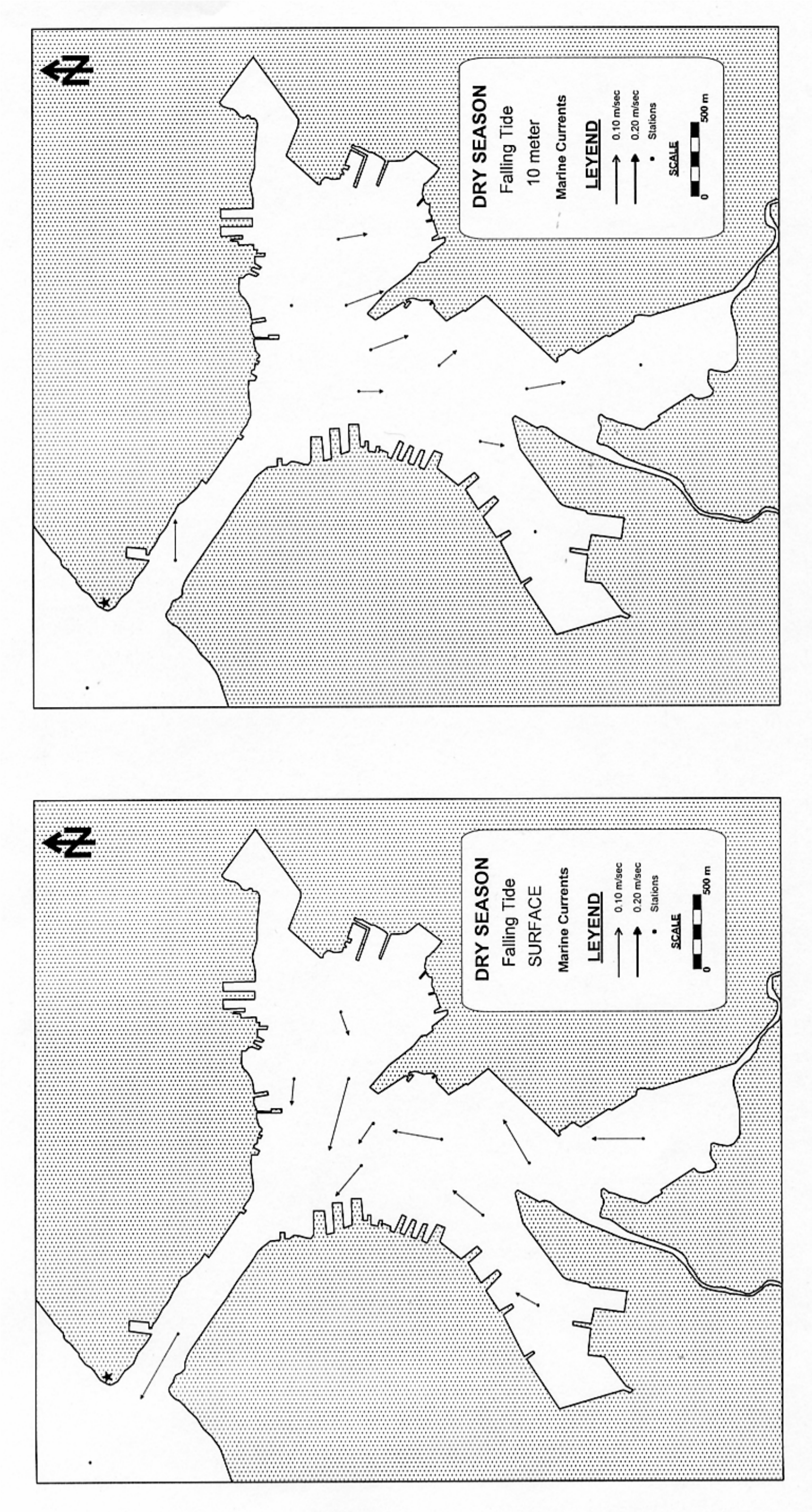


THE DEVELOPMENT STUDY ON THE IMPROVEMENT OF SEWERAGE AND DRAINAGE SYSTEM FOR THE HAVANA BAY	Figure 4.30 Current Pattern in Havana Bay during Ebb Tide (October 2002-wet season)
JAPAN INTERNATIONAL COOPERATION AGENCY	





THE DEVELOPMENT STUDY ON THE IMPROVEMENT OF SEWERAGE AND DRAINAGE SYSTEM FOR THE HAVANA BAY	Figure 4.31 Current Pattern in Havana Bay during Flood Tide (December 2002-dry season)
JAPAN INTERNATIONAL COOPERATION AGENCY	



THE DEVELOPMENT STUDY ON THE IMPROVEMENT OF SEWERAGE AND DRAINAGE SYSTEM FOR THE HAVANA BAY	Figure 4.32 Current Pattern in Havana Bay during Ebb Tide (December 2002-dry season)
JAPAN INTERNATIONAL COOPERATION AGENCY	

APPENDIX

The fundamental equations applied in the hydrodynamic model are as follows.

- Mass conservation equation

$$\frac{1}{\rho c_S^2}\frac{\partial P}{\partial t}+\frac{\partial u_i}{\partial x_j}=S_{ss}$$

- Momentum conservation equation in three dimensions

$$\frac{\partial u_i}{\partial t}+\frac{\partial (u_i u_j)}{\partial x_j}+2\Omega_{ij}u_j=-\frac{1}{\rho}\frac{\partial P}{\partial x_i}+g_i+\frac{\partial}{\partial x_j}\left(\nu_t\left\{\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right\}-\frac{2}{3}\delta_{ij}k\right)+u_i S_{ss}$$

- Conservation equation for salinity

$$\frac{\partial S}{\partial t}+\frac{\partial}{\partial x_j}(Su_j)=\frac{\partial}{\partial x_j}\left(D_S\frac{\partial S}{\partial x_j}\right)+S_{ss}$$

- Conservation equation for temperature

$$\frac{\partial T}{\partial t}+\frac{\partial}{\partial x_j}(Tu_j)=\frac{\partial}{\partial x_j}\left(D_T\frac{\partial T}{\partial x_j}\right)+S_{ss}$$

Where

u_i : Velocity in X_i directions
ρ : Local density of the fluid
Ω_{ij} : Coriolis tensor
P : Fluid pressure
g_i : Gravitational vector
ν_t : Turbulent eddy viscosity
δ : Kronecker's delta
k : Turbulent kinetic energy
t : Time
T : Water temperature
S : Salinity
D_T : Dispersion coefficients for water temperature
D_S : Dispersion coefficients for salinity
S_{SS} : Source-sink terms

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