SEDIMENT RESUSPENSION, SETTLING, AND TRANSPORT: RESULTS, NEEDS, AND FUTURE DIRECTIONS AT NWRI. MINUTES OF A WORKSHOP HELD AT THE NWRI, MAY 30/86

by

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NWRI Contribution # 86-18

INTRODUCTION.

Commonly occurring forms of nutrients and contaminants are readily adsorbed and desorbed to and from fine particles of suspended materials. Resuspension and settling represent a source and sink for such materials. In shallow lakes and in the nearshore zones of deep lakes, near-bottom water movements due to both surface waves and longer-term currents may be vigorous enough from time to time to resuspend unconsolidated bottom sediments. Resuspension provides opportunities for accelerated exchange between the water and the suspended material; it is easy to imagine situations that could lead to improvement and/or degradation in water quality depending on the sediment-water partitioning mechanisms and the relative concentrations in each compartment of the system (R.J. Allan, 1984. The Role of Particulate Matter in the Fate of Contaminants in Aquatic Ecosystems. NWRI Contribution 84-18). Modelling of the pathways and fate of toxic contaminants would be improved by including algorithms for sediment-water exchanges; such algorithms could be reasonably expected to be dependent on the dynamics of resuspension and settling. A recent review by Abdelrhman and Bedford, soon to be published in JGLR, summarizes present-day knowledge of resuspension processes as they might apply to Lake Erie. The potential for complexity is large, but it is also significant that the paper can only conjecture about Lake Erie on the basis of what has been learned elsewhere because in situ measurements of sufficient refinement to characterize this dynamic environment have yet to be made. One can further imagine that sediment recycling in Lake St. Clair may influence the exportation of contaminants from that basin. Taste and odour problems in Great Lakes water supplies may be related to episodes of resuspension. Hypolimnetic oxygen demand in Lake Erie appears to be increased by resuspension of unoxidized organic material (ref: Charlton). These are only a few concerns drawn from the program areas of NWRI.

It has been recognized at NWRI for some time that sediment transport processes outside the surf zone were important but largely unstudied. Early (1975) attempts to include qualitative measurements of turbidity at bottom mounted current meter sites (CATTS system) were unsuccessful because of the tendency of the turbidity meters to become progressively fouled. A bottom mounted array of 3 electromagnetic current meters originally designed to explore the thin central Lake Erie hypolimnion, was reconfigured to place all three current meters within 1 metre of the bottom and deployed in Lake Ontario (1982) and Lake St. Clair (1985). This last arrangement is a precursor of the Benthic Boundary Array, a project initiated by APSD that has received some support through the Scientific Equipment Development Working Group (SEDWG). Experience has been slowly accumulated at NWRI, and we

are ready to proceed vigourously. In this workshop we propose to review NWRI experience in estimating sediment fluxes and in accounting for resuspension. We seek guidance in formulating a physical research program that meets the needs of other disciplines in the NWRI program areas. The Upper Great Lakes Connecting Channel Study in Lake St. Clair provides a focus for these discussions.

ATTENDEES.

F.M. Boyce	APSD (Chairman)
P.F. Hamblin	
G.K. Rodgers	
J. Bull	
D.C.L. Lam	
E. Halfon	
J. Jerome	
A.G. Bobba	
Y. Marmoosh	
M. Charlton	AED
B. Oliver	ECD
J. Lawrence	AMD
M. Skafel	HRD
N. Rukavina	
J. Coakley	
A. Zeman	
F. Roy	
J. Valdmanis	
K. Bedford	Civil Engineering Department
R. Van Evra	Ohio State University Columbus, Ohio
B. Lesht	Argonne National Laboratory Chicago, Illinois
N. Hawley	Great Lakes Environmental Research Laboratory Ann Arbor, Michigan

SUMMARIES OF PRESENTATIONS.

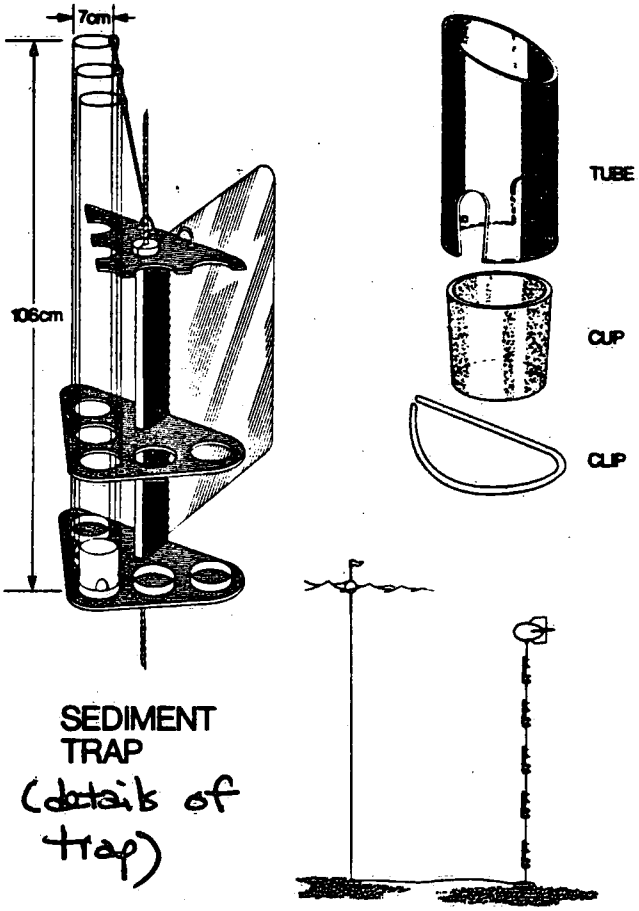
1. Sediment trap technology. (M.N. Charlton)

Many trap configurations have been proposed and tested over the years. The best results are obtained with a simple vertical cylinder of high enough aspect ratio so as to ensure still water at the bottom of the trap. Flume experiments confirm the importance of the aspect ratio but also reveal that the catch efficiency, while high, is not 100%, and depends on horizontal current speeds, particle sinking rates, etc. The working assumption is that the traps provide an integrated measure of the downward flux of particulate material; the observer must infer a partitioning between the material contributed from the water column (organic detritus, horizontally advected material) and material contributed from resuspension of the sediments in the immediate area.

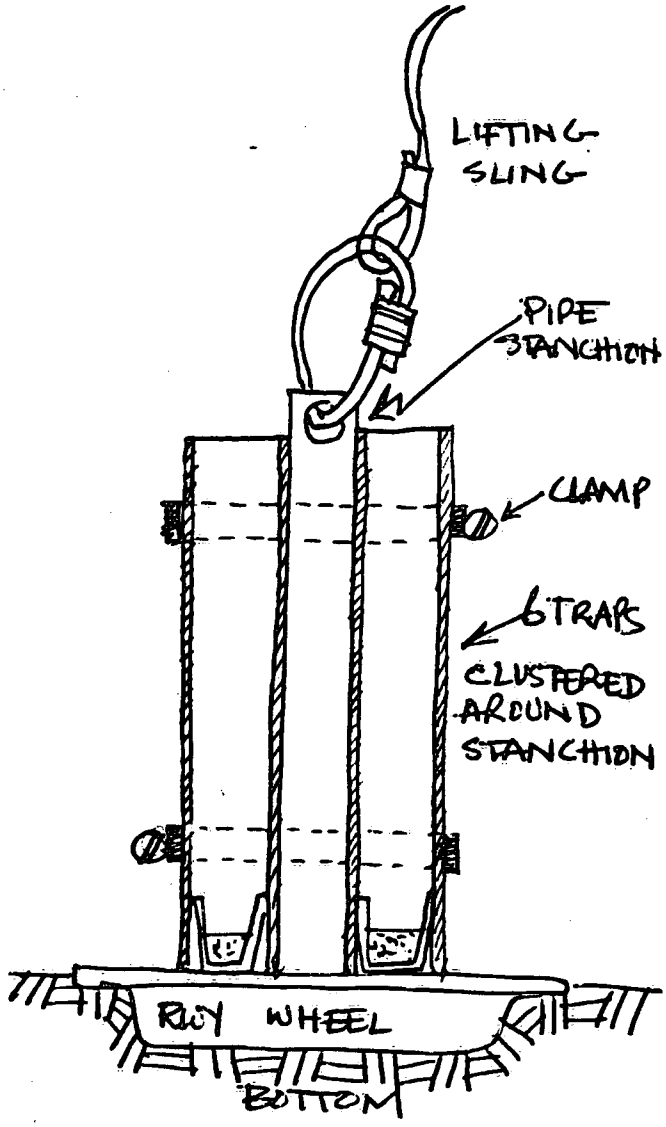
The sediment trap used in the 1985 Lake St. Clair study is shown in Figure 1.1, and the distribution of trapping stations through the lake is shown in Figure 1.2. The refurbishment interval for the traps was nominally two weeks. B. Oliver has analysed the trapped material and reports that the key contaminants are found everywhere in the basin, but there are pronounced spatial gradients (Figure 1.3). Although several mechanisms can be invoked to explain the relatively high concentrations found in Anchor Bay, this feature remains unresolved. Despite an integrating time of two weeks, the contaminant concentrations are highly variable and may indicate a physically "noisy" system with a high degree of horizontal patchiness, or perhaps be the result of sporadic inputs. Observations show that the downward flux of sediment correlates negatively with the percentage organic material, and comparison of the relation observed in Lake St. Clair with other situations suggests that the traps are catching mostly resuspended material. Sediment trap catches were also found to be spatially variable with the lowest returns being found in Anchor Bay, and the highest in the open lake. The quantitites trapped could be supplied however, from a very thin (mm) layer of bottom sediment. Some further observations - the sediment trap catch is highly seasonal and is probably related to seasonal wind stress patterns; highest contaminant concentrations occur when the sedimentation rates are lowest. It was conjectured that the export of suspended material through the Detroit River is twice that entering from the St. Clair river.

Comments: N. Rukavina observed that the lake sediments have a high sand content and that sand is not a good adsorber of some organic materials. G.K. Rodgers reports that the river normally carries a very small bedload; there is need for a sediment budget for the basin.

Figure 1.1



Sediment trap design and mooring arrangement.



LAKE ST. CLAIR CONFIGURATION

Figure 1.2
Sediment Trap Locations
in Lake St. Clair
1985

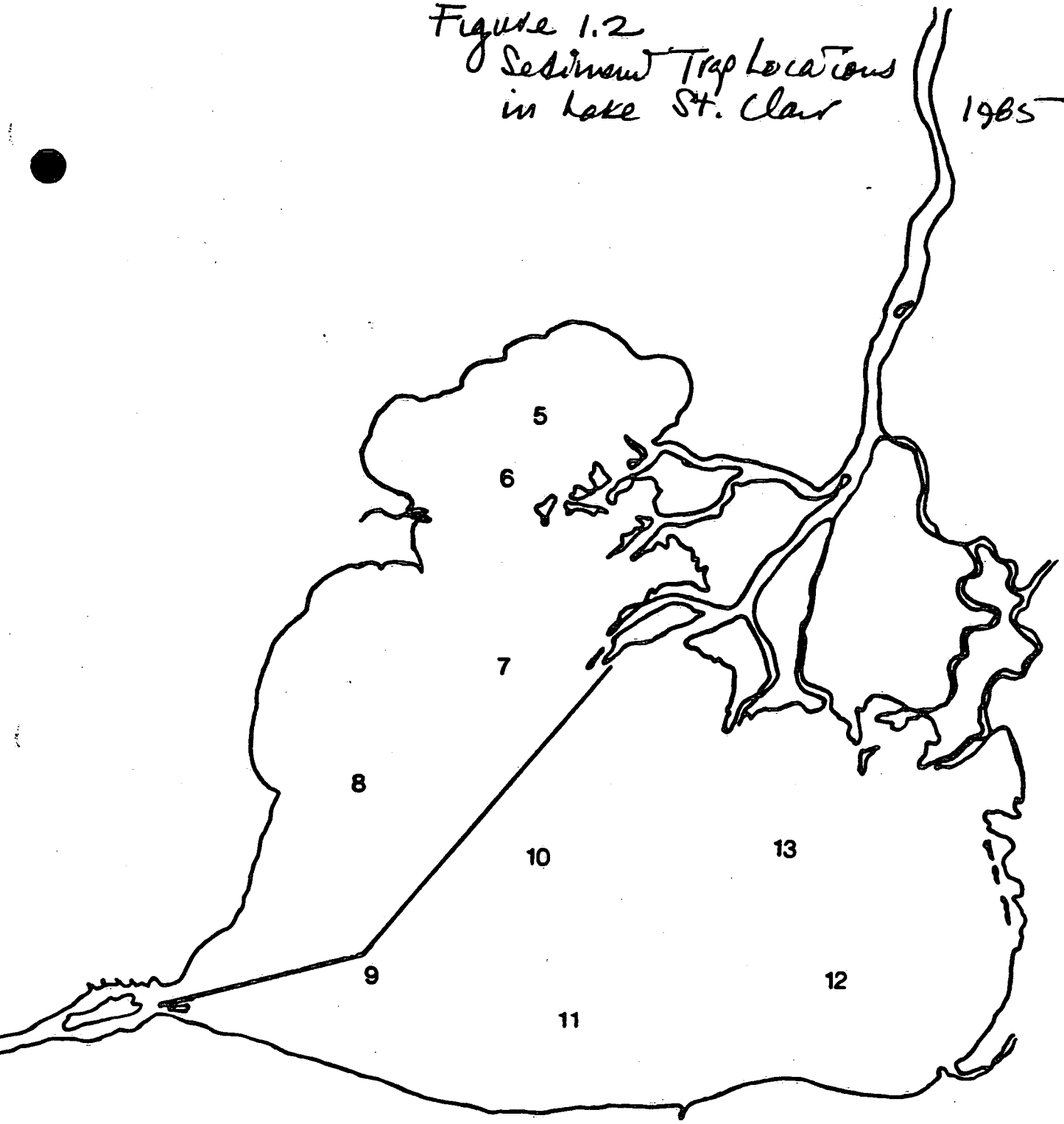
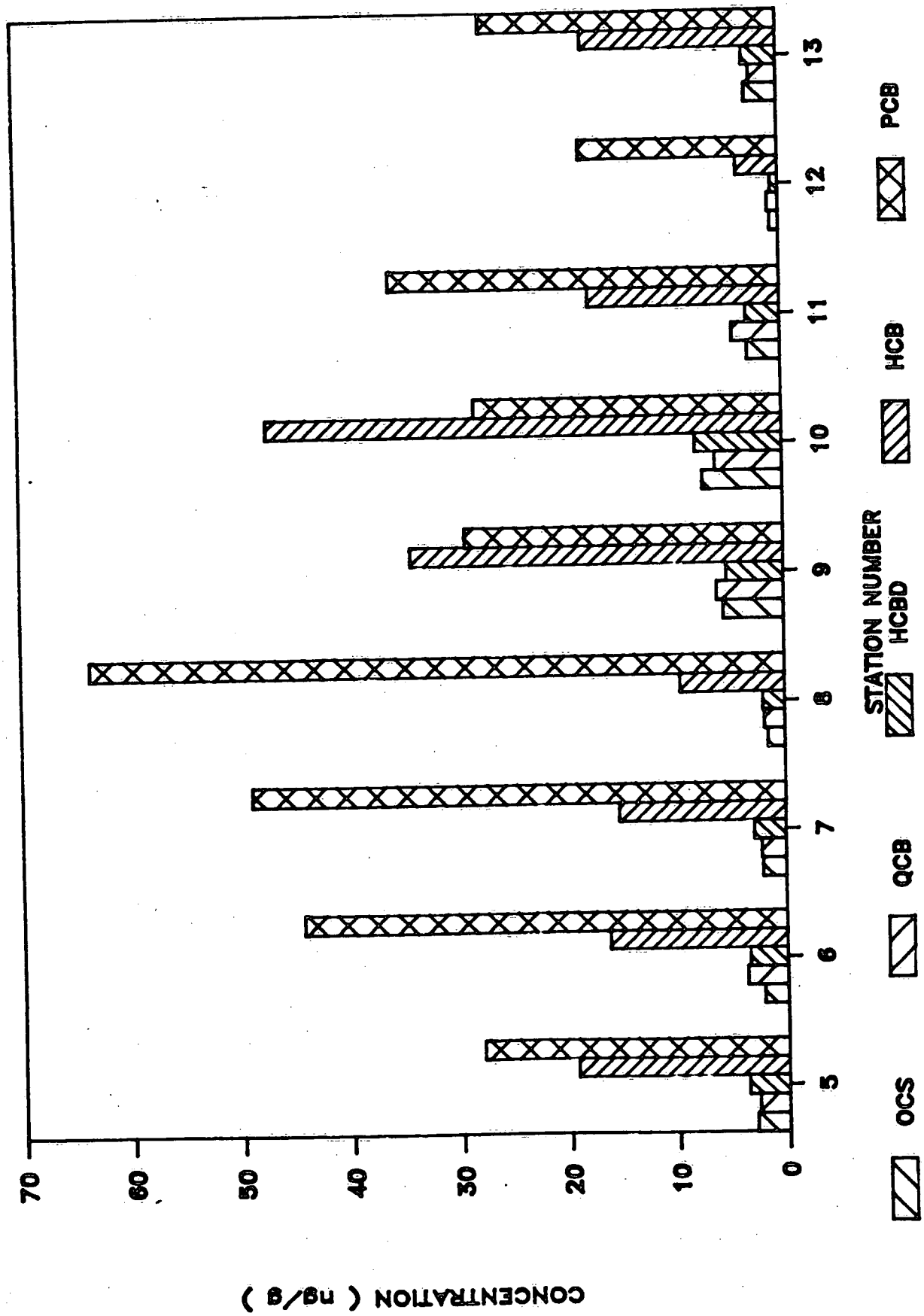


Fig 1.3 Contaminant concentrations in Hgps by station



2. The Hydraulics Division Progam in Nearshore Sediment Transport (M. Skafel)

Noncohesive sediments.

The focus of this work is to provide better models of erosion, transport and deposition of sand in the surf zone. The principal mechanical energy sources are waves and wave-related alongshore currents. Specifically, one seeks to measure the water velocity and sediment concentration profiles as functions of the wave field and sediment properties. The recent Canadian Coastal Sediment Study in Atlantic Canada brought together many specialists. Their assessment of overall ability to deal quantitatively with these processes ranges from pessimism to relative satisfaction. Reports of this experiment are on file with M. Skafel.

Cohesive sediments.

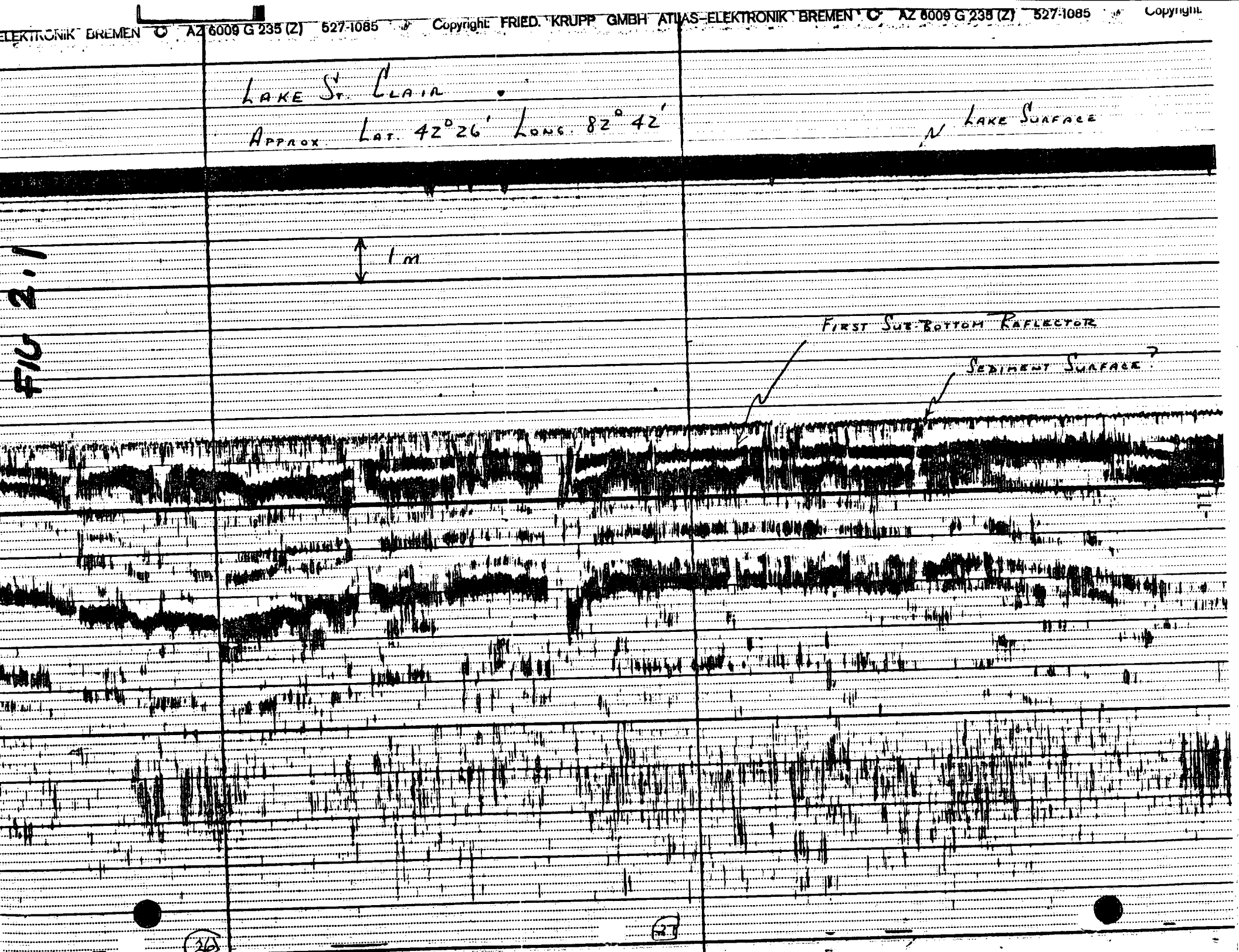
Studies are in progress on the erosion of consolidated glacial tills. This material is a major source of fine sediments to the nearshore zone that may act to dilute contaminated sediments arriving from the land. An assessment of the rates of erosion and the trajectories of the suspended materials are the goals of several studies. At Stoney Creek, detailed echo-sounding is used to determine the rate of erosion and bed roughness, always an uncertain parameter in the calcualtion of bottom stress, is being measured by testing plaster of paris replicas of the lake bottom in a hydraulic flume. Tracer studies of sediment movements are being conducted in the vicinity of the Toronto waterfront. Echosounding has been used to map the distribution of surface sediments from the shore to a depth of 20 m. In Lake St. Clair, echo-sounder transects (1985) revealed sub-bottom sediment layering (Figure 2.1). More detailed observations of local erosion and deposition rates have been made with a high-resolution, downward-looking echo sounder mounted on a rigid underwater frame (Figure 2.2). Three of these last instruments will be installed in Lake St. Clair during the coming field season. Other work addresses the geotechnical character of the materials and the properties of the near-bottom flow regime.

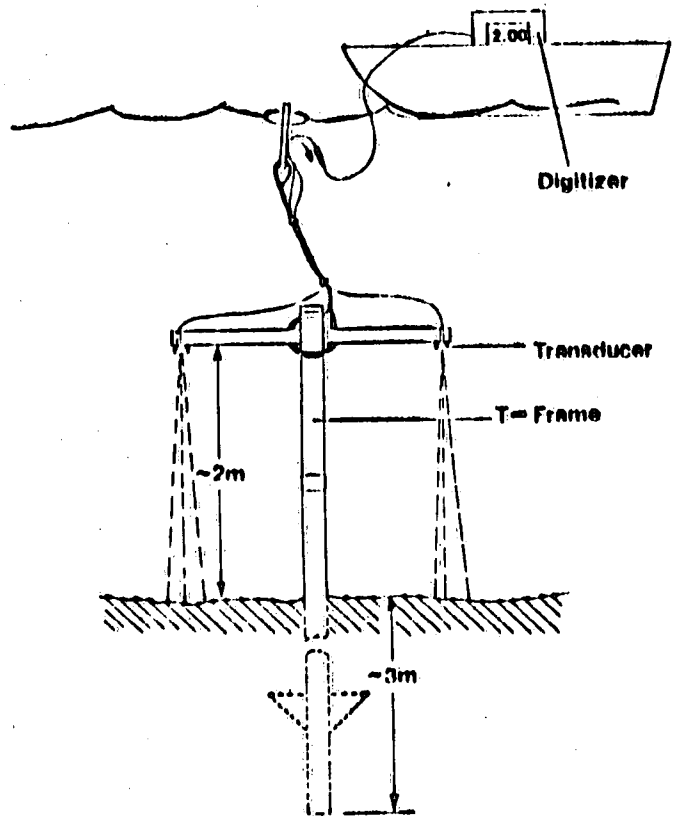
Of particular interest to the workshop is the study performed in Lake St. Clair on wave generation and dissipation in shallow water. Simultaneous transmissometer and current meter time series are being studied. Laboratory tests were conducted on bulk sediment samples, including a wave flume experiment intended to determine the flow regime under which active erosion (resuspension) might take place. The importance of the in situ cohesive properties of the sediment was demonstrated, although the results are not directly applicable to the natural

environment. Finally, suitable wave forecasting models for shallow water have not been developed. These models are needed to predict resuspension due to wave action in shallow water.

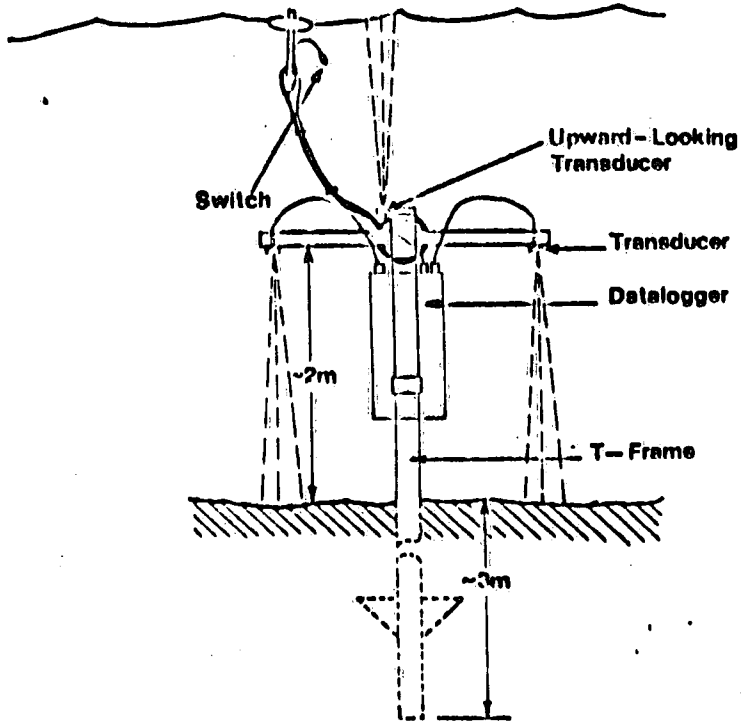
Discussion:

The speaker was asked to describe the calibration of the transmissometer used in the shallow-water wave experiment in Lake St. Clair: Surficial sediments from the lake (containing all size fractions) were stirred into water and a calibration curve relating output voltage of the instrument to sediment concentration was developed. J. Jerome felt that the relationship between transmission and sediment concentrations was reliable.





MANUAL

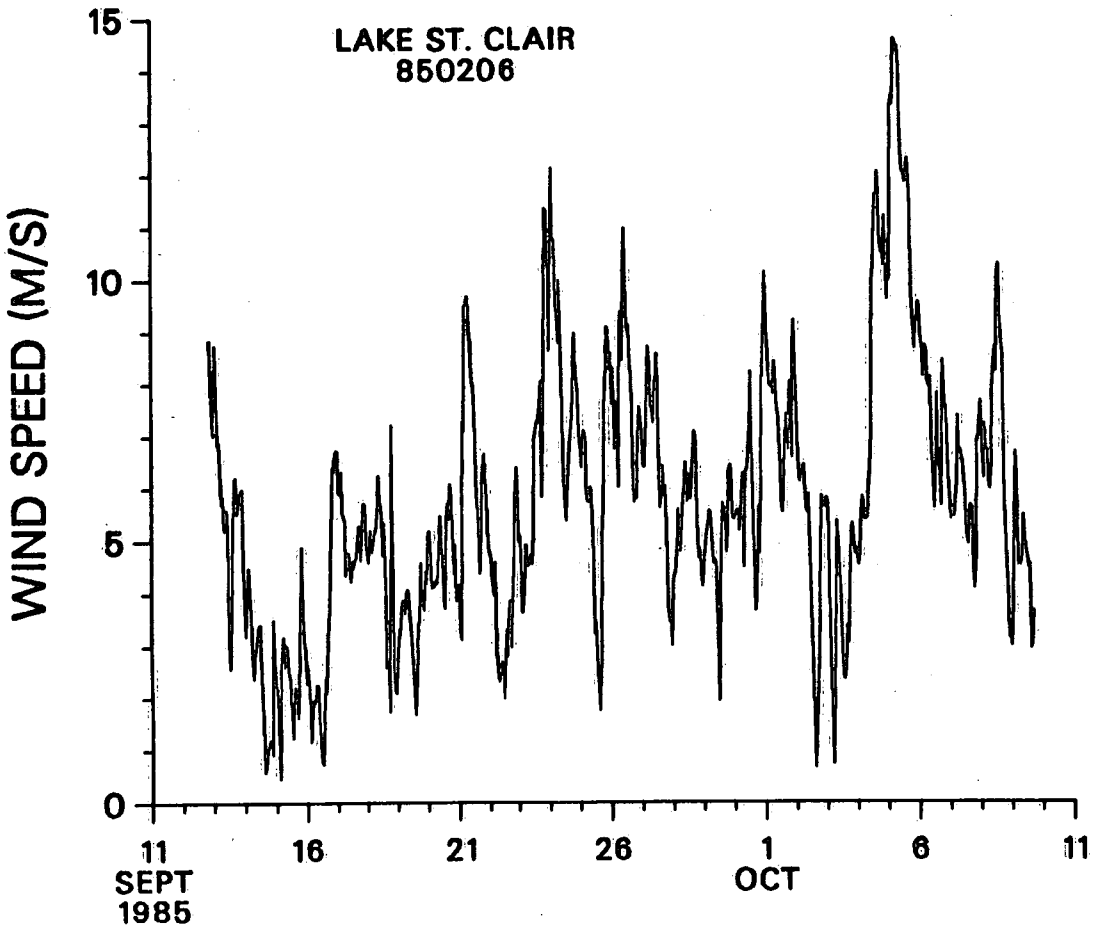


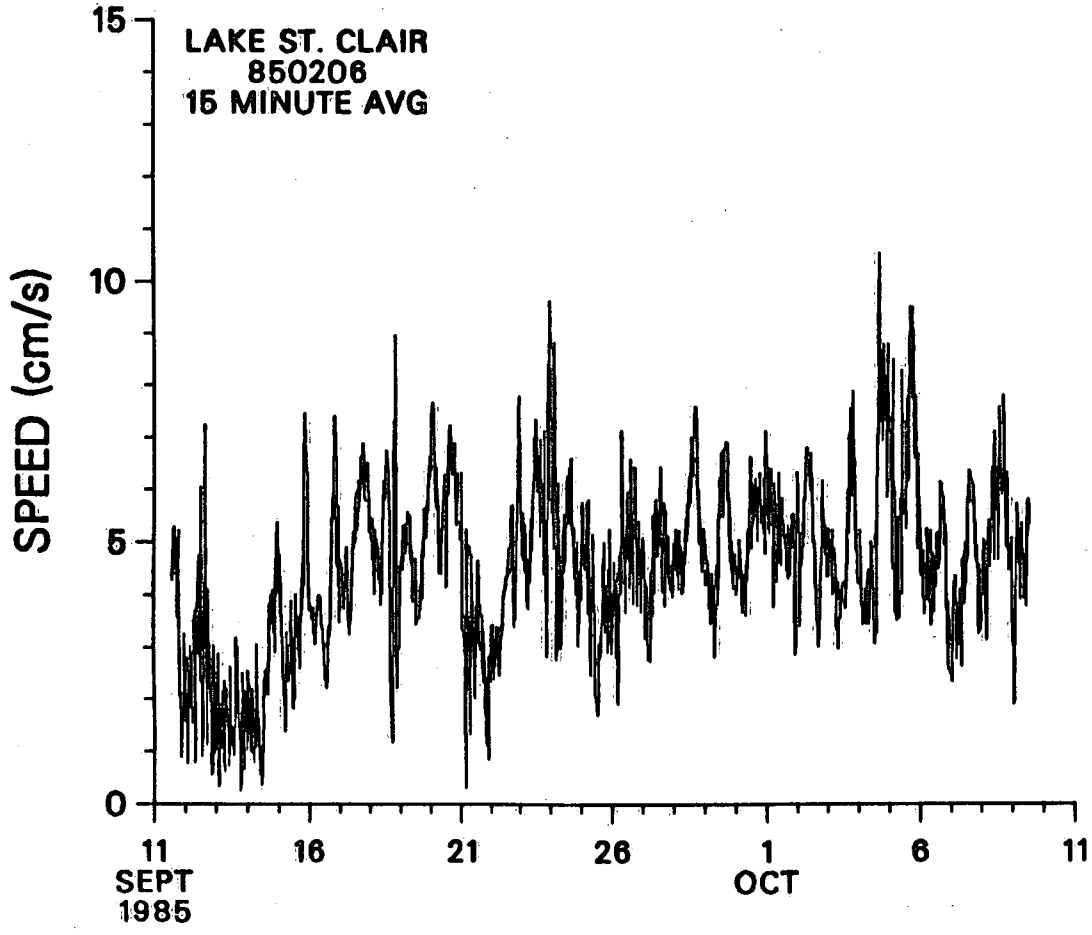
AUTOMATIC

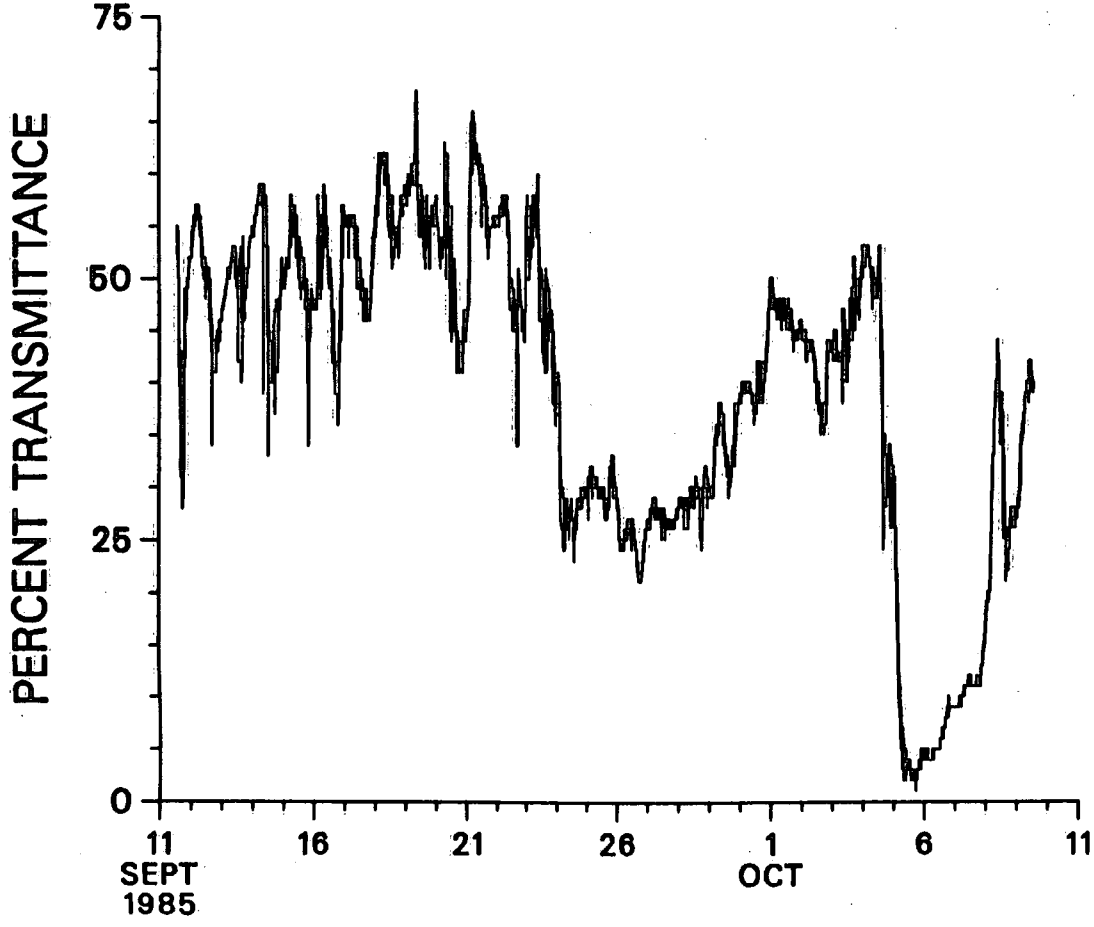
3. Time Series Measurements of Current and Optical Transmission at One Metre Above the Bottom in Lake St. Clair. (B. Lesht)

The main thrust of this study is empirical with the measurement program kept as simple as possible. With good spatial and temporal coverage, an empirical signature of both resuspension and horizontal transport events may be determined. The study provides valuable calibration data for models. The measurement platform carries a 4.5 cm Marsh McBirney EM current meter and a Sea-Tech 25 cm path length transmissometer 70 cm above the bottom. In the first deployment, the instrument sampled in bursts of 1.5 minute duration at a rate of 4 samples per second (the bursts were repeated at intervals of **** hours). In the second experiment, the instrument recorded 5-minute averages. The high-speed sampling showed a negative correlation between peaks in the rms velocity and peaks in the optical transmission. This record may yield a relation between flow speed and sediment concentration, and may also identify local resuspension events. During the second, longer, experiment, the transmissometer became progressively fouled. Comparison with nearby profiles of transmission made from a vessel allows a correction to be made. At the experimental site, near the NWRI tower, two episodes of low transmission occurred during the September 11 to October 11 experimental period, each being associated with high wind stresses (Figures 3.1, 3.2, and 3.3).

Discussion.
J. Coakley asked whether the threshold velocity for resuspension to be determined empirically from the data set would take wave orbital motions into account. In response to the comment by N. Hawley that the abovementioned episodes of low transmission could be due to the input of highly turbid water from the St. Clair river, and not due to local resuspension, P. Hamblin asked asked if wave data and water intake turbidity data were available from Lake Huron at the entrance to the St. Clair River. Such data might indicate whether a rise in sediment concentration were due to local resuspension or advection downriver from the Lake. J. Jerome observed that air photos taked 24 hours after a storm show sediment plumes entering the lake. N. Hawley described the "Sea-Flume" experiments for next year.


LAKE ST. CLAIR
850206
WIND SPEED (M/S)
15
10
5
0
11
SEPT
1985
16
21
26
1
OCT
6
11


LAKE ST. CLAIR
850206
15 MINUTE AVG
SPEED (cm/s)
15
10
5
0
11
SEPT
1985
16
21
26
1
OCT
6
11


PERCENT TRANSMITTANCE
75
50
25
0
11
SEPT
1985
16
21
26
1
OCT
6
11

4. Upper Great Lakes Connecting Channels Study; Lake St. Clair: Some Preliminary Results. (P.F. Hamblin, Y. Marmoosh)

Seston and Optical Transmission.

From simultaneous observations of seston concentrations (filtered normally from 1 litre water samples) and optical transmission, empirical relations were developed relating optical transmission to suspended sediment concentrations, both total sediments and the organic fraction (Figure 4.1). Surprisingly, the relation between transmission and the organic component of the suspended sediments contains less scatter than the relation for total dissolved solids. This work was performed by Y. Marmoosh and is described in his year-end report.

Kenney and Rosa Samplers.

Two sediment trapping systems were employed, in addition to the network maintained by M. Charlton. Both systems were designed to investigate the vertical distribution of sediment concentrations/vertical fluxes. The "Kenney Sampler" was designed by B. Kenney of the Freshwater Institute in Winnipeg (Kenney, 1985. Sediment resuspension and currents in Lake Manitoba. J. Great Lakes Res. 11: 85-96). It consists of a compartmented vertical column ported at 10 levels to admit horizontally moving water (see Figure 4.2a). The "Rosa Sampler" was developed by F. Rosa of NWRI and consists of an array of "conventional" sediment traps mounted on a tripod and arranged at levels from 0.2 to 2.0 metres above the bottom (Figure 4.2b). A timer and release mechanism removes the caps from the tubes after the disturbance created by the lowering of the frame has dissipated. Our version of the Rosa Sampler also carried a short (2m) Kenny Sampler for purposes of comparison. A 4 m Kenny Sampler was placed on the central tower and a mechanism provided for the raising and lowering of it to change sample bottles.

Figure 4.3 shows the catch rate for three periods of deployment of the Kenney Sampler in the open lake. The four low catches represent background levels, while the largest rate was measured during an active storm event (October 6-7, 1985). Because of the horizontal porting, the sampler is thought to measure horizontal transport of suspended material (product of velocity and sediment concentrations). Some confirmation of this notion is to be found in the comparison of profiles of the catch rate with those formed from an observed suspended sediment profile and a simulation of the velocity profile during the storm. The pronounced minimum in the catch rate at 1 m above the bottom may be due to the sheltering of the inlet by a structure on the tower or by the vertical distribution of suspended sediment during the storm. The large sediment catches are correlated with strong wind events.

The profiles from the conventional traps on the "Rosa Tower" show the expected decrease in collection rate with distance from the bottom. All three catches of horizontal sediment transport were below what is considered to be the threshold value established from exmination of the results of 7 episodes at the other site.

Horizontal Sediment Transport.

From the optical transmission profiles taken on lakewide monitor cruises, and using the empirical relation between transmission and sediment concentration, a distribution of sediment concentration through the lake is estimated. A numerical water transport model that assumes a constant vertical eddy viscosity is used to estimate the velocity profile as well as currents at the current meter positions. Comparison between the observed velocity profiles made at the mid-basin tower with the computed profiles showing reasonable agreement in the bottom half of the profile but poor agreement (particularlry with regard to direction) near the surface. Nevertheless, the combination of current and sediment profiles yields a net sediment transfer vector. The magnitude and the direction of this vector is shown in Figure 4.4. Simulation of drogue trajectories which may be considered as sediment tracers were encouragingly close to observations in Lake St. Clair. Simulated speeds at 1 m above bottom are in good agreement with current meter observations but directions differ by as much as 30 degrees.

MCATS Evaluation.

The MCATS system (Figure 4.5) comprises three 10 cm Marsh McBirney EM current meters suspended 20, 30, and 40 cm above the lake bottom on an aluminium tripod. The recording schedule was a burst of 1200 one-second samples (20 min) every 3 hours. Although the system returned data through its entire deployment, the results raise many difficult questions. There is no physical reason why the phases of the current meter signals should vary substantially from the top to the bottom of the array. Cross-spectral analysis of the records show large phase shifts throughout the entire spectrum that would be consistent with the inversion of some signal leads at the time the system was installed. No evidence was found to support this hypothesis despite much detective work and post-field tests. Verification of the MCATS data against the information from a nearby Neil-Brown current meter located 1m above the bottom showed some general correspondence in direction but poorer agreement in speed. Comparison of the horizontal current spectrum calculated from linear surface wave theory and observations of surface wave heights with that observed at the MCATS current meters shows that these last "smear" out the spectrum in the vicinity of the surface wave peak. This is consistent with the laboratory observations of Aubrey and Trowdridge (1985) that raise doubts as to the ability of Marsh-McBirney EM Current Meters to track

rapidly varying oscillatory flows in the presence of a mean flow. Reluctantly we are forced to abandon the MCATS data.

Total Suspended Sed.

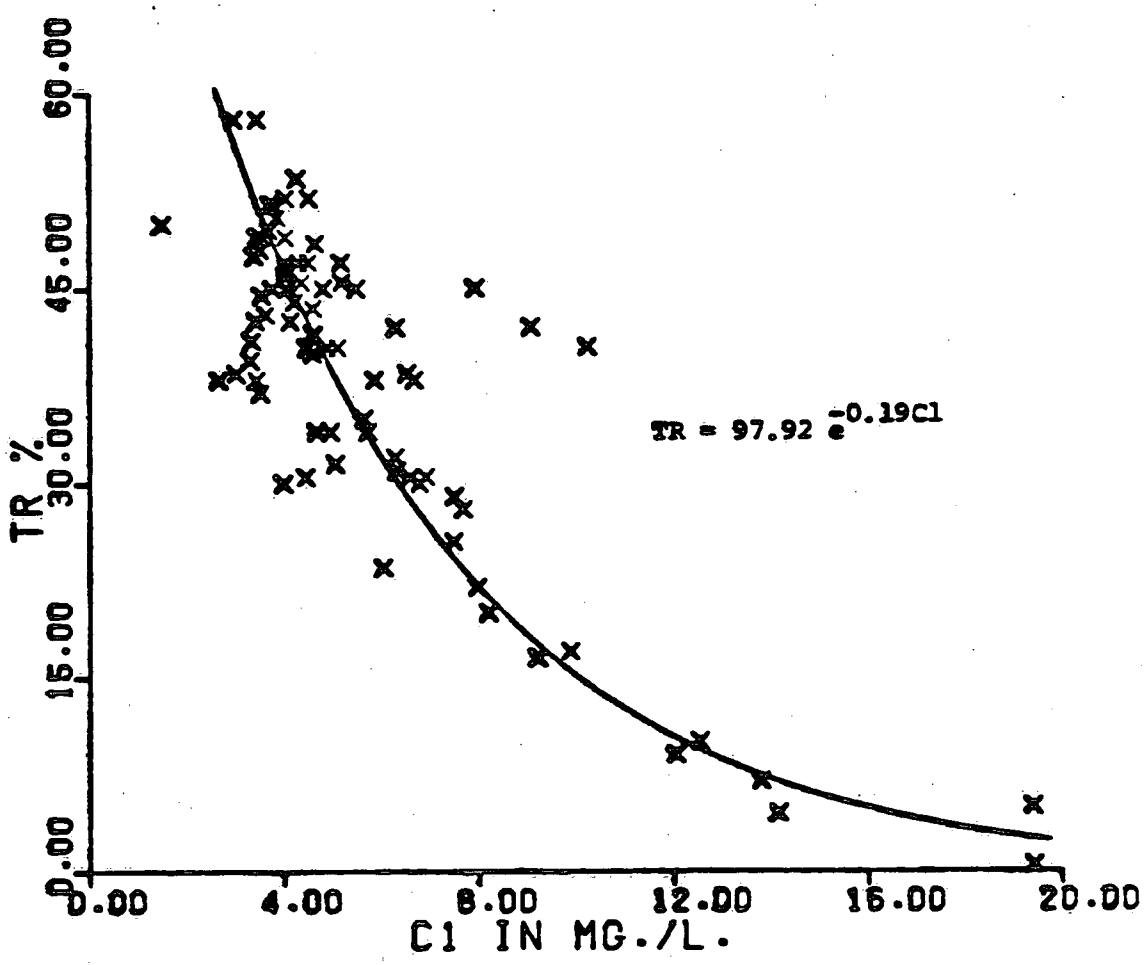
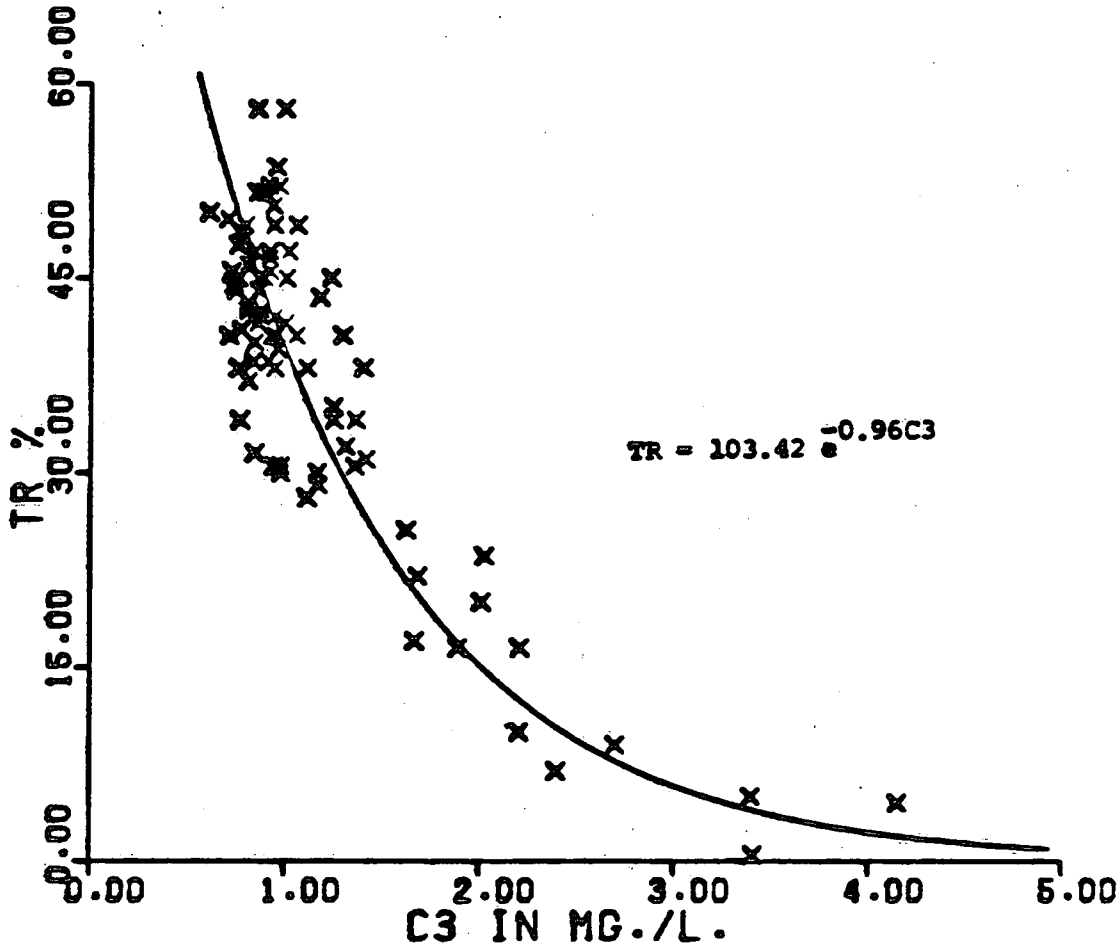
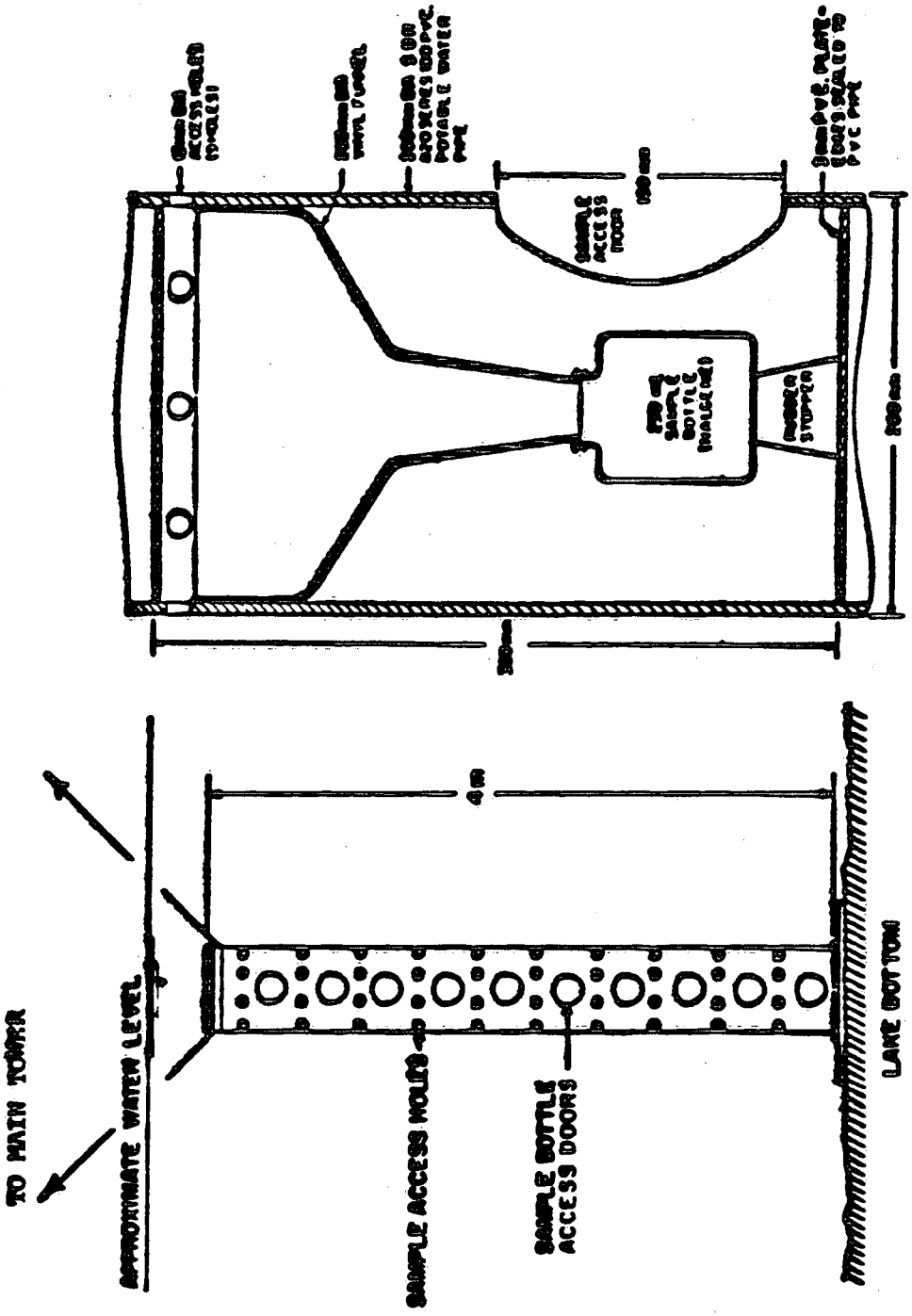
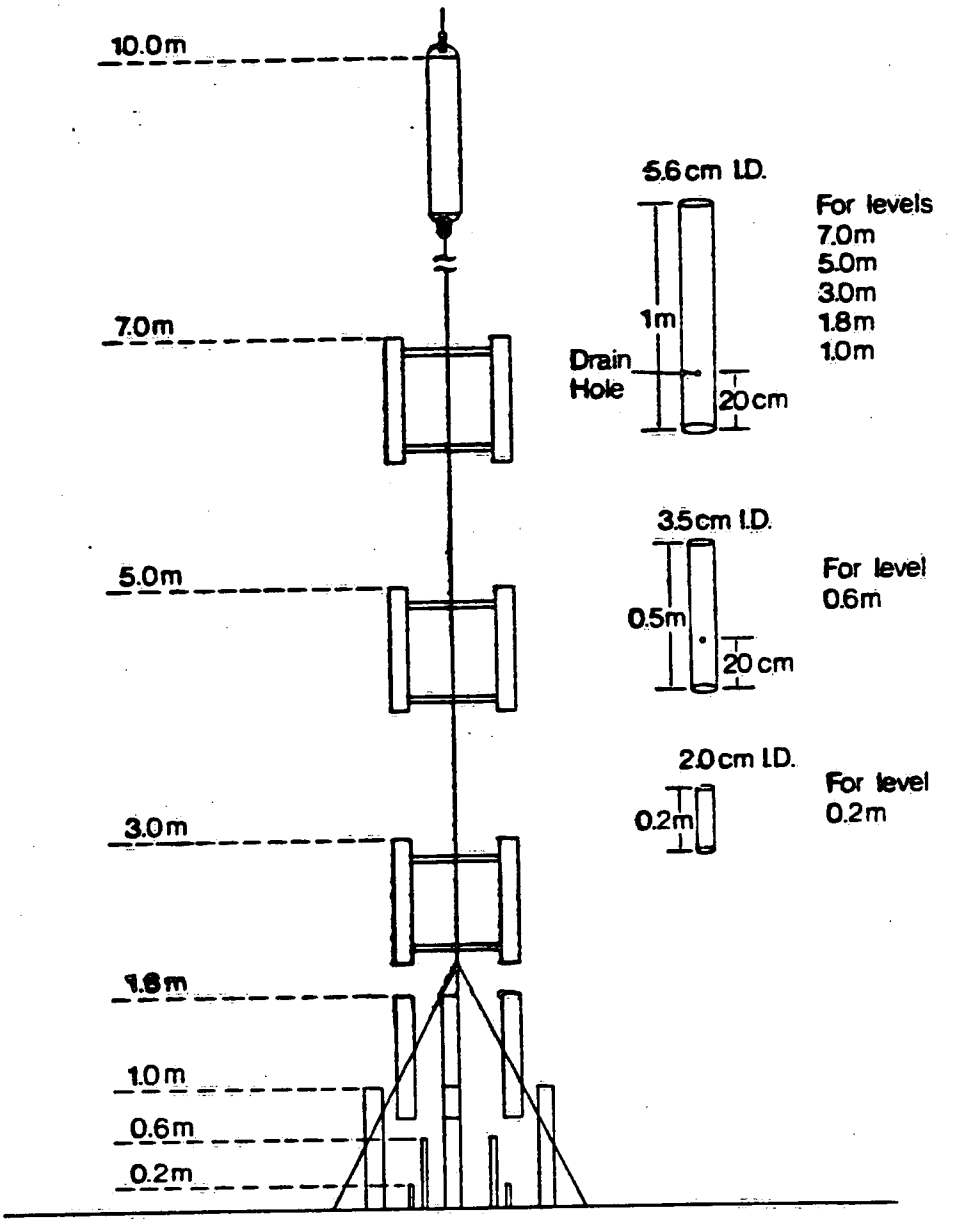


Figure 4.1b
Organic Component
Suspended Sed.



Kenney Sampler





RESUSPENDED SEDIMENT SAMPLER
(design of H. Savile and F. Rosa)

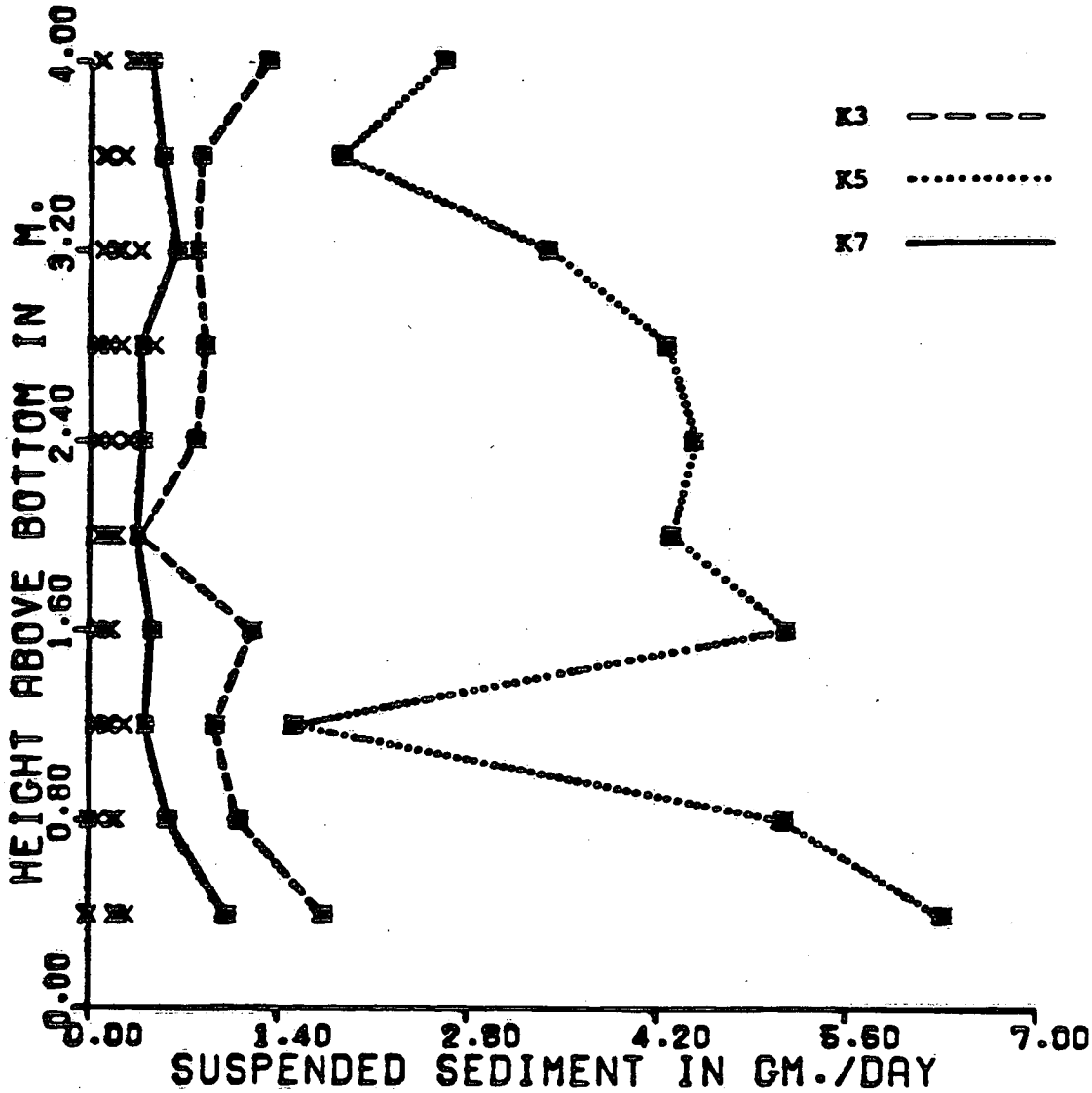

HEIGHT ABOVE BOTTOM IN M.
0.00
0.80
1.60
2.40
3.20
4.00
0.00
1.40
2.80
4.20
5.60
7.00
SUSPENDED SEDIMENT IN GM./DAY
K3
K5
K7

Figure 4.4
Sediment Flux Vectors
August 14, 1985

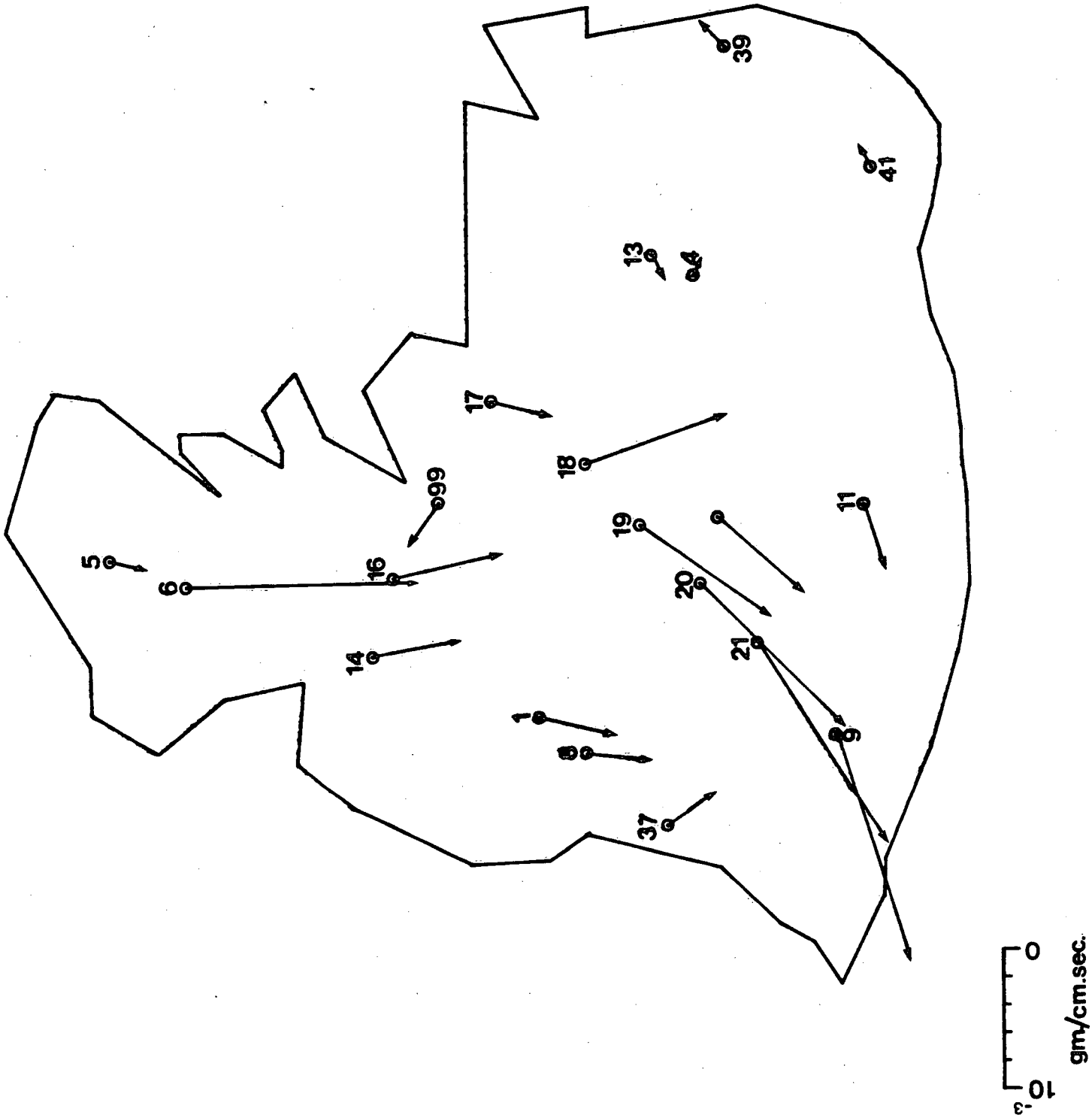
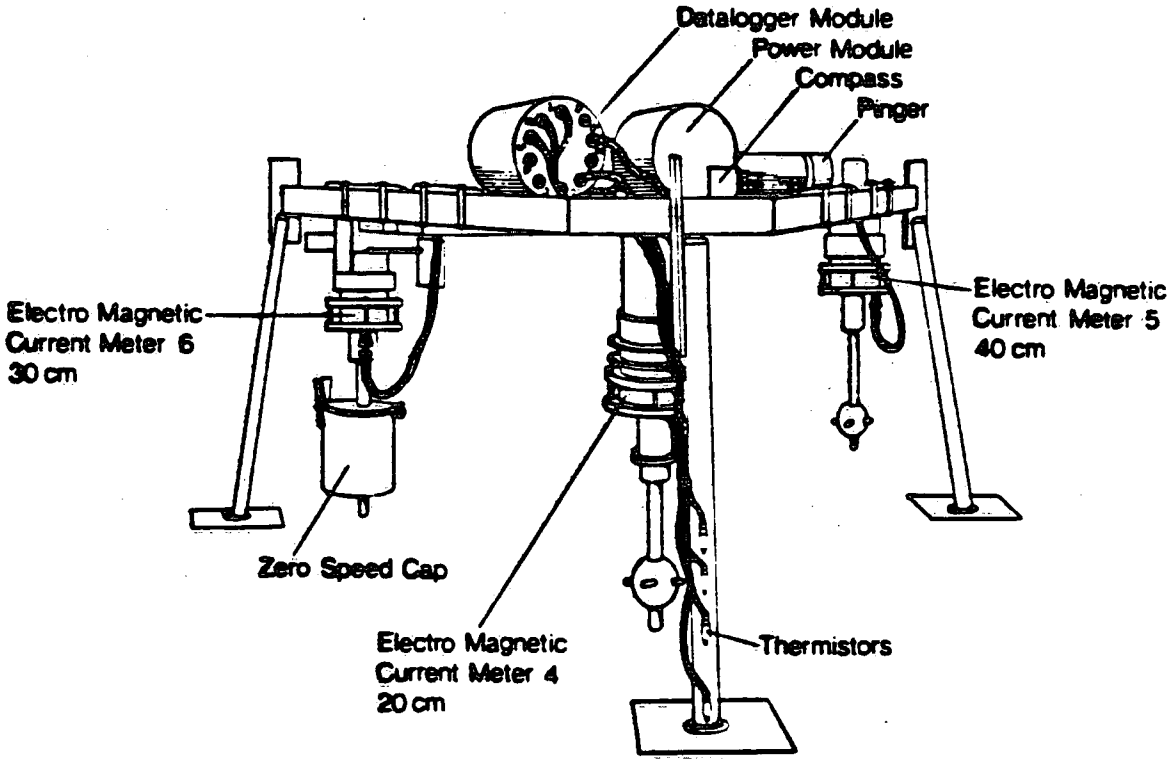


Fig 4.5


Datalogger Module
Power Module
Compass
Pinger
Electro Magnetic
Current Meter 6
30 cm
Electro Magnetic
Current Meter 5
40 cm
Zero Speed Cap
Electro Magnetic
Current Meter 4
20 cm
Thermistors

5. Dynamics of Sediment Resuspension in the Benthic Boundary Layer. (Prof. K. Bedford, Ohio state)

At least three boundary layer situations must be considered, that of steady flow, boundary layers for oscillatory motion, and combined wave and current flows. The distribution of suspended sediment itself forms another boundary layer. The combined wave and current boundary layer has been formulated theoretically by Grant but verification is difficult, and the sediment portion of the layer has not been tested. In order to verify each of these regimes and to establish the parameters particular to the experimental situation, a special set of measurements would be required. In the uncontrolled lake situation, all three of the regimes described above could be in action at different times. Direct measurement of boundary layer processes, such as the evaluation of shear stress, is difficult, requiring small current meters that respond rapidly to all three orthogonal velocity components. The required sampling rates are high in order to cope with the wave orbital motions and turbulent shear stresses. Very few sets of measurements exist that meet the extremely stringent conditions.

The favoured approach is an enlightened empiricism in which sampling strategies would be guided by theory (how close to the bottom? how often?) but where the dependent and independent variables would be linked empirically. Central to this idea is some method of measuring sediment concentration profiles in the water column from the bottom upwards as a resuspension event proceeds. Since optical transmission is a sensitive function of both sediment grain size and concentration, its measurement may not yield unequivocal results. Questions of spatial and temporal resolution arise, as does the matter of flow interference by the instrument itself. An acoustic backscattering device has been developed at Ohio State in which a gated receiver is able to discriminate the signal backscattered from a relatively small volume of fluid in the path of the outgoing acoustic wave-packet. The backscattered energy can be related to sediment concentration for simple grain-size distributions. A particular virtue of the approach is the excellent vertical resolution obtainable and its speed of operation. Reasonable verification of the system has been obtained in the case of a steady, simple boundary layer in an application on the East Coast. A control volume approach was outlined that relied on the absence of horizontal gradients in the horizontal sediment flux in order to infer the vertical flux of sediment at some height above the bottom. A time-dependent display of the backscattering intensity as a function of height above the bottom shows a high degree of intermittency, presumably related to fluctuations in the flow field. It is proposed to deploy this system in Lake St. Clair during the early fall

intensive period near the NWRI tower where supporting flow data can be obtained.

(Editor's Note: Professor Bedford kindly supplied a copy of his lecture notes and diagrams. These alone provide an excellent short course in the physics of near-bottom flows and are reproduced almost in their entirety in Figures 5.1 through 5.20.

Fig 5.1

BENTHIC BOUNDARY LAYER (BBL)

DEFINITION

BOWDEN - LAYER EXTENDING ABOVE AND INTO THE BOTTOM WHERE STRONG PHYSICAL CHEMICAL AND BIOLOGICAL GRADIENTS OCCUR.

EXCHANGES OF MATERIAL WITHIN BOTTOM AND WATER INCLUDED IN DEFINTION

BBL Resuspension is function of Bottom Shear, Type, and Shape

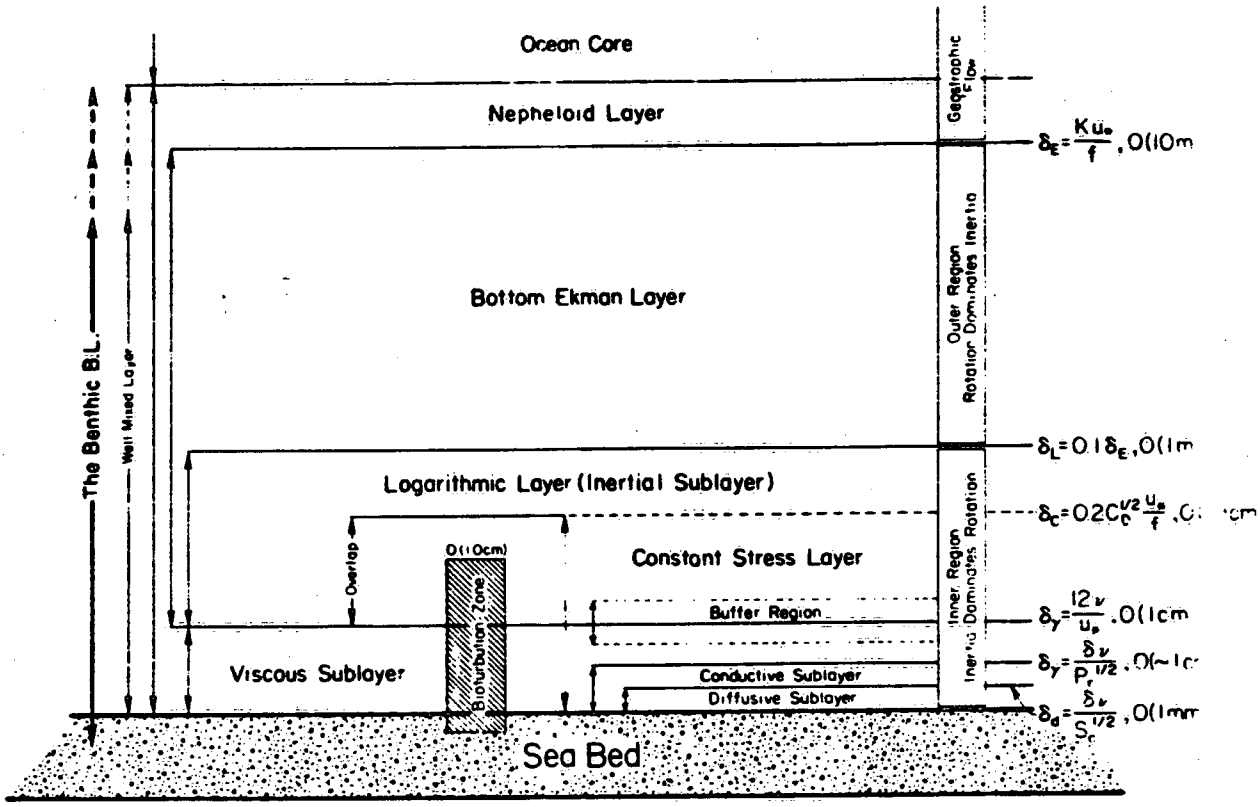
FORCING FUNCTIONS - ORIGIN OF SHEAR

1. All quite STRONG AND LARGE IN SPACE/time SCALES COMPARED TO BBL
2. Persistant - INERTIAL, EKMAN CIRCULATION
3. Periodic - tides, seiches
4. Episodic - wind waves, internal waves, storm surges etc.

METHODS FOR CHARACTERIZING BBL ACTIVITY

1. EMPIRICAL
2. Boundary LAYER - AVERAGING, Reynolds Stress
3. Structural

Fig 5.2


Ocean Core
Nepheloid Layer
Bottom Ekman Layer
Logarithmic Layer (Inertial Sublayer)
Constant Stress Layer
Buffer Region
Viscous Sublayer
Conductive Sublayer
Diffusive Sublayer
Sea Bed
The Benthic B.L.
Well Mixed Layer
Overlap
O(10cm)
Bioturbation Zone
Geostrophic Flow
Outer Region
Rotation Dominates Inertia
Inner Region
Inertia Dominates Rotation
$\delta_E = \frac{K u_*}{f}$, O(10m
$\delta_L = 0.1\delta_E$, O(1m
$\delta_c = 0.2 C_c^{1/2} \frac{u_*}{f}$
$\delta_\gamma = \frac{12\nu}{u_*}$, O(1cm
$\delta_\gamma = \frac{\delta\nu}{P_r^{1/2}}$
$\delta_d = \frac{\delta\nu}{S_c^{1/2}}$, O(1mm

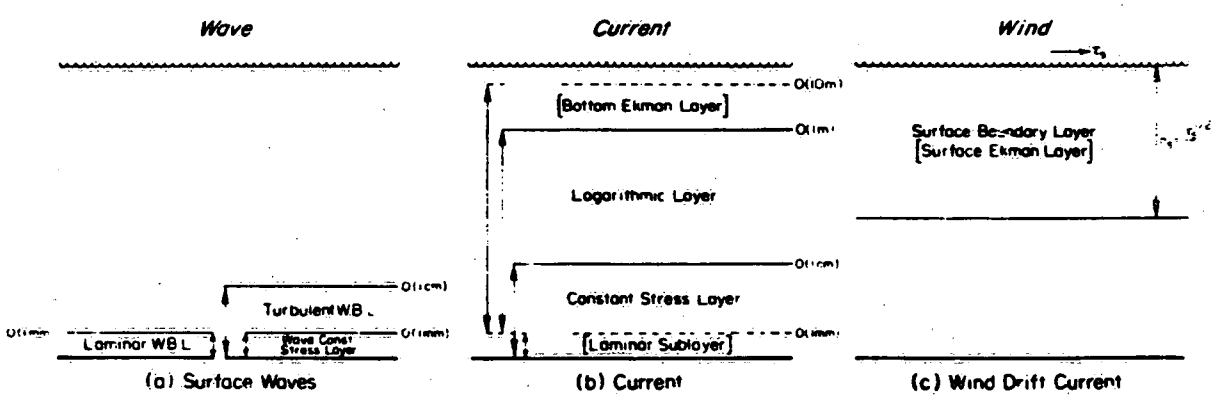

Wave
Current
Wind
O(10m)
[Bottom Ekman Layer]
O(1m)
Logarithmic Layer
O(1cm)
Constant Stress Layer
O(1mm)
[Laminar Sublayer]
Surface Boundary Layer
[Surface Ekman Layer]
Turbulent WBL
Laminar WBL
Wave Const Stress Layer
(a) Surface Waves
(b) Current
(c) Wind Drift Current

TABLE 6

Typical Values of The (BBL) Parameters

Parameter	Deep Sea	Continental Shelf	Reference	Lake Erie Calm	Lake Erie Stormy
Bottom Ekman layer thickness (mid latitudes)	10 m 10 5	50 m 100 50	Gust (1982) Bowden (1978) Wimbush (1976)	~60m	~20m
Logarithmic layer thickness	1-2 m 1 1	5 m 10 10	Gust (1982) Bowden (1978) Wimbus (1976)	~2m	~20m
Viscous sublayer thickness	1 cm 1 2	1 cm 0.1	Gust (1982) Bowden (1978) Wimbush (1976)	1cm	0.1
Conductive sublayer thickness	1 cm		Wimbush (1976)	1cm	1cm
Diffusive sublayer thickness	0.2 cm 0 (1 mm)		Wimbush (1976) Boudreau & Guinasso (1982)	O(1mm)	O(1mm)
Wave viscous boundary layer thickness		2 mm	Smith (1977)	---	1mm
Time averaged horizontal velocity	0.1-5cm/sec 4 3	1-50cm/sec 40 30	Gust (1982) Bowden (1978) Wimbush (1976)	1-5 cm/sec	10-20cm/sec
Free stream velocity	3 cm/sec		Wimbush & Munk (1979)	~5cm/sec	~5 cm/sec
Friction velocity	0.04-0.8 cm/sec 0.2 0.1	0.4-2cm/sec 2 1	Gust (1982) Bowden (1978) Wimbush (1976)	0.25cm/sec	1cm/sec
Roughness length	1 cm	5 cm	Gust (1982)	5 - 10cm	
Drag coefficient	10^{-3} 3.1×10^{-3}	10^{-3}	Gust (1982) Sternberg (1972)	$1.2\ 10^{-3}$ - 2.5×10^{-3}	
Bed shear stress	$O(10^{-2}$ dyne/cm^2)	O(1 dyne/cm^2)		$O(10^{-2}$ dyne/cm^2)	O(1 dyne/cm^2)

Parameter	Deep Sea	Continental Shelf	Reference	Lake Erie Calm	Lake Erie Stormy
Characteristic eddy viscosity	8cm^2/sec 1	200 cm^2/sec 100	Wimbush (1976) Boudreau and Guinasso (1982)	40cm^2/s	
Dissipation rate of turbulent kinetic energy (constant stress layer)	$O(10^{-3/2}$ watt/unit mass)	O(1/z) watt/unit mass		$O(10^{-3/2})O(1/z)$	
Molecular viscosity (Kinematic viscosity)	1.8×10^{-2} 1.5×10^{-2} cm^2/sec		Boudreau and Guinasso (1982) Chriss & Caldwell (1982)	SAME	
Von Karman's Constant	0.41		Nowell (1983)	SAME	
Diffusion coefficient of salt	2×10^{-5} cm^2/sec		Bowden (1978)	does not apply	
Diffusion coefficient of heat	1.4×10^{-3} cm^2/sec		Bowden (1978)	SAME	
Adiabatic temperature	10^{-6} C^0/cm		Wimbush (1976)	does not apply	
Bioturbation zone	0 (10 cm)		Gust (1982)	SAME	
Constant stress layer thickness	10 cm		Wimbush & Munk (1970)	O(10cm)	O(1m)
Kolmogorof length (logarithmic scale)	0.5 cm		Wimbush & Munk (1970)	0.1 - 0.5cm	
Monin Obukhov length scale	100 m		Wimbush & Munk (1970)	10 - 20m	

Fig 5.3

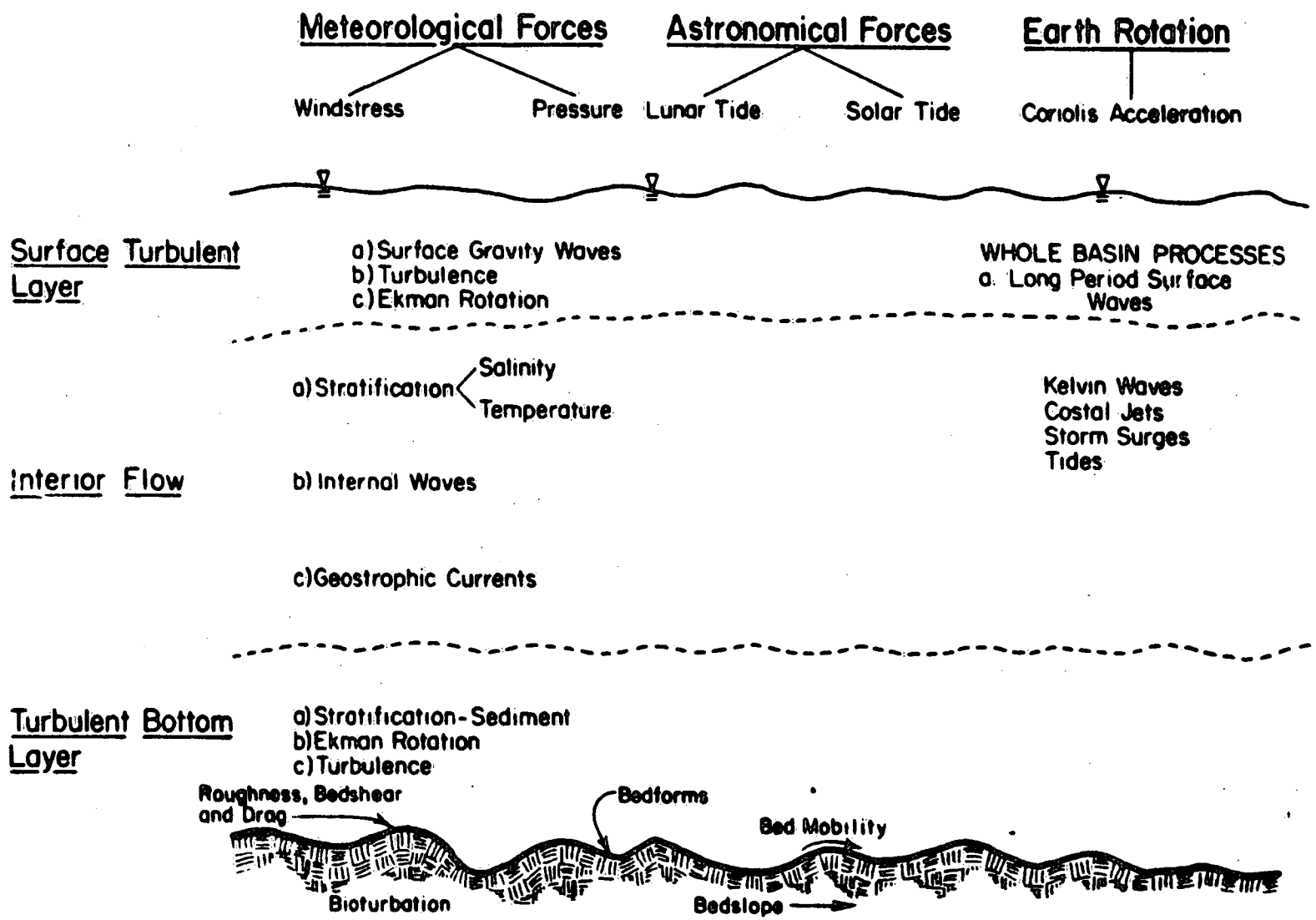

Meteorological Forces
Windstress
Pressure
Astronomical Forces
Lunar Tide
Solar Tide
Earth Rotation
Coriolis Acceleration
Surface Turbulent Layer
a) Surface Gravity Waves
b) Turbulence
c) Ekman Rotation
WHOLE BASIN PROCESSES
a. Long Period Surface Waves
a) Stratification
Salinity
Temperature
Kelvin Waves
Costal Jets
Storm Surges
Tides
Interior Flow
b) Internal Waves
c) Geostrophic Currents
Turbulent Bottom Layer
a) Stratification-Sediment
b) Ekman Rotation
c) Turbulence
Roughness, Bedshear and Drag
Bedforms
Bed Mobility
Bioturbation
Bedslope

Fig 5.4

Fig 5.5

EMPIRICAL APPROACHES

1. **BASIS** $F_z = C\{f(\tau_b - \tau_{cr}, d_i, \gamma_s, \beta)\}^r$

F_x = horizontal flux

F_z = vertical flux of sediment $\left(\frac{M}{L^2 t}\right)$

* $\bar{F}_T$ = Total flux = $\bar{F}_T = F_x i + F_y j + F_z k$

τ_b = local bottom shear (L^2/t)

τ_{cr} = critical shear (Shield's Diagram) for grain diameter in question (L^2/t)

d_i = "average" grain diameter (L) (i = 50%, 90%

γ_s = sediment specific weight (M/L^2t^2)

C = coefficient

r = power

β = any other variables to be considered.

2. **Comments**

a. In-situ validations are site-specific

b. Are only predictive if validation conditions are replicated.

c. Laboratory validations can't reproduce complexity of field conditions; validations are limited.

d. F_z itself can not be directly measured; only concentration can be inferred with currently available instrumentation

BOUNDARY LAYER APPROACHES

Fig 5.6

Objective Predictive Expression for Average Vertical Profile of Velocity or Sediment Concentration

* **Background Note** : Expressions AND Methodology Developed for flat Bottom channel with only a mean velocity forcing function in streamwise direction. i.e $\overline{w} = 0$

BASIS:

$$\overline{u}(z^*) \triangleq \frac{1}{TL}\int_0^{\delta} u(x^*, z^*, t)\,dx^*dt; \quad \overline{c}(z^*) \triangleq \frac{1}{TL}\int_0^{\delta} c(x^*, z^*, t)\,dx^*dt$$

$$\overline{w}(z^*) \triangleq 0$$

u = horizontal velocity (L/t); c = sed conc. (M/L^3)

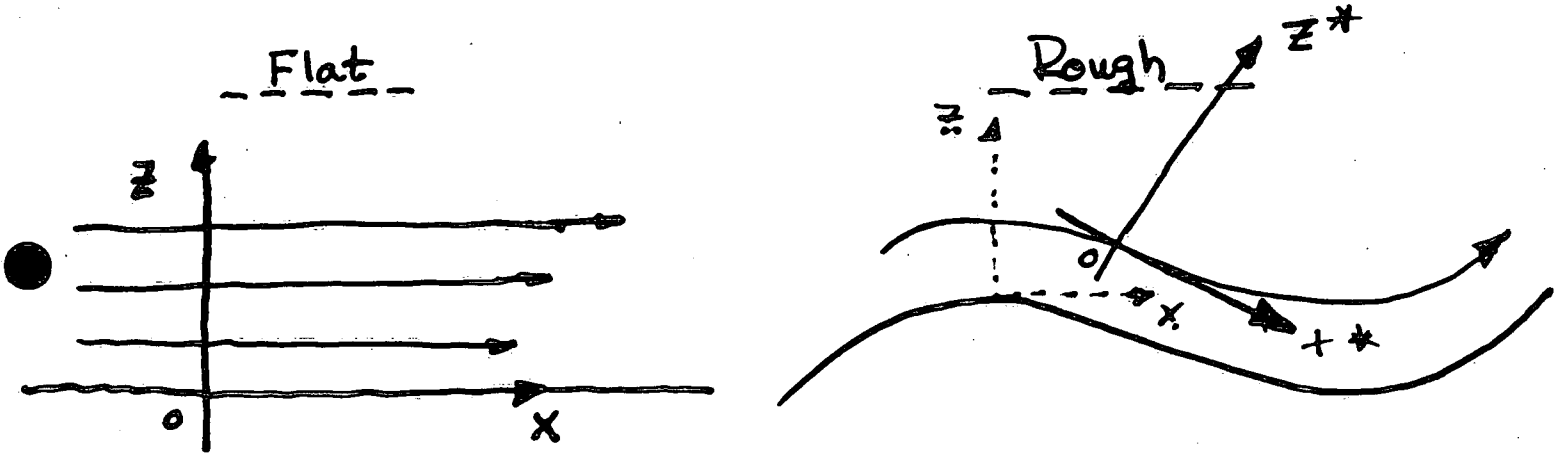
δ = height above bottom (L)

x^* = horizontal streamwise coordinate

z^* = vertical coordinate such that x^* and z^* coordinate rotation gives $\overline{w} = 0$

T, L = Averaging Time and Length respectively

COORDINATE SYSTEM NOTE:



ADVANTAGES TO A BL. APPROACH

Fig 5.7

1. CAN integrate BASIC EQUATIONS TO ACHIEVE PREDICTIVE SOLUTIONS FOR $u(z)$ and $C(z)$
2. If BL. profile for $u(z)$ can be measured and confirmed then very simple predictive expressions for τ_b are achieved
3. If BL profile for $C(z)$ can be measured and confirmed then very simple expressions for F_z are achieved; i.e.

$$F_z = E_z \, \partial\bar{C}/\partial z - w_s \bar{C}$$

where E_z = Turbulent Eddy Diffusivity
w_s = Particle Settling Velocity
$\partial\bar{C}/\partial z \Rightarrow$ From Measured BL. Profile.

SIGNIFICANT DISADVANTAGE

1. For Velocity Profiles only two in-situ experiments have been performed with the precision necessary to confirm the existance of a theoretically expected BL. These layers were ephemeral.
   Grant et. al. (1984) – CODE – only 30% of record.
2. No confirmed sediment layers

Fig 5.8

Comments on Boundary Layers

1. Each theoretical profile is developed by assuming one or at most two dominant processes affecting the flow; i.e. waves, currents, bed load transport, stratification, bedform size and shape etc. i.e. each form is a potential simplification of the in-situ case.

2. For a long term deployment at one site a variety of theoretical BL profiles might be needed to fully describe the data. The succession of various flow regimes each with different dominant processes precludes one universal description even at one fixed point. NOAA —

3. Field Programs do not recognize No 2 and often fail to collect <u>all</u> relevant information needed for all the theoretical models

4. When theoretical assumptions are matched to correct data records BL methods work (Grant et. al. 1984 - CODS). Lake Erie regimes 3,4,5 are excluded but prevalent.

5. BL methods incorrectly portray shear stress — structural Approach —

Fig 5.9

COMMENTS ON B.LAYER SAMPLING REQUIREMENTS

Basis - Grant et. al. (1984), Bowden (1978).

1. In absence of ANY PERIODIC MOTIONS WITH Period less THAN 2T or equal to it at least 10-15 minutes of data collected at one Hertz or greater is required.

2. At least three vertical point measurements of u or C are required to confirm a BL. Hypothesis, more if a nonlinear log variation is expected.

3. Each Point measurement must contain all three velocities in order to resolve x^*, z^*.

4. No. 3. excludes the use of 2 axis ECM and Ducted Impeller CM.

5. For log. B.L Profiles R = 0.997 is required for 95% Confidence Interval reliability.

6. The number of point measurements for Sediment BL. analysis will require bulky instruments that disturb the flow. Turbidimeters are intrusive and disruptive.

Fig 5.10

RESUSPENSION FLUX

A mass/momentum approach

1. Boundary Layer Equation

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + w\frac{\partial c}{\partial z} - w_s\frac{\partial c}{\partial z} = D\frac{\partial^2 c}{\partial z^2}$$

ignore (for now) advection: Similar to W. Grant, J. Smith boundary layer assumption

2. Vertically and Temporally integrate equation

$$\overline{\alpha}^t = \frac{1}{T}\int_t^{t+T} \alpha\, dt \quad ; \quad \overline{\overline{\alpha}}^{z,t} = \frac{1}{d}\int_0^d \overline{\alpha}^t dz$$

3. Final Equation

$$\frac{d}{dt}\int_0^d \overline{c}^t dz = \overline{w_s c}^t\Big|_{z=d} - \overline{wc}^t\Big|_{z=d} - \overline{w'c'}^t\Big|_{z=d}$$

$$\underbrace{+\overline{w'c'}^t\Big|_{z\cong 1cm} - \overline{w_s c}^t\Big|_{z\cong 1cm}}_{\text{NET FLUX}}$$

4. Resuspension flux $\rightarrow$ $\overline{w'c'}^t\Big|_{z\cong 1cm}$

we know or can estimate other terms.

Fig 5.11

DATA COLLECTION

BOTTOM SITTING TOWER : U. of CONNECTICUT (F. Bohlen) & Ohio State Univ.

Univ. of Connecticut

1. Low frequency Currents (Marsh McBirney); 1M
2. Nephelometer
3. Wave Height and Direction
4. Water Quality Sampler - Sediment Samples.
5. 8 mm (super) & strobe movie system

Ohio State University

1. INSTRUMENTS
   a.) Marsh McBirney (511) one horiz, one vertical; located 68 cm off bottom; data collected at 4 Hz.

   b.) Pressure transducer, 1 Hz.
   c.) Thermistor , 1 Hz.
   d.) Edo Western 3 MHz transponder range gated 1@1 1 cm "bin" forms a vertical profile of particle scattering;

profiler collected data as follows:
32 profiles per second → ensembled averaged into one profile: stored the ensemble averaged profile: effective frequency 1 Hz.

2. ACOUSTIC SIGNAL PROCESSING

Using procedures developed by WHOI (J. Lynch) and OSU (C. Lubicki, Bedford) on the ABSS HEBBLE system the scattering intensities have been converted to relative and absolute concentration.
- Result; a profile of sediment concentration

3. DEPLOYMENT SCHEDULE

a. Continuously at above frequencies for 3.8 hours; 12 August 85

b. Block Sample: 15 minutes continuously every three hours; duration is 2.5 days. (Resolve tidal activity

13 Aug 85 - 15 Aug 85.

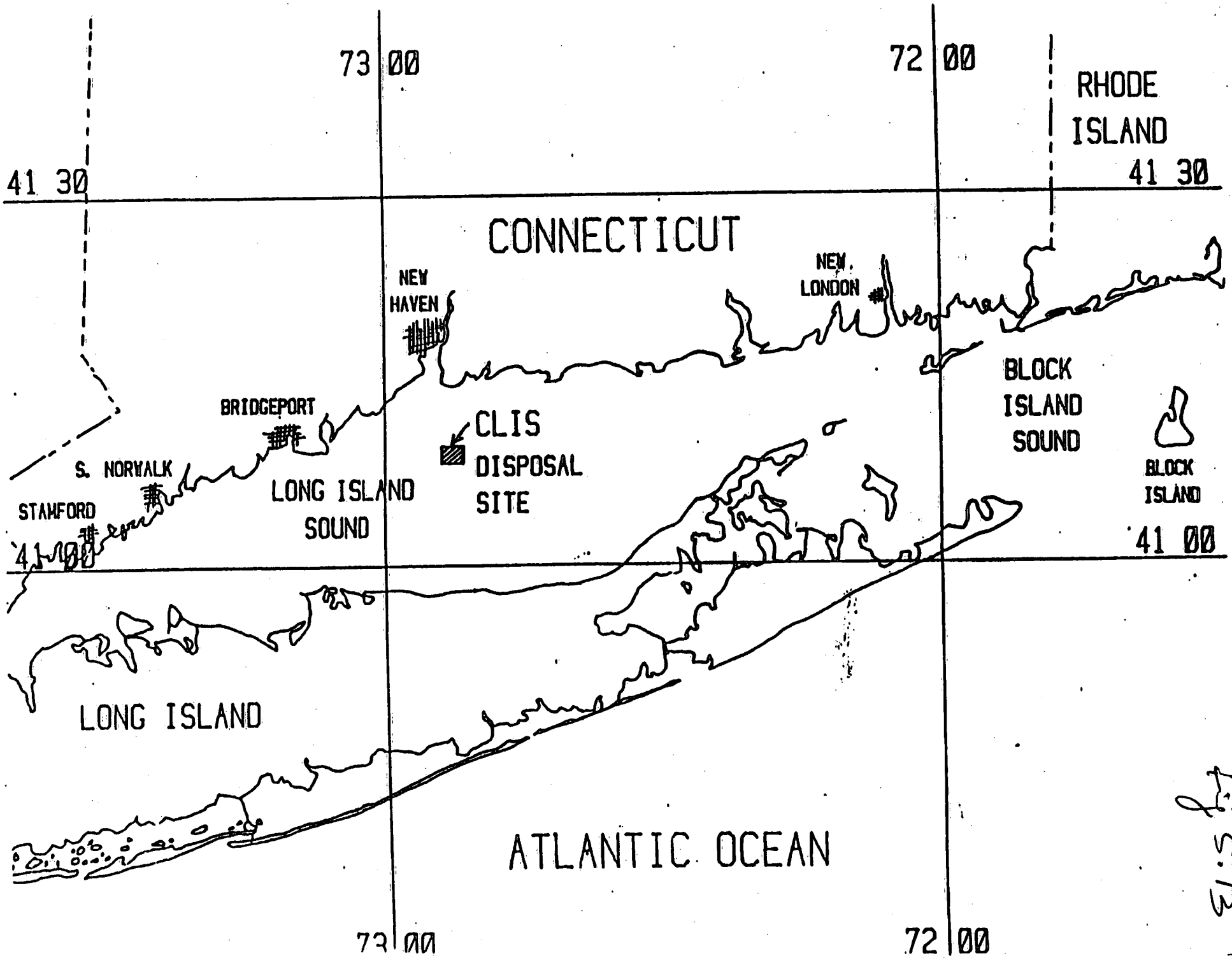
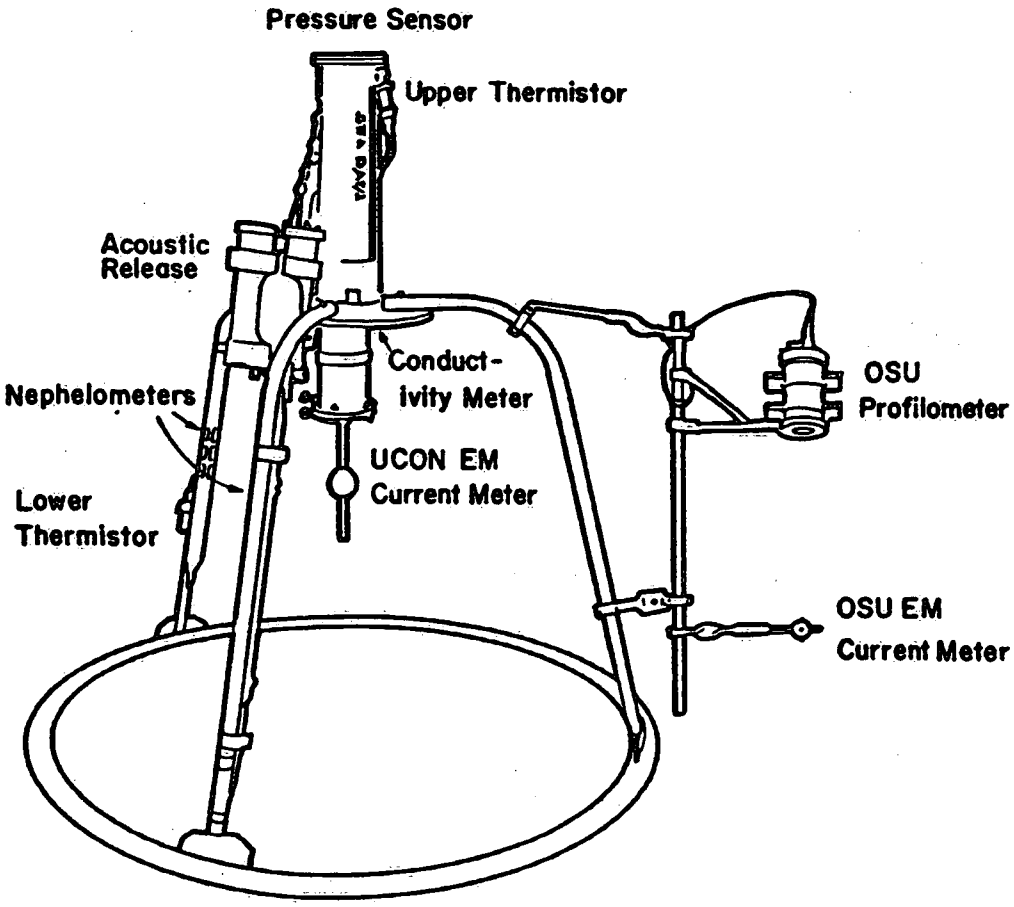

73 00
72 00
RHODE ISLAND
41 30
41 30
CONNECTICUT
NEW HAVEN
NEW LONDON
BLOCK ISLAND SOUND
BRIDGEPORT
CLIS DISPOSAL SITE
S. NORWALK
STAMFORD
LONG ISLAND SOUND
BLOCK ISLAND
41 00
41 00
LONG ISLAND
ATLANTIC OCEAN
73 00
72 00

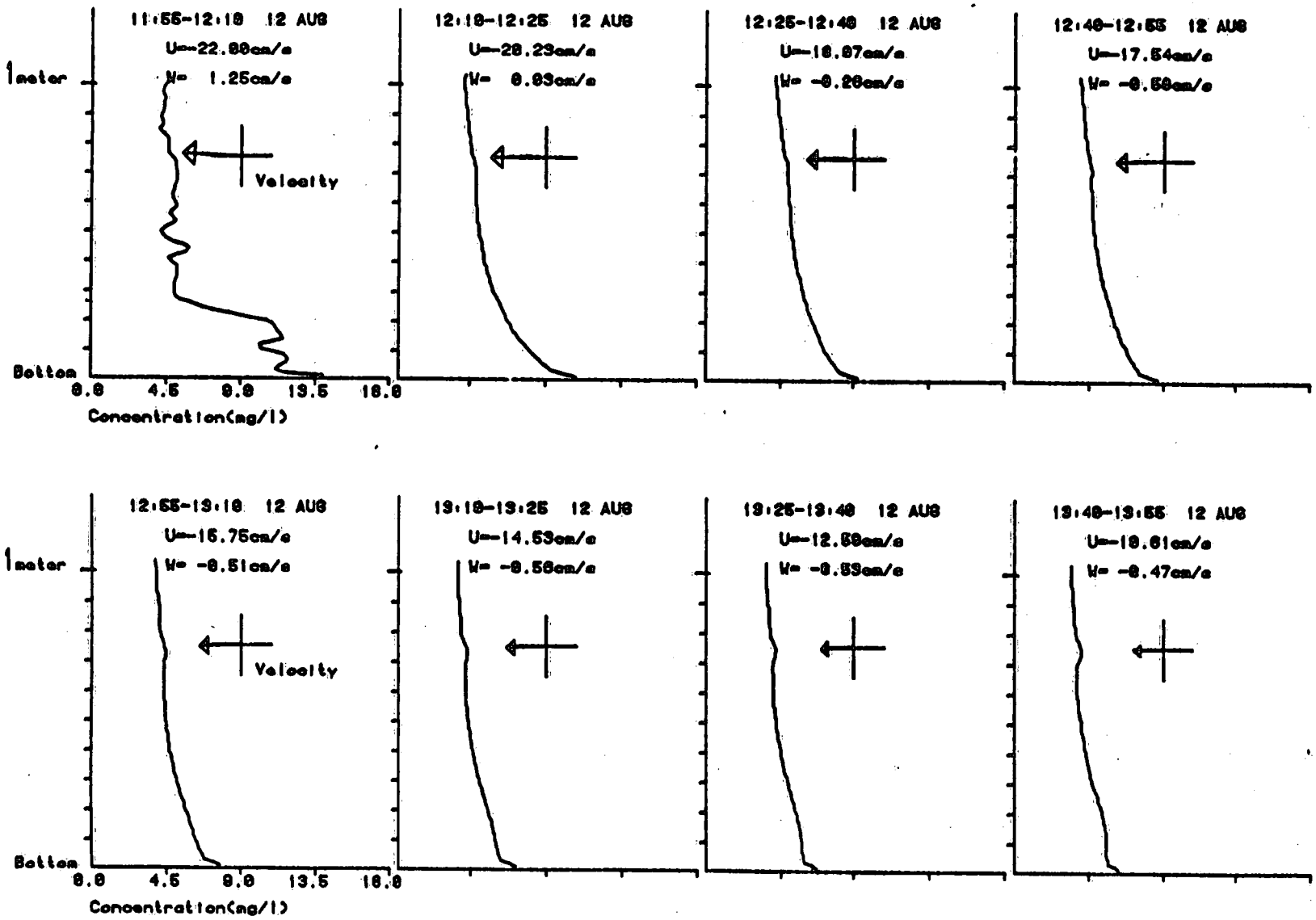
Fig 5.M

Fig 5.14



Instrumentation at Connecticut

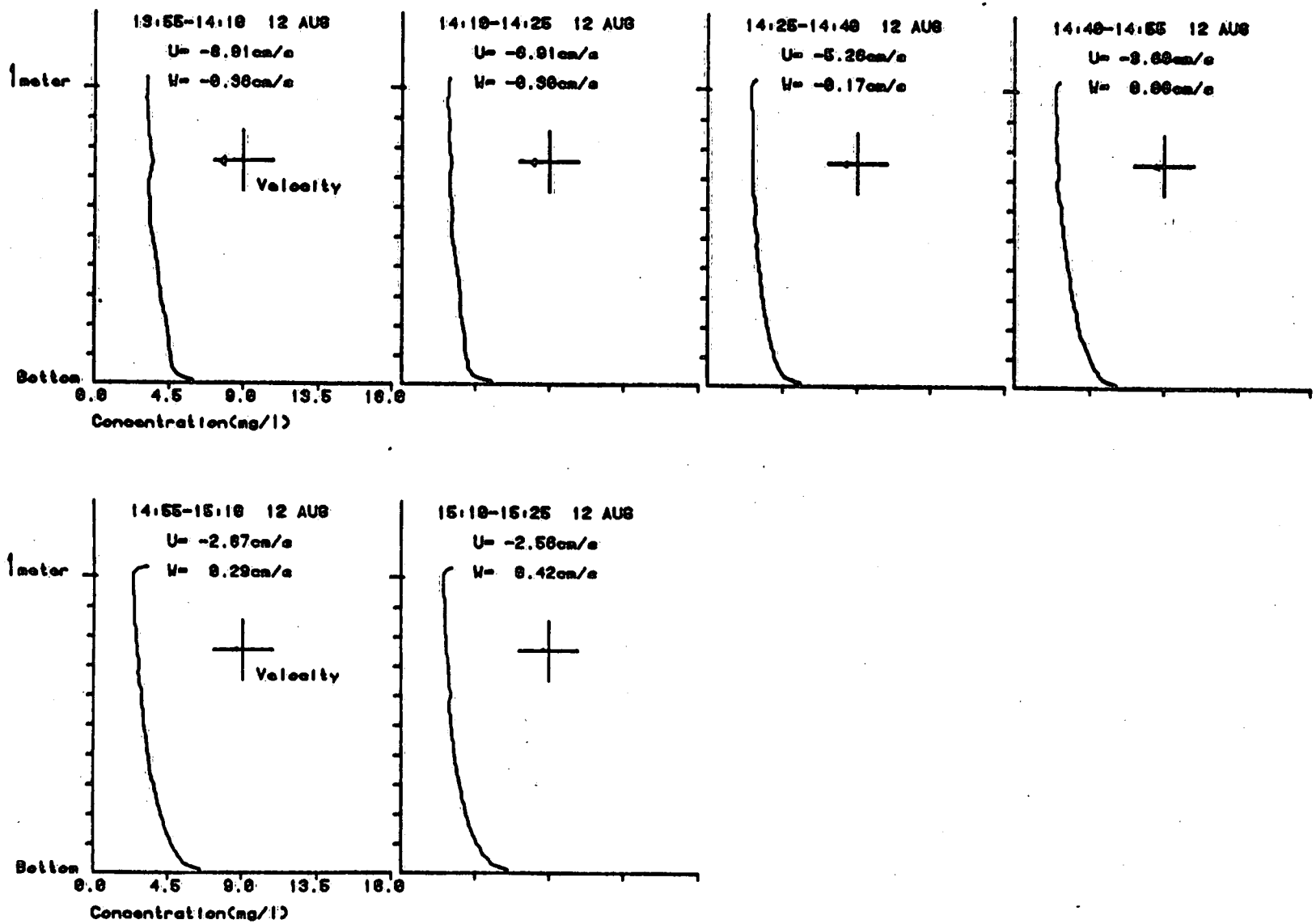
Concentration Profiles & Velocity Vectors



CONNECTICUT 1985, (Continuous segments, 15-min. averaged)

Fig 5.15

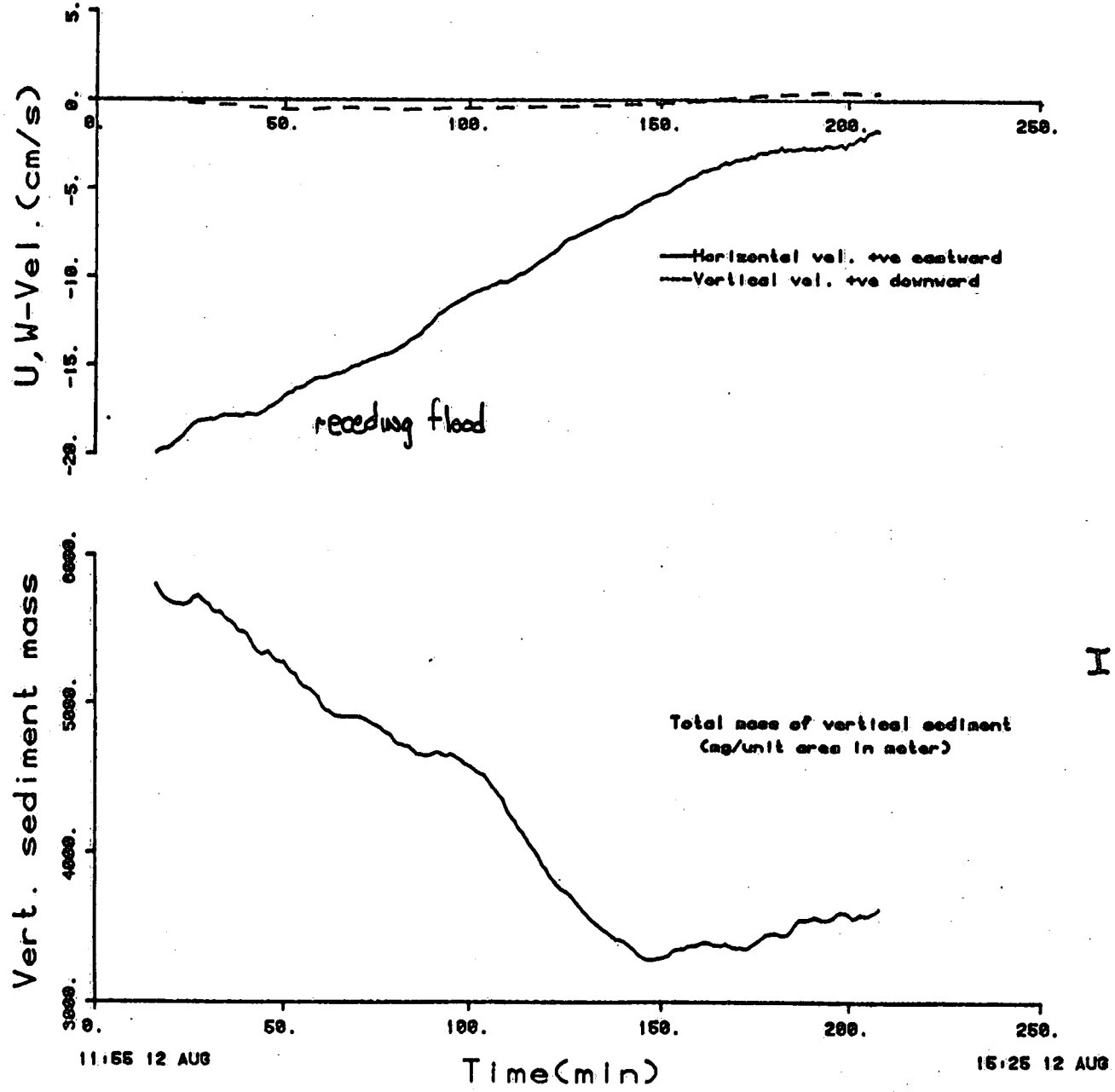
Concentration Profiles & Velocity Vectors



CONNECTICUT 1985, (Continuous segments, 15-min. averaged)

Fig 5.16

U,W - Velocity & Total Mass of Vertical Sediment Plots

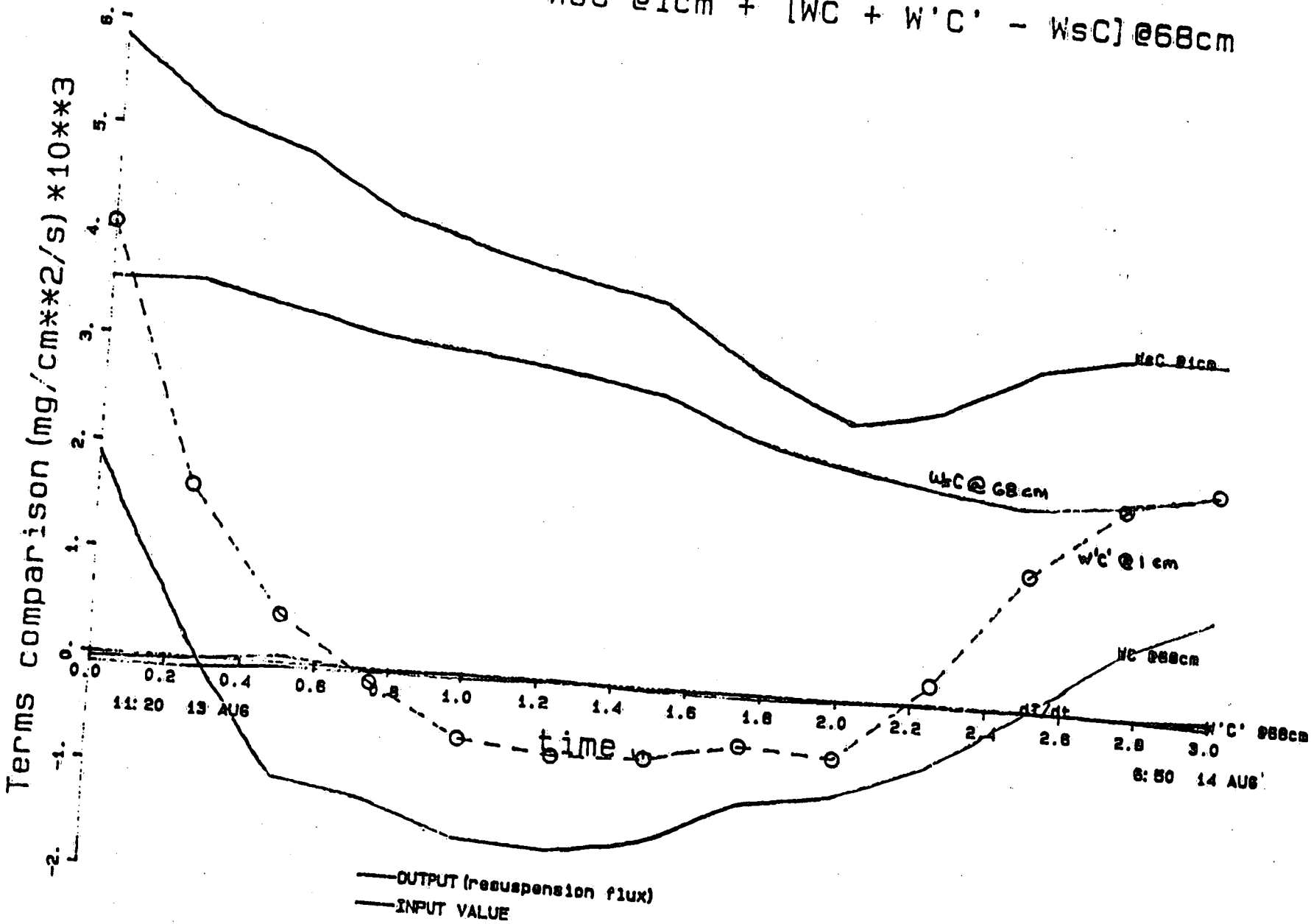


$$I = \int_0^{100cm} c\,dz$$

CONNECTICUT 1985, (Continuous segments, 15-min. averaged)

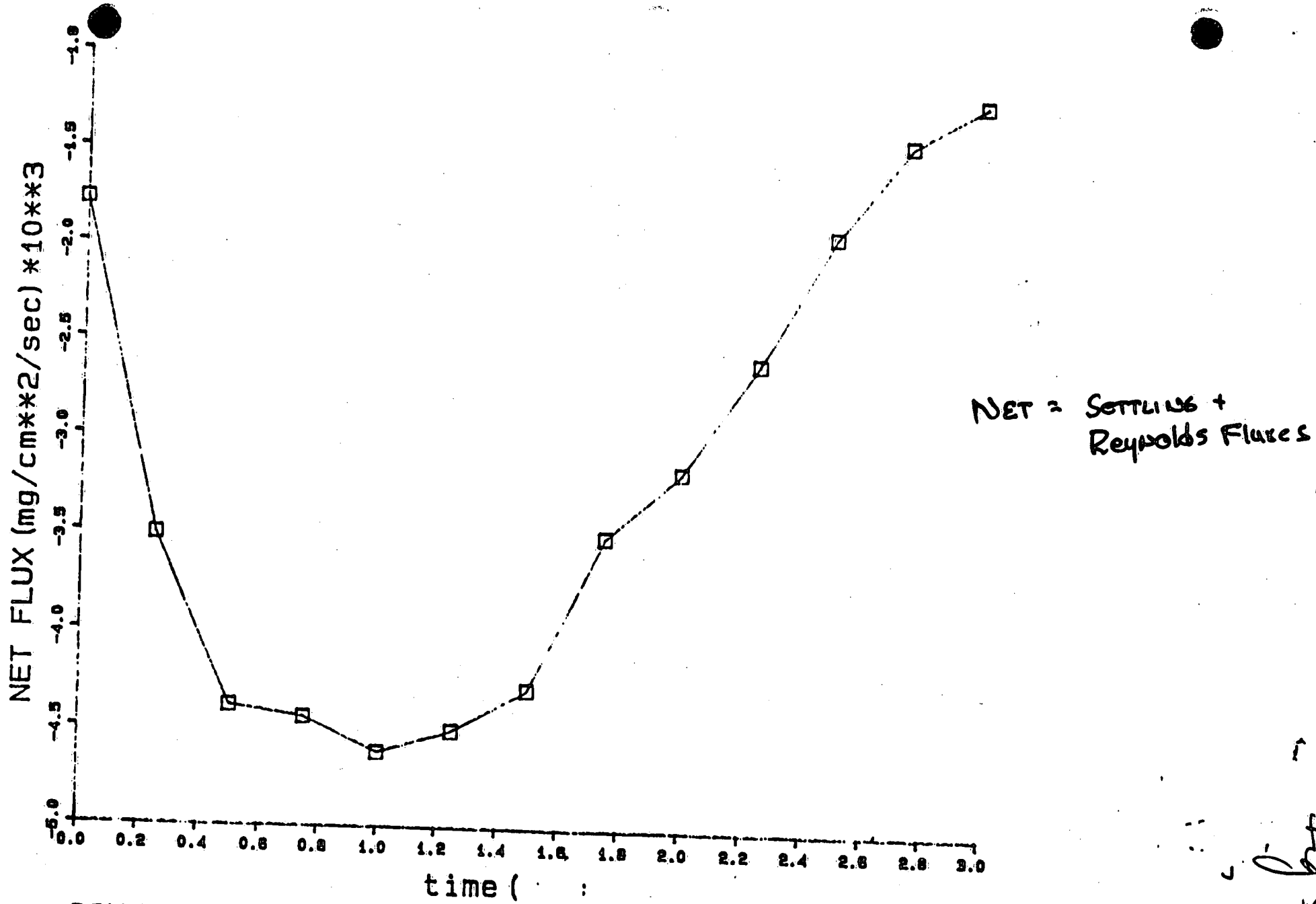
Fig 5.17

W'C' @1cm = dI/dt + WsC @1cm + [WC + W'C' - WsC] @68cm



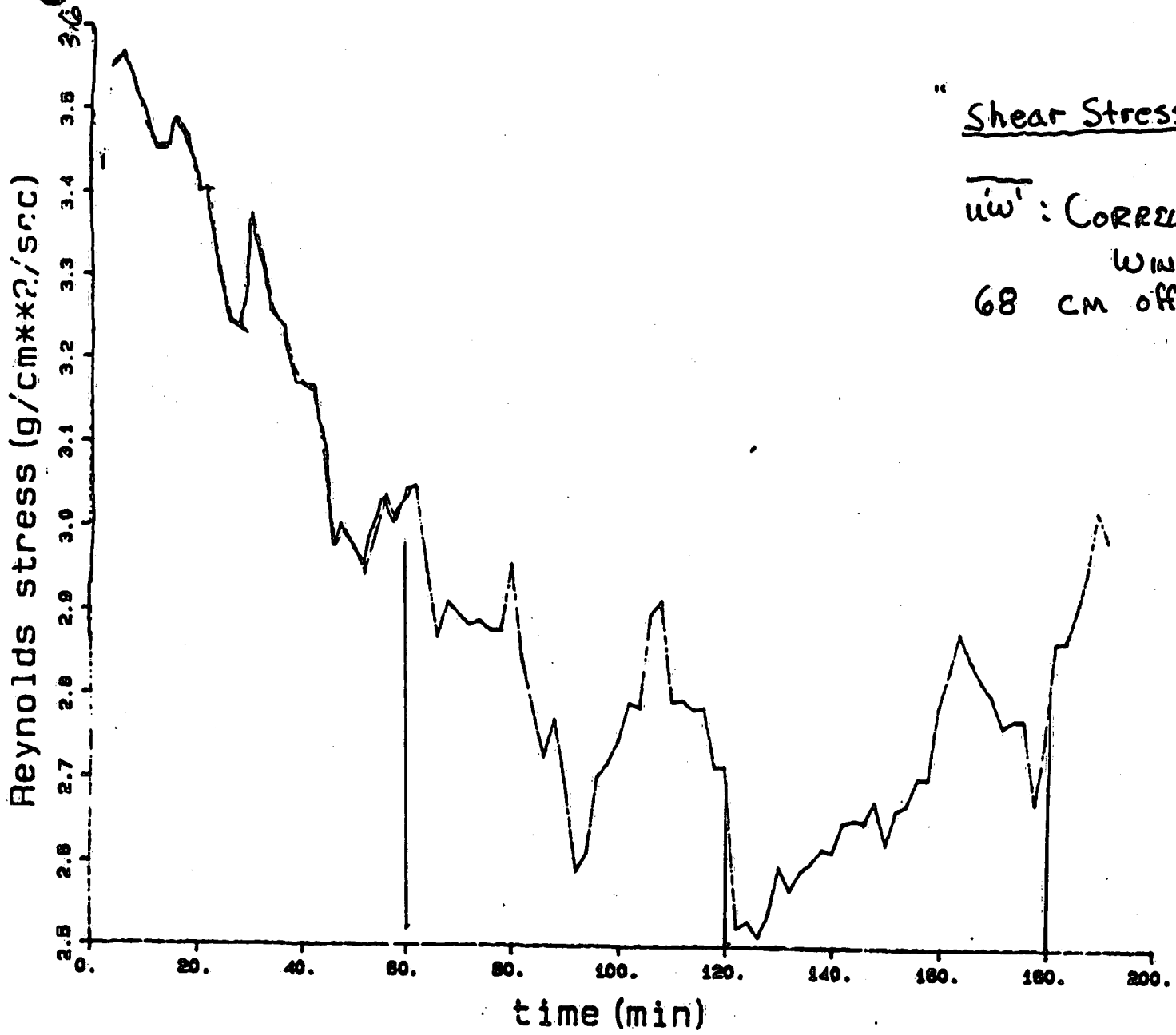
CONNECTICUT 1985, (Continuous segment, 15-min averaged)

Fig 5.18



CONNECTICUT 1985. (Continuous segment. 15-min averaged)

Fig 5.19



"Shear Stress"

$\overline{u'w'}$: CORRELATION ; 1 MIN AVG WINDOW

68 CM off BOTTOM

CENTRAL LONG ISLAND SOUND (CONTINUOUS)

Fig 5.20

6. Sediment Contaminant Interactions. What Information is Needed? (B. Oliver)

A fraction of the contaminants introduced into the water column will be absorbed onto the particulate material suspended in the water. The ratio of the contaminant concentration in the sediments to the concentration in the water defines a partitioning coefficient. The coefficient, particular to a given contaminant, is "normalized" for the presence of organic carbon. In order to determine the fraction of contaminant dissolved in the water, one must know the "normalized" partition coefficient and the suspended solid concentration in the water (Figure 6.1 and 6.2).

Information Needed for UGLCC Study

- Suspended sediment concentrations as a function of season (long time scales) and weather (shorter time scales).

- Concentrations of contaminants in the suspended solids.

- Rates of release of chemicals from in-place sediments on the lake or river bed.

- Fate of particles in the system - the portion transiting, the portion ultimately buried.

Lake Ontario.

Figure 6.3 shows the estimated masses of some chlorobenzenes in Lake Ontario compartments. Total quantities in the sediments are two orders of magnitude greater than the amounts in the water column. The partitioning coefficient for these substances is a function of solids concentration. The rate of desorption of materials from contaminated sediments into the water column is a marked function of water temperature. Timescales for significant (50%) desorption of 1,3,5 -TCB range from 200 hours at 40 C to 2000 hours at 4 C. Assuming that a sediment layer 1mm thick is in a constant state of flux (resuspension and settling) and that the bottom temperature remains close to 4 C, rates of contaminant loading due to sediment desorption are calculated. While these loadings are small compared to inputs from the Niagara River, they are not insignificant.

Information Needed for Lake Ontario (similar to list above for UGLCC).

- Rates of sediment resuspension in bottom waters.

- Residence times of particles in the water column.

- Suspended solids concentrations as a function of depth.

- Contaminant concentrations on suspended solids .

- Release rates from sediments for various chemicals.

- Release rates via diffusion from pore water.

- Impact of bioturbation on resuspension and chemical release (physical mixing at sediment surface, ingestion at depth and release at surface, pelletization).

In summary, lack of knowledge of contaminant/bottom sediment/suspended sediment/water interaction leads to uncertainty in assessing the effects and fate of contaminants in aquatic ecosystems. More work is required in order to understand and to quantify the chemical, biological, and physical processes involved. Well-coordinated multidisciplinary studies are strongly recommended.

Figure 6.1

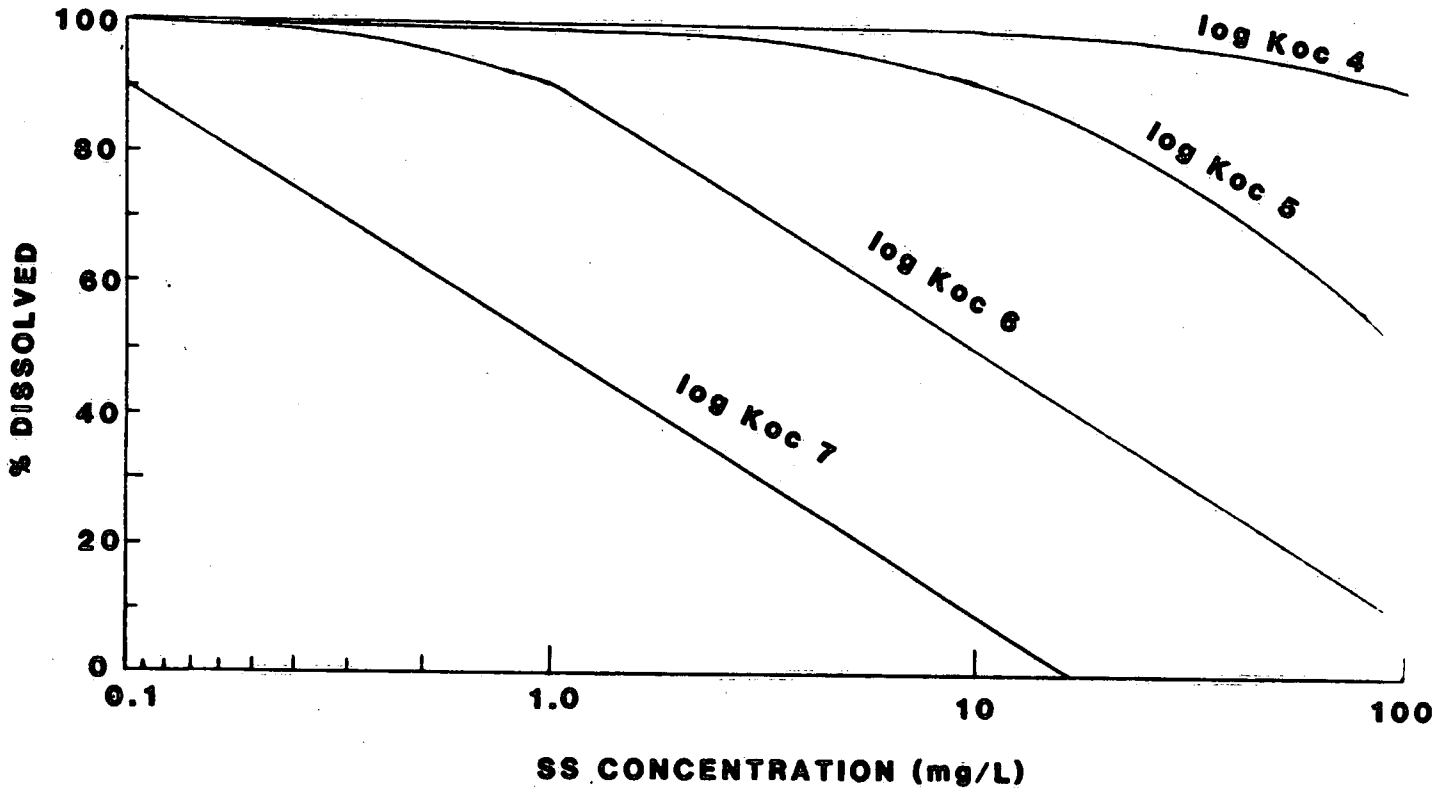

100
80
60
40
20
0
% DISSOLVED
0.1
1.0
10
100
SS CONCENTRATION (mg/L)
log Koc 4
log Koc 5
log Koc 6
log Koc 7

Figure 6.2

IMPORTANCE OF SUSPENDED SEDIMENTS ON CONTAMINANT TRANSPORT IN DETROIT RIVER (5mg/L)

	%WATER	%SS	logKoc	logKow
HCE	99	1	4.0	3.6
HCBD	90	10	5.3	4.8
HCB	56	44	6.1	5.5
OCS	45	55	6.5	6.2
PCB's	45	55	-	-

Figure 6.3

Masses of CB's in Lake Ontario Compartments (kgs)

Compartment	1,2,4-TCB	1,2,3,4-TeCB	QCB	HCB
Bottom Sediments	11,000	3300	4100	8500
Lakewater	700	210	90	90
Suspended Sediments	10	4	4	9
Biota	2	2	2	8

7. Modelling the Sediment-Water Interface. What Information is Needed? (D. Lam and E. Halfon)

The modelling of sediment/water/nutrient interaction was seriously undertaken more than a decade ago by Lam and Jacquet in their simulation of internal phosphorus loading to Lake Erie. The algorithms developed for this model stayed close to physical theory and consequently involved many parameters. A somewhat different approach has been taken in Lake St. Clair, essentially that of a control volume bounded below by the sediment/water interface and by the free surface above. Very simple paramterizations of the resuspension flux and the settling flux are proposed (Figure 7.1). The data from the late-fall shallow water wave experiment (Skafel and Donelan) has been used to test this approach (Figures 7.2 and 7.3). This model development requires concurrent measurements of winds, waves, concentrations of suspended solids and accumulated sedimentation in traps.

A sediment resuspension model developed by Ackers and White, 1973 (Sediment transport: new approach and analysis. J. Hydraulics Div. ASCE, 99:2041-2060) has been modified by Krishnappan and subsequently used by Halfon in the model TOXFATE to simulate the movement of toxid contaminants from the bottom sediments into the water column of Lake Ontario. The energy predicted by this model at the sediment/water interface is similar to that measured by Charlton at several Lake Ontario sites. The model shows that predicition of the fate of contaminants in the Great Lakes depends strongly accurate estimates of sediment resuspension and of the diffusion of contaminants out of the bottom sediments remaining in place. As pointed out by Oliver (this report), bottom sediments contain a large percentage of some of the toxic contaminants found in lake ecosystems.

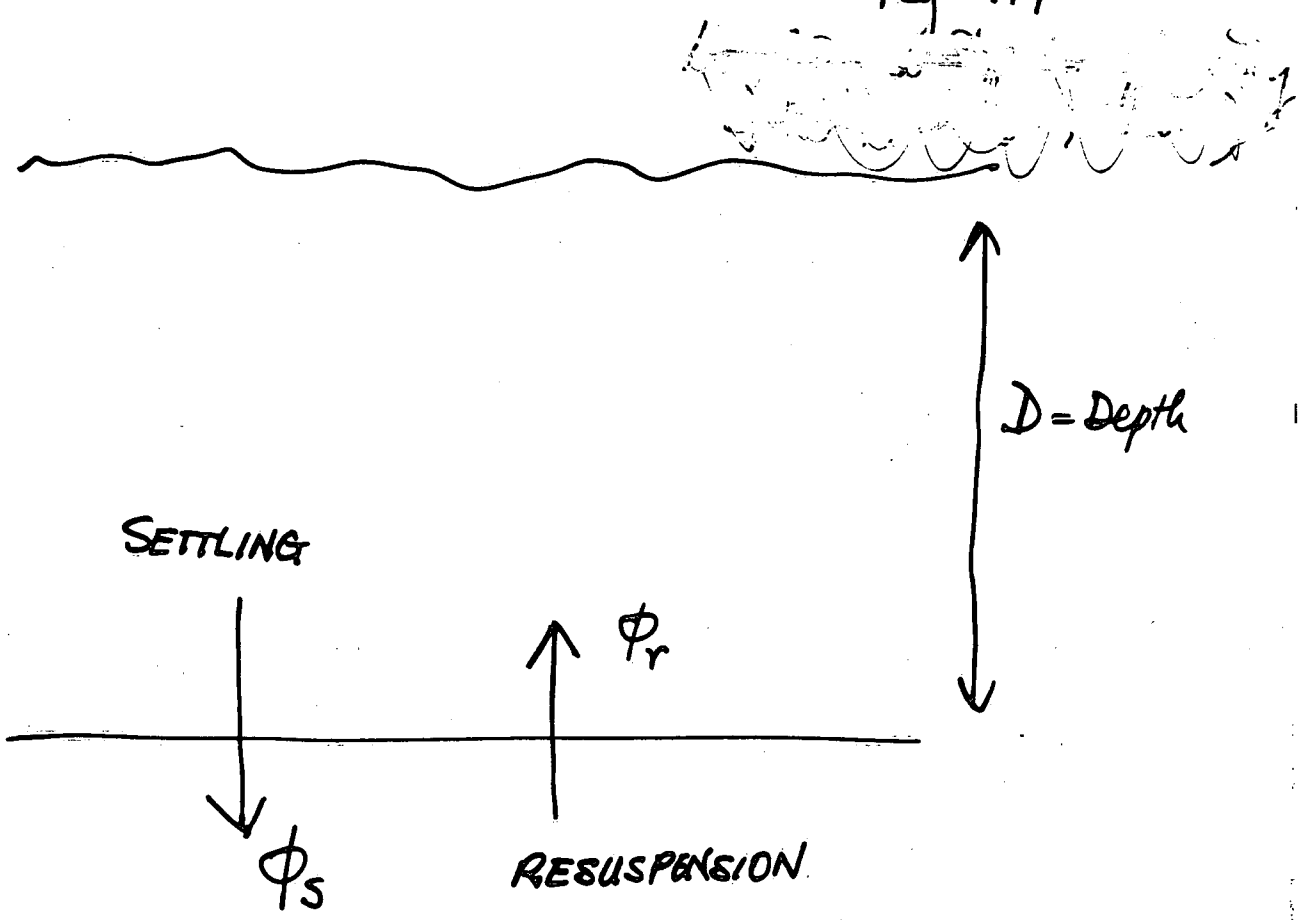
Clearly, and for many reasons, suspended sediment concentrations will vary with distance from the bottom. Contaminant concentrations in the suspended sediments and the bioavailability of contaminants depends on the desorption rate of the contaminant from the sediment. These rates have to be provided by environmental toxicologists while the sediment fluxes are provided by physicists and geologists.

Ecological modelers require algorithms for computing the mass of sediment resuspended as a function of energy conditions at the bottom computed from winds and bottom topography and of the physical properties of the sediment in place.

The total trajectory of toxic contaminants in Lake Ontario from introduction to final disposal is played out with a timescale of many years. The modelling of long-term lake-wide effects requires

a parameterization of short-term, local processes. One can imagine a "sediment climatology" of a major basin with spatial zones defined according to water depth, bottom material, exposure to storms, position relative to sources of sediments and contaminants, and other factors. This knowledge could be developed in a qualitative way following some exploratory fieldwork. The challenge would then be to synthesize the results into a plausible and verifiable overall model.

Fig 7.1



$$D\frac{dc}{dt} = \phi_r - \phi_s$$

$$\phi_r = R(u - u_c) \quad g\,m^{-2}h^{-1}$$

$$\phi_s = S \cdot c \quad g\,m^{-2}h^{-1}$$

$$\frac{dc}{dt} = r(u - u_c) - \sigma c \qquad r = \frac{R}{D},\ \sigma = \frac{S}{D}$$

Fig 7.2

SKAFEL, M.G. AND M.A. DONELAN: SETTLING AND RESUSPENSION OF FINE SEDIMENT BY WAVES (IN PREPARATION)

NOTE: ANALYSIS NOT COMPLETED, PRELIMINARY DATA

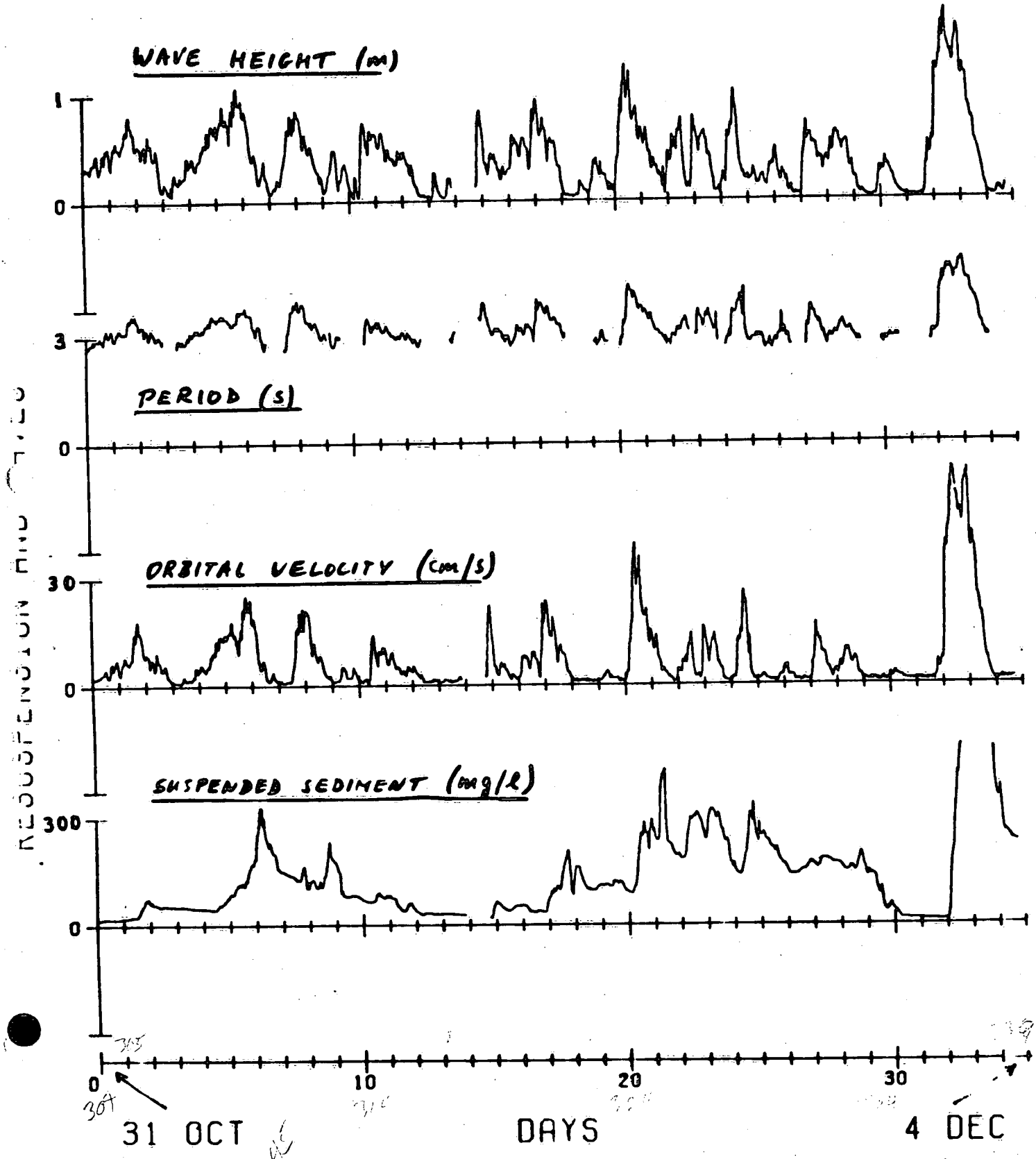
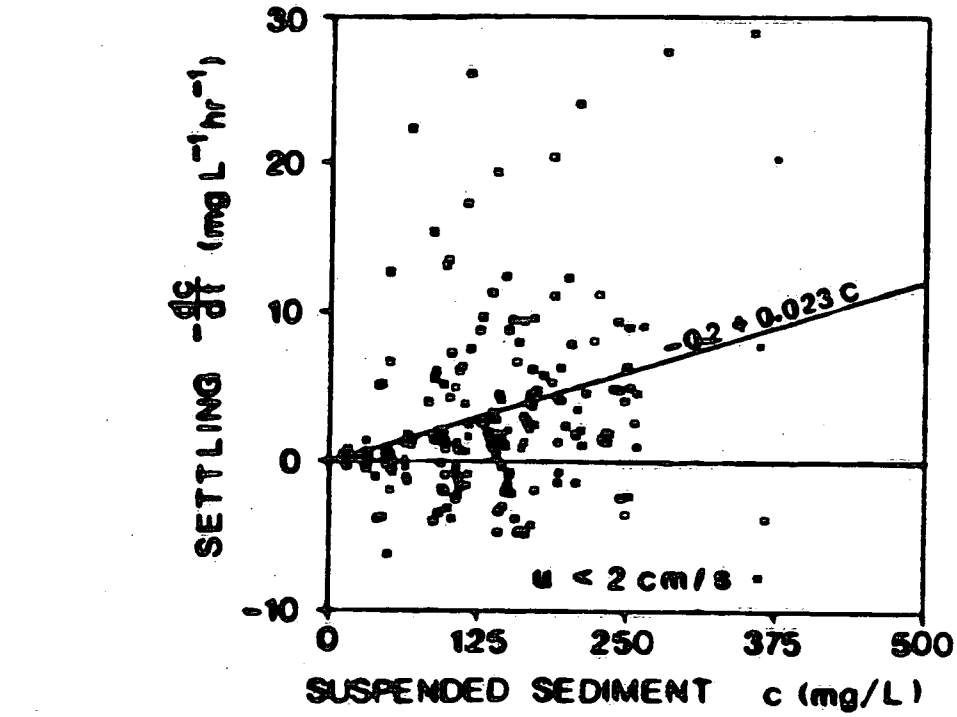
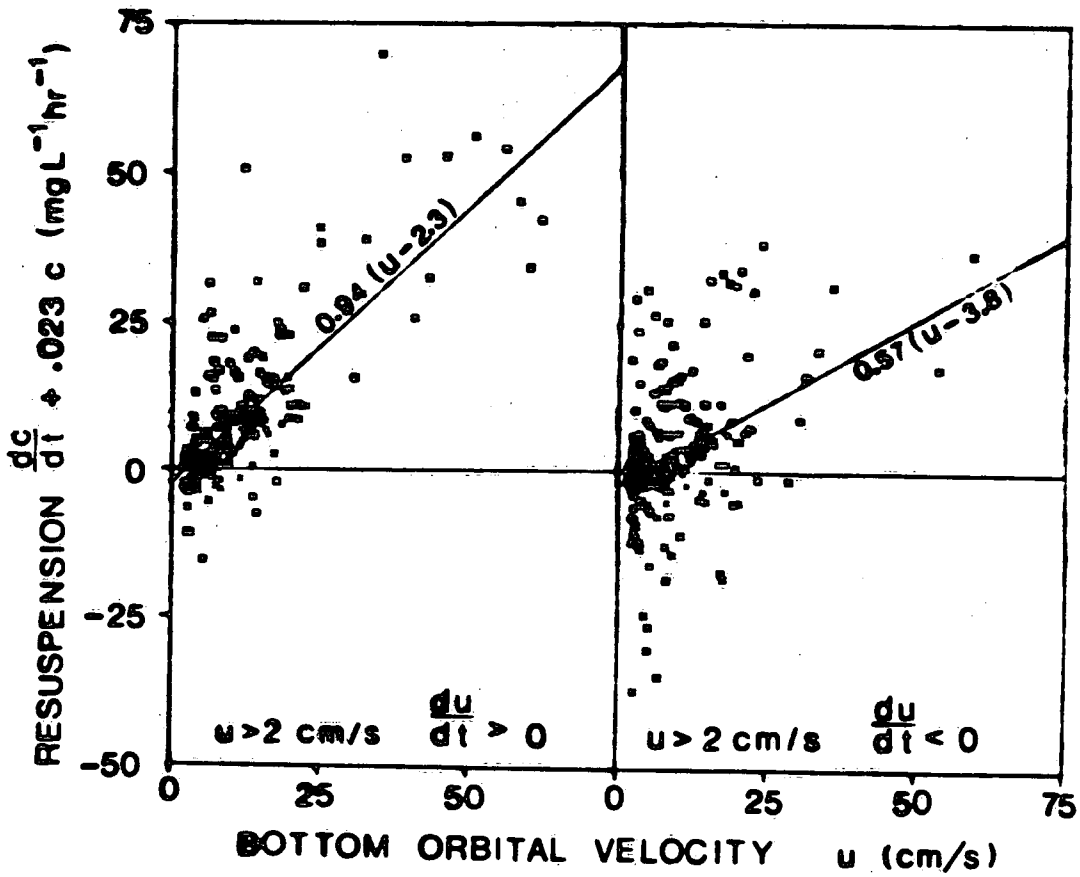


Fig 7.3


SETTLING $-\frac{dc}{dt}$ (mg L^{-1}hr^{-1})
30
20
10
0
-10
-0.2 + 0.023 C
u < 2 cm/s
0
125
250
375
500
SUSPENDED SEDIMENT c (mg/L)


RESUSPENSION $\frac{dc}{dt}$ + .023 c (mg L^{-1}hr^{-1})
75
50
25
0
-25
-50
0.94 (u-2.3)
0.57 (u-3.8)
u>2 cm/s $\frac{du}{dt}$ > 0
u>2 cm/s $\frac{du}{dt}$ < 0
0
25
50
0
25
50
75
BOTTOM ORBITAL VELOCITY u (cm/s)

8. Summary and Conclusions. General Philosophy. Short Term - Lake St. Clair, 1986. Long Term Prospects. (F.M. Boyce, P.F. Hamblin, M. Skafel)

The range of sediment-related problems of legitimate concern to NWRI is large. The movement of unconsolidated material (sand and silt) in the nearshore zone is primarily a civil-engineering problem but interfaces other disciplines to the extent that bottom topography influences water exchanges, weed growth, etc. The Hydraulics Divsion has been actively engaged in the study of shore processes for many years and has a broad network of contacts in Canada and abroad. The Canadian Coastal Sediment Study and others like it will serve to maintain and to extend that network. As the size-range of the suspended material decreases, and as its organic content increases, the prospects for interaction among nutrients, contaminants, and water increase. In this workshop, we are primarily concerned with these possibilities, and especially with the relations between physical movements of suspended material and the partitioning of nutrients and contaminants through the system. Nevertheless, the evironments in which these actions can be expected to take place range from the wave-dominated surf zone to the current-dominated abyssal zones. Special emphasis is given here to the Upper Great Lakes Connecting Channel Studies by virtue of our experience and our immediate obligations to them.

The contribution of physical studies to these problems is locally, one of relating the degree of physical agitation of the water column to the fluxes and concentrations of suspended materials, and lake-wide, one of determining the transport of suspended materials by horrizontal currents. The existence of several overlapping flow regimes/boundary layer configurations is a powerful argument for an empirical approach to the problem rather than an attempt to fit a set of measurements to a particular theory. Verifications and improvements to theories may arise out of the work, but the search for these is not the driving force. At this stage of our understanding, a strong case can be made for the collection of simple, long-term measurements of a variety of suspended sediment parameters. These basic data may then lead to the formulation of more accurate simulations and a more realistic theoretical framework than are now available.

Physical Agitation.

Near the bottom, fluid motion is constrained to move parallel to the bottom and vertical turbulence scales with distance from the boundary. Time scales of deterministic or non-random motion range from those associated with surface waves (periods as short as 3 seconds) to motions that may be considered as essentially steady. The simplest "agitation" measurement is thus a horizontal velocity sampled so as to allow for the documentation of both

short and long-period motions. Such measurements, made at a standard reference height may serve as a convenient parameter for the estimation of bottom stress or for the detection of agitation thresholds for resuspension (Lesht and Hawley, personal communication). A closely-spaced vertical array of such measurements constitutes a mean boundary layer profile approach. A direct estimate of the vertical turbulent flux of suspended material can be obtained in principle from simultaneous measurements of vertical velocity and concentration.

Concerning the location of the measurements above the bottom, we note that earlier work has often selected the 1 m level in the same sense that meteorologists choose the 10 m height as the standard reference elevation for wind measurements. Accurate vertical postitioning is less critical at this height because vertical gradients decrease with distance from the bottom. For very smooth boundaries, the 1m height may lie outside the region of strong curvature of the velocity profile. On the other hand, Saylor and Miller report at the latest Great Lakes Conference on a logarithmic velocity profile above the bottom of Lake Michigan that is at least 10 m thick. Sampling below 1m height is recommended, preferrably at two levels - as close as possible to the bottom, given the instrument configuration, and at a level intermediate between the two positions. The desirability of sampling above the 1m height depends on the particular field situation.

Three basic methods of velocity measurement are available as stand alone, self-recording instruments, impellor type, electromagnetic, and acoustic. The impellor instruments perform poorly in sediment-laden water; their threshold speeds, already high, tend to increase as the bearings degenerate. Electromagnetic current meters, in our experience are not sufficiently stable to measure reliably the low speeds sometimes encountered. The larger ones perform badly in oscillatory flows because of interfering eddies generated by the large measuring head. Acoustic current meters work better at low speeds and their structure is open enough to avoid severe contamination by eddy-shedding.

A minimum sampling frequency of 1 hz is required to track oscillatory motion due to surface waves. Turbulent flux measurements would require even faster sampling. At these rates, the data storage capacity of the recording system is soon used up. The burst-sampling strategy assumes that the wave conditions vary relatively slowly so that a period of high speed sampling may be alternated with a period of slow sampling. The length of the high-speed burst is chosen to yield stable statistical properties of the sample. In order to preserve phase information between sensor levels, sensor activation and recording should be centralized in a single micro-processor-controlled data logger.

Horizontal transport of suspended material by large-scale flows is not discussed here. Development of transport models is a continuing process at NWRI. Special attention is required to account for the non-uniform distribution of suspended material in the water column.

Sediment Concentration.

It would be desirable to obtain vertical distributions of suspended sediments and their properties. Charlton has demonstrated how the organic fraction of the material is a clue to its origin. Size distribution of the particles and settling rates would also be useful information. Unfortunately, it is very difficult even to approach a complete and defining suite of measurements. Optical properties of sediment suspensions (transmission or scattering) are often used to infer sediment concentrations. This approach requires careful and frequent calibration since the optical properties depend strongly on both the size distribution of the suspended materials and its concentration. Acoustic backscattering measurements have been developed by Bedford and others. The more sophisticated techniques offer excellent spatial resolution in the vertical but, like the optical methods, are potentially ambiguous. The rapidity with which information can be collected permits the visualization of intermittent resuspension processes. Data-gathering rates are high and the system requires complex onboard data-processing. Frequent calibration is required.

Direct water sample collection offers the most reliable method of "calibrating" the indirect optical and acoustic procedures. Unless this can be automated, the supporting sample collection will be sparse and biased to fair weather. Automated water samplers have been developed at NWRI and others are available commercially. Although the process appears straightforward, careful engineering is required to ensure reliability, and there are potential problems of samples undergoing changes with storage. One possibility would be to automate the seston filtering procedure by building a machine similar to an automatic air-quality monitoring device. Sediment traps should be considered as a low-cost adjoint to water sample collection.

1986 Lake St. Clair Program.

The open-lake measurements made in 1985 suggest that resuspension events are relatively rare. Two such episodes were observed (see Lesht's records, this report) and it cannot be ruled out entirely that the decreased optical transmission is the result of sediment tranported into Lake St. Clair from Lake Huron. Examination of a collection of satellite images of Lake St. Clair assembled by Bukata and his colleagues shows only occasional sediment plumes in the main body of the lake that can be unequivocally associated with input from the St. Clair River. Such a plume would transit

the lake within days and given the infrequent passages of the satellite (once in 15 days during 1985), the chances of observing the leading edge of the plume as it exits the St.-Clair River are small. On the other hand, almost all the images show a band of high surface turbidity along the south and east shore. The expanse of this plume suggests that it is most probably material resuspended by surface wave action on the shore located downwind of the prevailing winds. Transport to the Detroit River entrance is less vigourous in this zone; it is not swept clear in a few days like the main body of the lake. Tentatively then, we identify two regimes coexisting in the Lake, a transport-dominated regime in the central part of the lake with infrequent resuspension, and a zone to the southeast that is somewhat decoupled from the hydraulic flow but is exposed to larger surface wave effects. In the second zone, resuspension is a frequent occurrence; the sediments and the water are strongly and physically coupled.

The lack of correspondence between the occasional velocity profiles measured at a mid-lake site in 1985 and those calculated from a circulation model suggests that the distribution of eddy viscosity is poorly known, particularly the contribution made by surface waves. Thus, in addition to the bottom boundary layer, velocity measurements should extend through the entire water column. Initially, a profiling device was suggested, capitalizing on our experience with the GVAPS system. However, the necessity to collect many samples at the high-speed rate in order to form stable averages meant that the profiling cycle would be too long. We decided then to place 5 of the Neil Brown vector-averageing current meters on a guyed tower (see Figure 8.1). The nominal distribution of the instruments in the vertical will be three in the first metre above the bottom and the remaining three in the upper part of the water column. Two of the current meters at the 1 m level will be oriented to measure the vertical component of velocity. The other instruments will be modified to allow the electronics cylinder to lie horizontally, instead of vertically, and thus to reduce the mutual flow interference of a closely spaced vertical array of current meters. The microprocessor aboard each current meter will be reprogrammed to form averages over each high-speed burst and to store them in the instrument's memory. The individual velocity components will be passed to a central data logging and controlling device mounted on the emergent part of the tower. Three transmissometers will be mounted on the tower and recorded separately but synchronously with the current meter measurements. Figure 8.1 summarizes the configuration. None of the recording devices in use at NWRI have the capacity to handle the large amount of data generated by five simultaneously operating current meters. Optically encoded disks look attractive but are as yet unproven in a difficult field environment. Instead we are relying on a frequency-modulated digital encoding system available to the current meter and the high information storage capacity of VHS video cassettes. The

drawback of this approach is the necessity to play back the tape at the original recording speed. This tower-mounted array will be located in 6m of water approximately 7 km northwest of the mouth of the Thames River (42 22.4'N by 82 30.5'W). This location is on the lakeward edge of the persistent band of high surface turbidity that is observed from the satellite.

Additional suspended sediment measurements will be made at a second tower located close to the current meter tower. The 4m Kenney Sampler and the wave and tide recorder will be installed here. At this tower too, we anticipate installing the Ohio State acoustic back-scattering suspended sediment profiler and to provide ship and launch support for its operation.

Two satellite stations consisting of a current meter and transmissometer at 1m above bottom will be installed at two inshore locations on either side of the Thames River mouth (42 20.8'N by 82 27.3'W, 42 19.7'N by 82 30.2'W). With a horizontal array of recording instruments, we should be able to distinguish between local resuspension events and the advection of turbid water from nearshore.

Servicing the tower mounted instruments will consume a large part of the available ship and launch time. The tape in the current meter array recorder will have to be replaced every few days. The Ohio State University system needs lifting and replacing at frequent intervals. While the vessel is at the tower site for these purposes, the opportunity should be taken to change the bottles in the Kenney sampler and to collect a number of transmission profiles both at the central and satellite stations. At other times the vessels will be used to collect quasi-synoptic transmission and temperature profiles, seston samples and other data on a network of mid-lake stations.

The information collected at the two main towers will be valuable input to the modelling program; an empirically-based formulation of the effective vertical eddy viscosity will allow more accurate prediction of the horizontal transport of water and suspended materials, the resuspension experiment will provide a data set for the development of the control-volume approach proposed in Article 7. Lakewide transmissomter and temperature surveys, supported by seston sampling, will test the working hypothesis of the two sediment regimes alluded to above. They will add to the store of information on the general distribution of suspended material referred to in Article 6. What happens under an ice cover remains in the realm of semi-informed conjecture and a thorough program would include several winter helicopter surveys with a profiling current meter, water sampling, and transmissometer measurements. As a first step to quantifying the fate of suspended material in Lake St. Clair, we should attempt to form a suspended sediment budget by regular and closely space sampling of the main inflows and outflows of the

lake.

Long-Term Possibilities.

The work in Lake St. Clair will provide experience of a shallow, wave-dominated regime. The contrasting situation, as yet unexplored from the point of view of sediment-water interaction,, is the deep water of Lake Ontario. Wave orbital motions will be detectable only during the most severe storms. Above the near-bottom constant stress layer there will be a more fully developed Ekman boundary layer such as that found by Saylor and Miller in Lake Michigan. We expect that suspended sediment composition will vary significantly with depth so that a single curve relating optical transmission to sediment concentration will be inappropriate. Adapting to this experimental situation will require additional effort, but past experience with profiling systems such as the GVAPS and the experience gained in the UGLCCS will be valuable.

Long Term Goals

The present study in Lake St. Clair of the distribution of suspended sediments, their origins, transport, rates and sites of deposition and resuspension, has been clearly linked to the problem of the transport and fate of contaminants in the aquatic environment in Chapters 6 and 7. Knowledge of sediment resuspension and deposition in Lake St. Clair may be applied to the assessment of the impact of dredging spoil disposal in the lake, to the exchange of sediments between nearshore and offshore areas, including the influence of sediment-laden tributaries, and to bottom stirring by ships. Finally, the effect of a prolonged high water level with its concomitant increase in the loading of unconsolidated sediment from the shore may be examined.

The findings of the Lake St. Clair study may be applied to other shallow water bodies such as the Western Basin of Lake Erie, Lakes Winnipeg and Manitoba, and Lac St. Pierre of the St. Lawrence River.

In the longer term, it would be desirable to extend our studies of suspended sediments to deep water bodies as well. Nepheloid layers in the deep open waters of Lakes Ontario, Michigan, Erie, and Georgian Bay have been identified, and similar structures are thought to exist in Lakes Huron and Superior. The role of sediments in the contaminant budget of Lake Ontario has been discussed in Chapter 6.

Expansion of the research program on suspended sediments initiated in Lake St. Clair to deeper waters will provide information useful in the mapping of contaminant pathways in

these water bodies. Such a program will require resources for instrumentation development in addition to the regular expenses for deployment and data analysis.

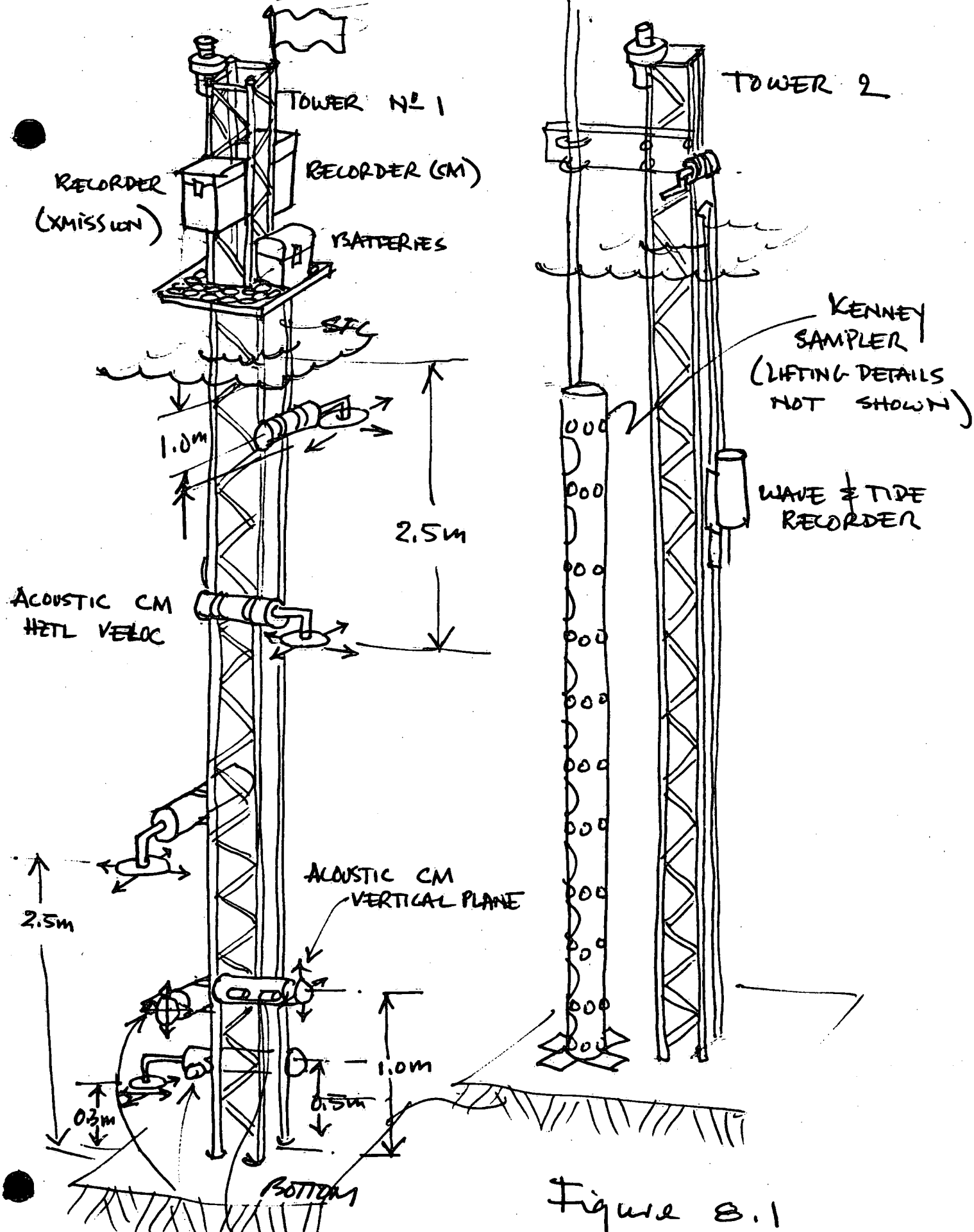


Figure 8.1
1986 Lake St Clair Experiment.
(proposed)