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REPORTS TO UGLCCS WORK GROUPS

by

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Environment Canada

MANAGEMENT PERSPECTIVE

The major findings up to April 1987 on the nature of the suspended sediments of Lake St. Clair, their movement in the lake and on associated simulation models are summarized in this report which was also submitted to the sediment and modelling working groups of the Upper Great Lakes Connecting Channels. The nature of the suspended sediment regime is required to determine Lake St. Clair's present and future role as a depositional area for contaminated sediments entering the Lake from the St. Clair River.

The principal finding of the study to date is that the condition for export of sediment from Lake St. Clair is quite restricted. Our observations indicate that waves of at least 50 cm in height and directed towards the Detroit River entrance are required for elevated Detroit River turbidities at the Windsor water intake. Since major northeasterly storms are quite rare in Lake St. Clair only several export events were obsered during each of the field seasons. The most severe storms resulted in no sediment export. Work continues on qualifying the sediment resuspension process in Lake St. Clair.

PERSPECTIVE-GESTION

Le rapport, présenté notamment aux groupes de travail sur les sédiments et sur la modélisation pour l'étude des canaux de communication entre les Grands Lacs d'amont (ECCGLA), résume les principaux résultats obtenus jusqu'à avril 1987 sur la nature et le mouvement des sédiments en suspension dans le lac Sainte-Claire ainsi que sur les modèles de simulation. On étudie la nature du régime des sédiments en suspension afin de déterminer le rôle présent et futur du lac Sainte-Claire en tant que zone de sédimentation des contaminants qui proviennent de la rivière Sainte-Claire.

ABSTRACT

Progress on the analysis and interpretation of field data collected in Lake St. Clair during the field seasons of 1985 and 1986 is discussed in this report which was also provided to the working groups of the Upper Great Lakes Channels Study in April, 1987. The first part deals with the physical characteristics of suspended sediments and their transport in the lake in suspension while the second part summarizes the major findings of mathematical modelling activities. Attention is devoted to the determination of the physical conditions under which sediment is exported out of Lake St. Clair into the Detroit River.

The principal finding of the study up to April 1987 is that the conditions for sediment export from Lake St. Clair are quite restricted. Our observations indicate that waves of at least 50 cm in height and directed towards the Detroit River entrance are required for elevated Detroit River turbidities at the Windsor water intake. Since major northeasterly storms are quite rare in Lake St. Clair only several export events were obsered during each of the field seasons. The most severe storms resulted in no sediment export. Work continues on qualifying the sediment resuspension process in Lake St. Clair.

RÉSUMÉ

Le rapport, présenté notamment en avril 1987 aux groupes de travail pour l'étude des canaux de communication entre les Grands Lacs d'amont (ECCGLA), indique les progrès de l'analyse et de l'interprétation des données recueillies sur le terrain, dans le lac Sainte-Claire, au cours des saisons 1985 et 1986. La première partie porte sur les caractéristiques et sur le transport des sédiments en suspension tandis que la seconde porte sur les principaux résultats de la modélisation mathématique. L'attention est centrée sur la détermination des conditions physiques du passage des sédiments du lac Sainte-Claire à la rivière Detroit.

1. PHYSICAL CHARACTERISTICS OF SUSPENDED SEDIMENTS

At Station 24 (see Figure 1) suspended sediment samples were collected at 10 levels during consecutive 3 to 7 day intervals through the field season of 1985 (see Marmoush (1986) and Marmoush and Smith (1986b) for details). Plots of the mean particle size and associated settling velocities are shown in Figures 2 and 3 based upon a laboratory size analysis. Similar analyses from Station 501 in the southeastern portion of Lake St. Clair during the field season of 1986 revealed that during the most energetic events the particle size distribution of the suspended sediments is bimodal (Figure 4a) with the fine sediment being most frequent in the size range 4 to 7 μm while the coarse fraction is estimated to be most frequent at 50 μm or greater. Particle size distributions for the less energetic periods are also bimodal. Figure 4b shows the vertical distribution of the percentage of coarse material having sizes of 22 μm or greater. It is seen that the sand fraction varies widely from one episode to another and, in general, increases towards the bottom. The sinking speeds corresponding to the modal sizes are 150 m/d for the coarse material and 2.6 m/d for the fine fraction. Suspended sediments are composed predominantly of inorganic material (about 90%) at this location.

2. SEDIMENT TRANSPORT

At Station 24 in 1985 (see Figure 1) a vertical column of 10 horizontal sediment traps collected sediments during 7 episodes. Shown in Figure 5 is the average catch per day at the 10 levels which may be interpreted as a horizontal flux ($g/m^2/s$) by multiplying the catch per day by 0.03. It is apparent that during most occasions the daily averaged horizontal sediment flux is within a background level of 18 $mg/(m^2s)$ but on 3 occasions rises to a maximum of 180 $mg/(m^2s)$. The highest occasion, October 2 to 11, 1985, coincides with the strongest wind event during the deployment on October 6. Similarly, the daily averaged horizontal sediment transport collected in 1986 behaves as in 1985 at the location 501 at the southeastern corner of the lake. Three of eight episodes are distinguished in Figure 6 above the background level of flux of about 18 $mg/(m^2s)$. The strongest horizontal flux occurred between September 30 and October 16 which probably originated from the most stormy condition on October 6 encountered during the experimental period. The instantaneous sediment flux on this day may be as high as 12000 $mg/(m^2s)$ based on the concentration shown on Figure 10 (d). The second most vigorous storm of November 4 occurred during the 7th episode, October 31 to November 5. Thus at both locations and years the horizontal sediment flux clearly responds to meteorlogical forcing. Instantaneous sediment flux at the nearshore Station 505 demonstrates a sharp rise in response to meteorological forcing on November 3 followed by a slower decay in Figure 15.

The spatial distribution of horizontal sediment flux is shown on Figure 7 as inferred from profiles of optical transmission, a relation established between optical transmission and suspended sediment concentration and the vertical profile of current as estimated from a 3-dimensional mathematical model of the wind and hydraulically forced circulation (Hamblin and Marmoush, 1986). The horizontal flux of sediment on September 14, 1985 (Figure 7) is probably typical of back-ground conditions prevalent between major storm events and thus tends to be greatest in the deepest and most swiftly flowing areas of Lake St. Clair. Unfortunately there are no lake-wide surveys of suspended sediment during extreme conditions.

River borne inputs of suspended sediments to Lake St. Clair from the St. Clair River have been calculated (Figure 8) from daily turbidities at water intake stations (Marmoush and Smith, 1986b). A notable event on November 11, 1985 which occurs on all four stations may be due to unusual meteorological conditions on Lake Huron. Winds on Lake St. Clair were northeast and not as strong as on October 6, 1985. Similar rapid increases of St. Clair River turbidity occur occasionally during the winter and early spring. The other major tributary, the Thames River, is not routinely monitored for turbidity. However, the daily turbidity at Tilbury, Figure 9, does indicate much higher values than at other nearshore stations in general which is probably due to the Thames River input. This is particularly the case on October 3, 1986. Tilbury is the only station which exhibits this peak value in contrast to the October 6 event which is apparent at Stoney Point, Tilbury and Belle River.

Another remarkable event in the nearshore suspended sediment regime occurs around December 1 and 2, 1986 and is one of the few events also present in the Detroit River at Windsor. This event is associated with waves of 1 m height on December 1 at Station 24 which may be compared with waves of 1.3 m on November 9. Since there is no response at Windsor on November 9 there must be some other explanation for the event of December 1.

Sediment resuspension was studied in Lake St. Clair in 1985 in order to determine the hydrodynamical conditions required for sediment resuspension. A vertical array of rapid response electromagnetic current meters was deployed at Station 24 for 3 weeks. An evaluation of the field performance of the sensors Hamblin et al. (1987) indicated that while the current meters were unsatisfactory as far as quantitative results they did at least provide some insight on the hydrodynamics. It was found that the orbital motions of the surface wind waves within 40 cm of the bottom were submerged within the general level of turbulent motions in the bottom boundary layer. However, during the somewhat unusual meteorlogical conditions when the hydraulic and wind driven circulations were opposed in the centre of the lake consequently reducing the bottom shear, wave orbital motions were detectable as close to the bottom as 20 cm. Under these conditions the linear theory and near-surface pressure fluctuations overestimate the near bottom orbital motions by about 30%.

At the time of writing the field data collected in 1986 have provided only qualitative insight to the sediment resuspension process. In Figure 10 (McCrimmon, 1987) the suspended sediment concentration near the bottom at Station 501 is compared to the near bottom orbital velocities at the same site and at Station 24, mid-lake, both inferred from near surface wave measurements and directly measured by a near-bottom current meter, and to the wind speed and direction measured also at the tower over the experimental period. It is seen that the suspended sediment concentration correlates closely with the orbital velocity of the waves and less directly with the wind speed and that the measured and inferred orbital velocities are close to one another especially during extreme conditions. More detailed behaviour of suspended sediment concentrations at 6 levels of measurement are shown in Figures 11 and 12 over the measurement period.

Analysis of the data collected at station 505 and 506 further supports the findings at the tower station, 501. In Figure 13 suspended sediment concentration at 505 is closely related to the orbital velocity measurements and to the near bottom shear (speed squared). Again there is a strong concentration peak (probably clipped) on October 6 and high level on October 14 to 17 which correlates well with the wave and orbital motion peaks shown on Figure 10. It is noted that the peak values are not registered properly since the standard deviation of the suspended sediment drops during the maximum. The data of Figure 13 are summarized statistically in the frequency diagram of Figure 14. It is seen that peak concentrations are associated with relatively strong flows to the southwest during the 17 day period of observation.

The question of the conditions required for export of suspended sediment into the Detroit River raised in the analysis of the 1986 data is examined further with reference to the 1985 data set. High turbidities at Windsor during the study period are seen in Figure 16 on October 21, November 2 and November 12 and on June 12 (not shown) (33 turbidity units). The waves on these occasions ranged from 45 to 60 cm as seen on Figure 17. As was the case in 1985, these were not the maximum wave events which occurred on June 1 and October 6. On these last two occasions winds were from the southwest direction as shown on Figure 18 in contrast to the high turbidity events coincident with strong winds from the northeast (June 12, October 21, November 12) or east (November 2). It is possible that peak turbidities lag the peak winds by about a day. It is included that waves of about 50 cm height or more are required as well as onshore directions in the vicinity of the Detroit River entrance. Since the conditions favouring removal of suspended sediments from Lake St. Clair are faily restricted this suggests that sediment export may be a local phenomenon, that is, the source of sediment may be nearshore and not from deeper open lake waters.

It is not possible at this time to separate the effects of horizontal advection from local resuspension but it does appear that local resuspension is likely to be the dominant process since orbital motions are approximately the same over large portions of the lake.

It would seem possible to conclude that under sufficiently severe meteorological forcing sediment resuspension of newly deposited fine grained sediments may take place throughout the lake basin even during periods of high water. Under these conditions coarse material would settle within an hour whereas the fine material would persist in suspension for several days after the storm. At this stage of the analysis it appears that significant amounts of sediment are exported from Lake St. Clair as indicated in Figures 9a and 16 under conditions of waves of at least 50 cm in height impinging on the southwest shoreline and thus may be a local process.

3. HYDRODYNAMICAL MODELLING

The primary focus of the modelling study of Lake St. Clair was to provide hydrodynamical modelling capability in the area of sediment transport and resuspension. Prior studis (i.e., Hamblin, 1979) had developed hydrodynamical models of the basic physical limnology of Lake St. Clair. In particular, the free gravitational modes were computed numerically from a high order finite element model as well as the steady wind driven circulation employing the standard Ekman dynamics and also by finite elements. In addition, the results of these two models were combined to provide a prognostic method of forecasting storm surges at the Belle River water level station (Hamblin, 1979).

In the present study the steady finite element model was extended to include the effects of inflow and outflow from the five main tributaries on the steady circulation and as well the hydraulic and wind driven circulation was interpolated across the elements to provide the input to a particle trajectory model. Figure 19 compares the observed drogue trajectory from satellite tracking methods and which was supplied by Murthy and Miners with the computed trajectory. The agreement is encouraging and suggests that more elaborate models of horizontal sediment movement employing sinking and resuspension may be constructed in the future. Another test of the circulation model validity is shown in Figure 20 where modelled currents compare reasonable well with metered currents averaged over a day.

Since vertical profiles of suspended sediment as deduced from optical transmission show some structure or stratification except during extreme conditions of high vertical mixing, the accurate computation of horizontal sediment transport must rely upon realistic simulation of the vertical structure of the horizontal flow field. The steady finite element model of the wind and hydraulic circulation was run in a three dimensional mode based on the average wind at the time of measurement of vertical profiles of current at station 24 in the centre of Lake St. Clair. Figure 21 shows the modelled and observed profiles of speed and direction at the central lake site. Agreement is good near the bottom and poorer (beyond the error limits) near the surface. Three additional comparisons are provided in the report by Marmoush (1986). These results suggest that the simple constant eddy diffusivity model employed herein is insufficient to account for the mean velocity profile and that a more elaborate specification perhaps including the effect of surface waves is required. Work continues to further improve the vertical current structure modelling capability.

Despite these uncertainties the simulated horizontal current distribution over a storm period October 18-22, 1985, was combined with measured profiles of suspended sediments on several occasions during the storm period. Theresultant magnitude of the horizontal sediment flux is compared to the sediment collected by a horizontal sediment flux trap also at station 24 in the centre of the lake based on the assumption of 100% trap efficiency.

It is evident in Figure 22 that the modelled sediment flux is in the same order as the measured flux but that details such as the low collection at one level remain unexplained. One further study is worthy of mention. During the one survey of Lake St. Clair in 1985 when profiles of suspended sediment were collected over a one day period, the flux of suspended sediment was computed at each of the 20 stations based on the simulated current and observed sediment profiles, and displayed in Figure 23. The divergence of sediment flux in cells defined by the station locations was computed in order to estimate the areas of deposition and/or erosion. It turned out that on the sampling day the concentration gradients of suspended sediments were too weak to distinguish clearly zones of deposition and erosion.

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Marmoush, Y.M.R. and Smith, A.A. 1986 b) Analysis of suspended sediment in lake St. Clair. Report prepared under contract to NWRI, August 1986.

Hamblin, P.F. and Marmoush, Y.M.R. 1986. Lake St. Clair: Some preliminary results. In: Sediment resuspension, settling and transport: Results, needs and future directions at NWRI. Eds. F. Boyce, P. Hamblin and M. Skafel. NWRI Contribution #86-18.

McCrimmon, R.C. 1987. Plots of Lake St. Clair Data Report prepared under contract to NWRI, March 1987.

LIST OF FIGURE CAPTIONS

7. Vertically integrated horizontal sediment transport, September 14, 1985.

8. Water intake turbidities, St. Clair River. (Standard turbidity units) a) Sarnia, b) Polysar, c) Imperial Oil, d) Walpole Island.

9. Water intake turbidities at water treatment stations around Lake St. Clair, a) Windsor, b) Belle River, c) Tilbury, d) Stoney Point and e) Mitchell Bay. (Standard turbidity units)

10. (a) Wind speed, (b) significant wave height at 501, solid line, at 24 dashed lines, (c) significant orbital motion at bottom of waves at 501, inferred, solid line, dashed line current meter 50 cm above bottom and, (d) average suspended sediment concentration at Station 501, solid line, dashed line standard deviation.

11. Time history of mean suspended sediment concentration at 6 levels at Station 501 based on readings every 2 hours or every 0.5 hours (mg/L).

12. Time history of the standard deviation of light extinction coefficient (m) at 6 levels at Station 501 based on readings every 2 hours or 0.5 hours (mg/L).

13. Sediment resuspension, 505 and 506. (a) 506, solid line orbital speed, dashed line speed squared, (b) significant concentration of 505 (mg/L), solid line, mean, dashed line standard deviations, (c) same as (a) for 505.

14. Suspended sediment concentration (mg/L) (a); and standard deviation of suspended sediment concentration as a function of current (cm/s) at Station 505(b).
15. Magnitude of horizontal sediment transport (g/m^2s) at 1 m above the bottom at Station 505 based on readings taken every 30 minutes.
16. Water intake turbidities at the Windsor water treatment station, September to December 1985.
17. Wave characteristics Station 24, May to November 1985. Solid line, orbital motion (cm/s); dotted line, significant wave height (cm); dashed line, period(s).
18. Wind stress components (pa) Station 24, May to November 1985. Solid line, east component, dashed line, north component.
19. Observed and computed drogue trajecteries, August 12-16, 1985.
20. Observed (solid lines) and computed (dashed lines) currents at 1 m depth averaged over August 14, 1985.
21. Modelled (dashed line) and observed current (solid line) profiles (a) speed, (b) direction.
22. Observed (solid line) and computed (dashed line) horizontal sediment collected by trap, October 18-22, 1985.
23. Calculated horizontal sediment transport, September 14, 1985, (gm/(cmsec)).

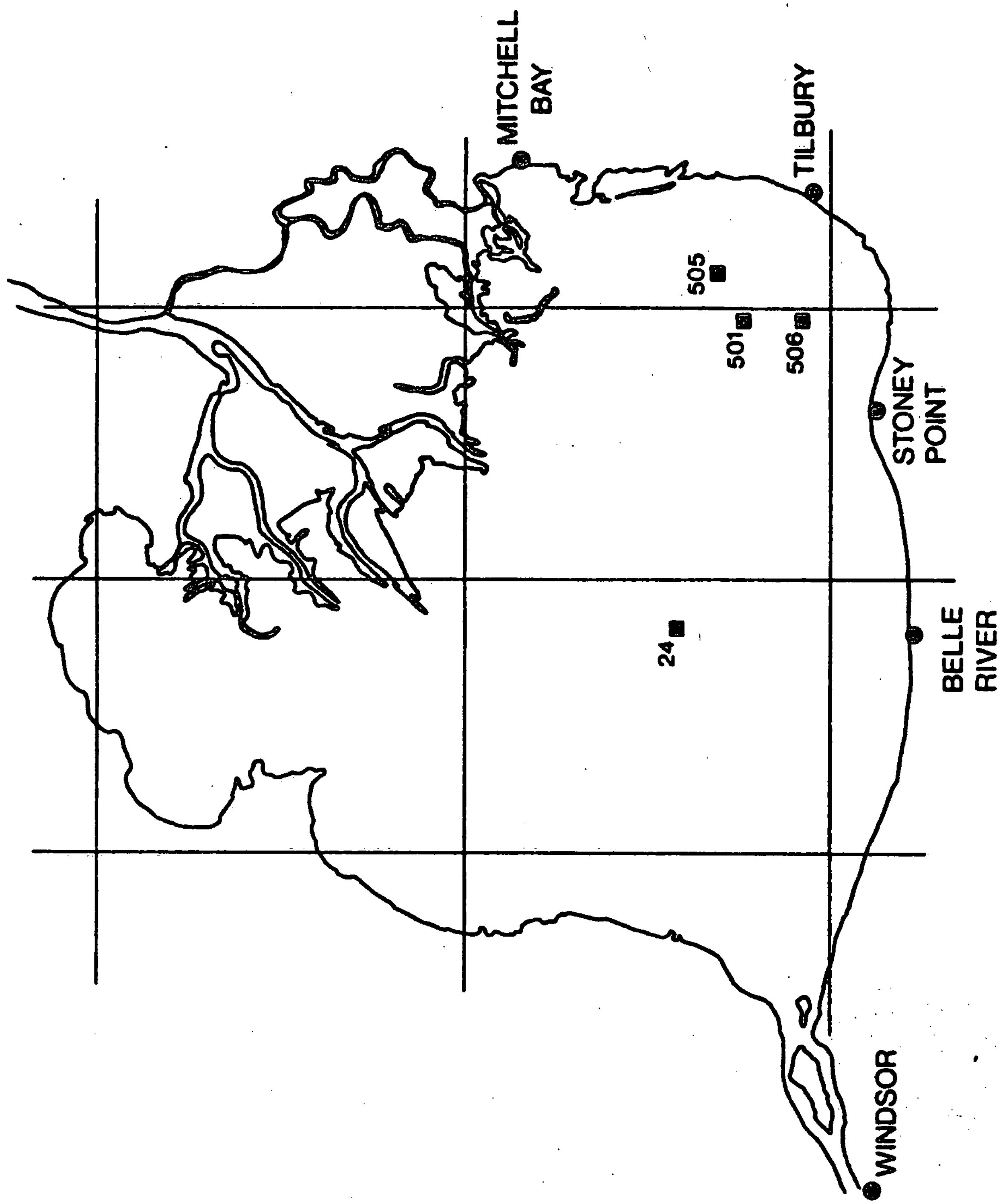
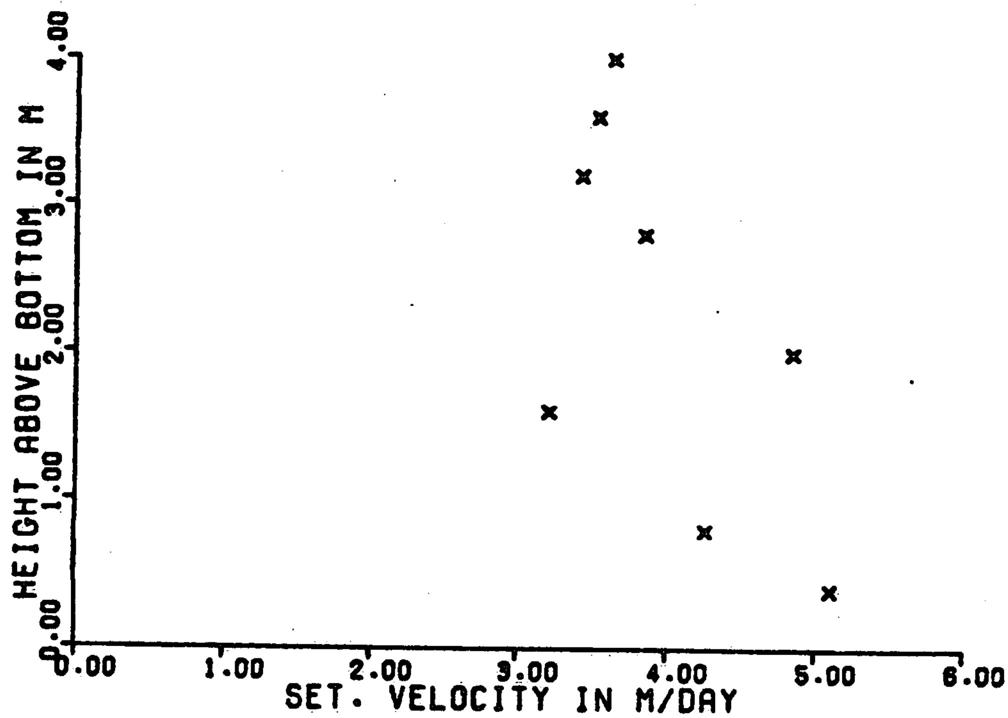

MITCHELL BAY
TILBURY
505
501
506
STONEY POINT
BELLE RIVER
24
WINDSOR

Figure 1


HEIGHT ABOVE BOTTOM IN M
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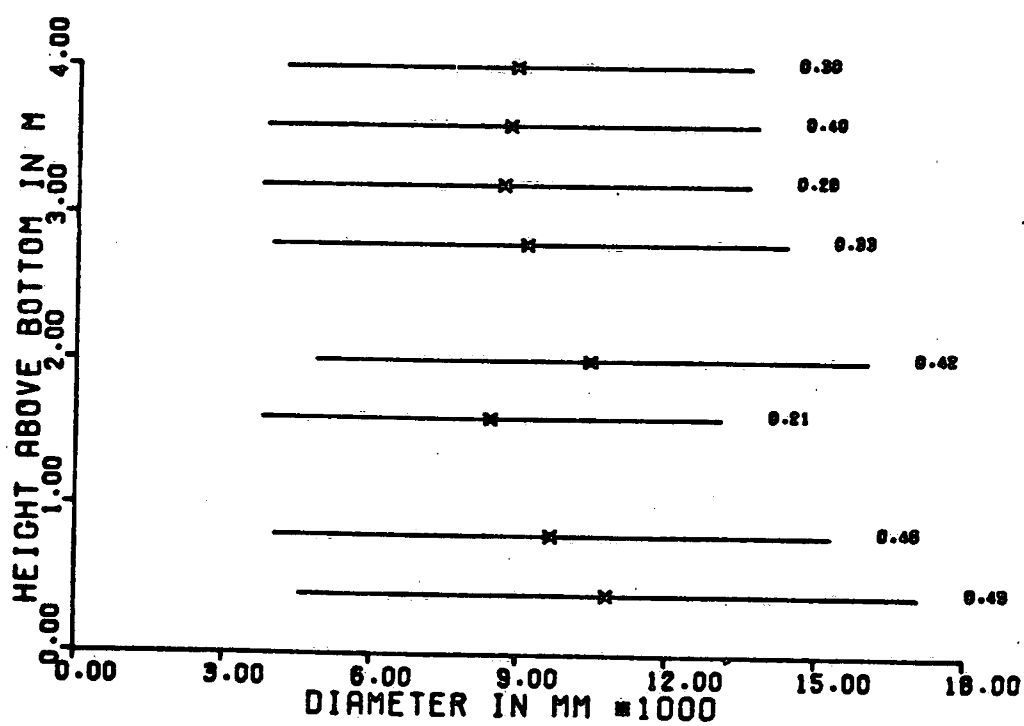
1.00
2.00
3.00
4.00
SET. VELOCITY IN M/DAY
5.00
6.00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1.00
2.00
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DIAMETER IN MM *1000
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9.00
12.00
15.00

Figure 2

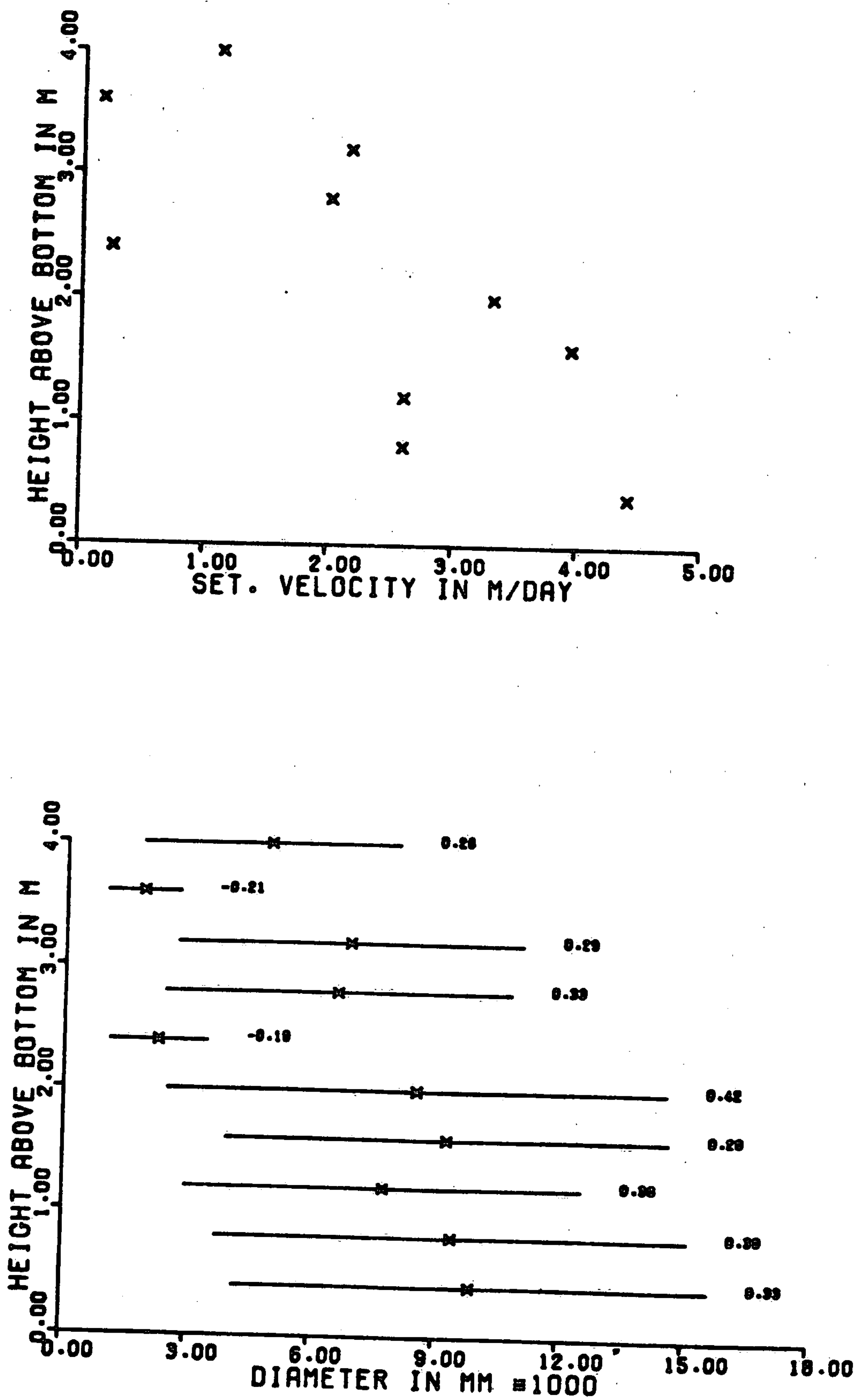
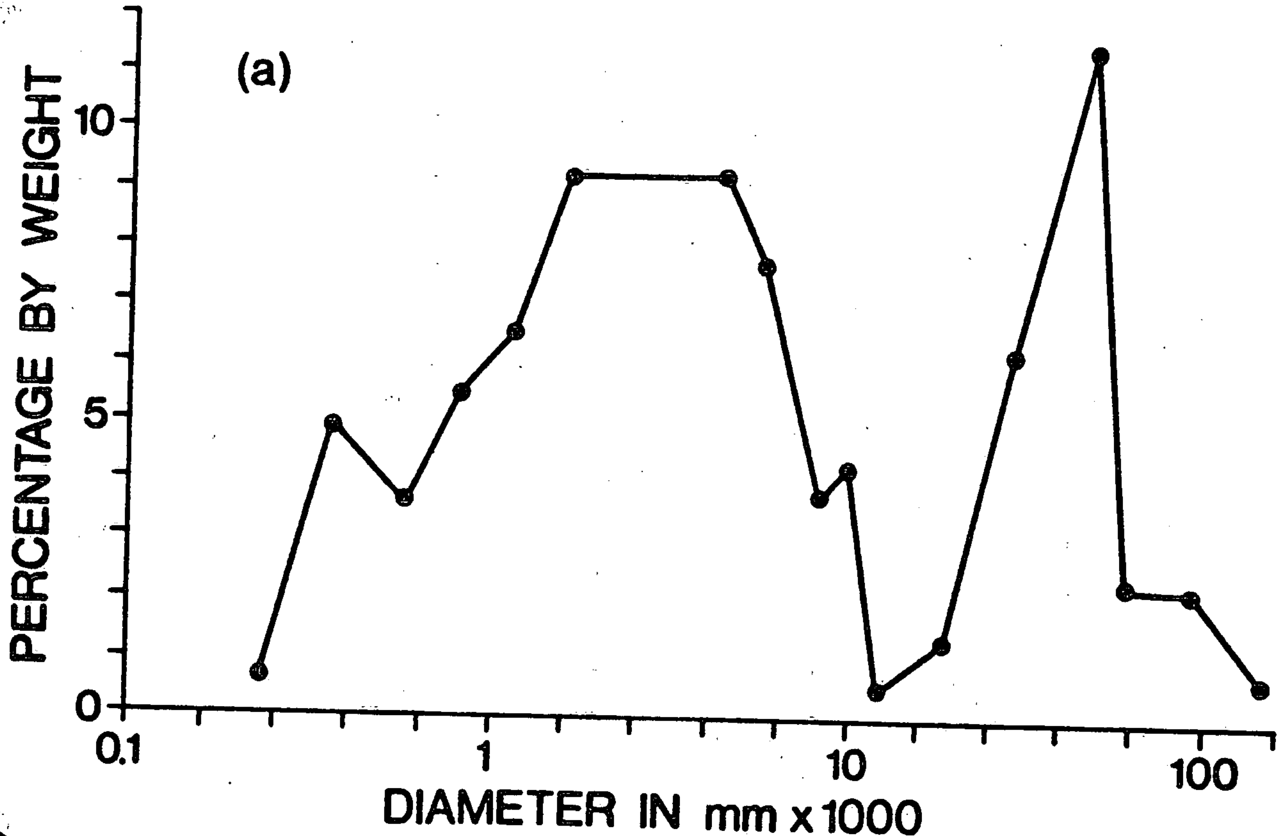

HEIGHT ABOVE BOTTOM IN M
0.00
1.00
2.00
3.00
4.00
0.00
1.00
2.00
3.00
4.00
5.00
SET. VELOCITY IN M/DAY
HEIGHT ABOVE BOTTOM IN M
0.00
1.00
2.00
3.00
4.00
-0.21
0.29
-0.19
0.42
0.33
0.00
3.00
6.00
9.00
12.00
15.00
18.00
DIAMETER IN MM *1000

Figure 3


(a)
PERCENTAGE BY WEIGHT
10
5
0
0.1
1
10
100
DIAMETER IN mm x 1000

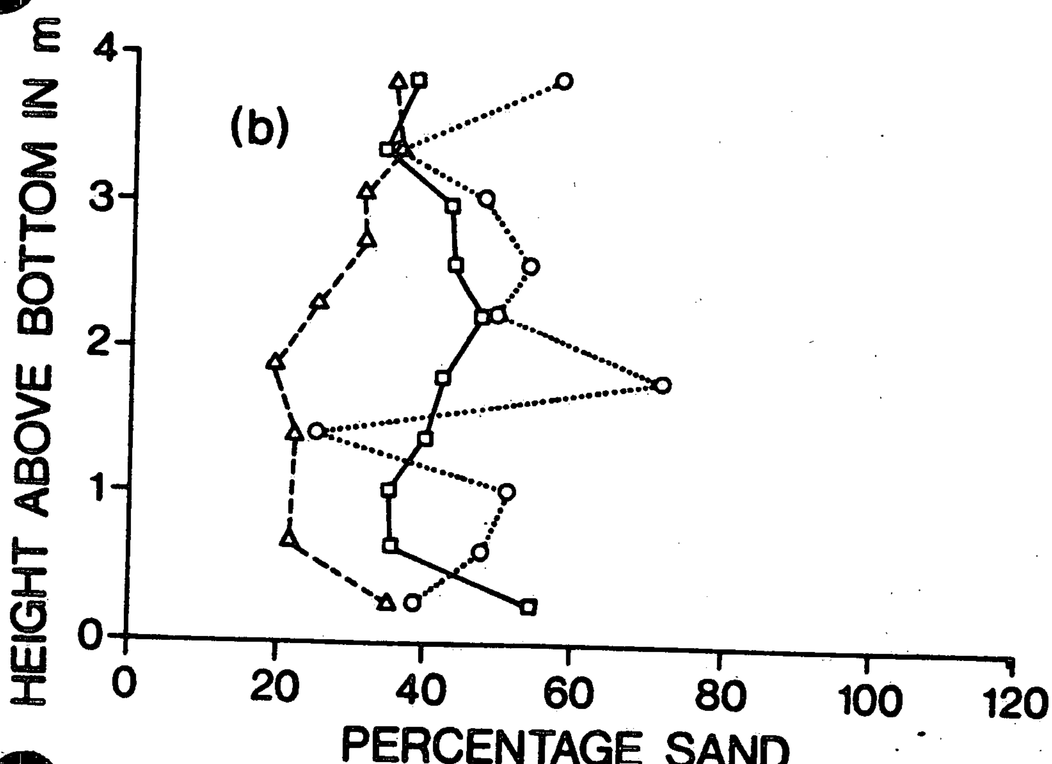
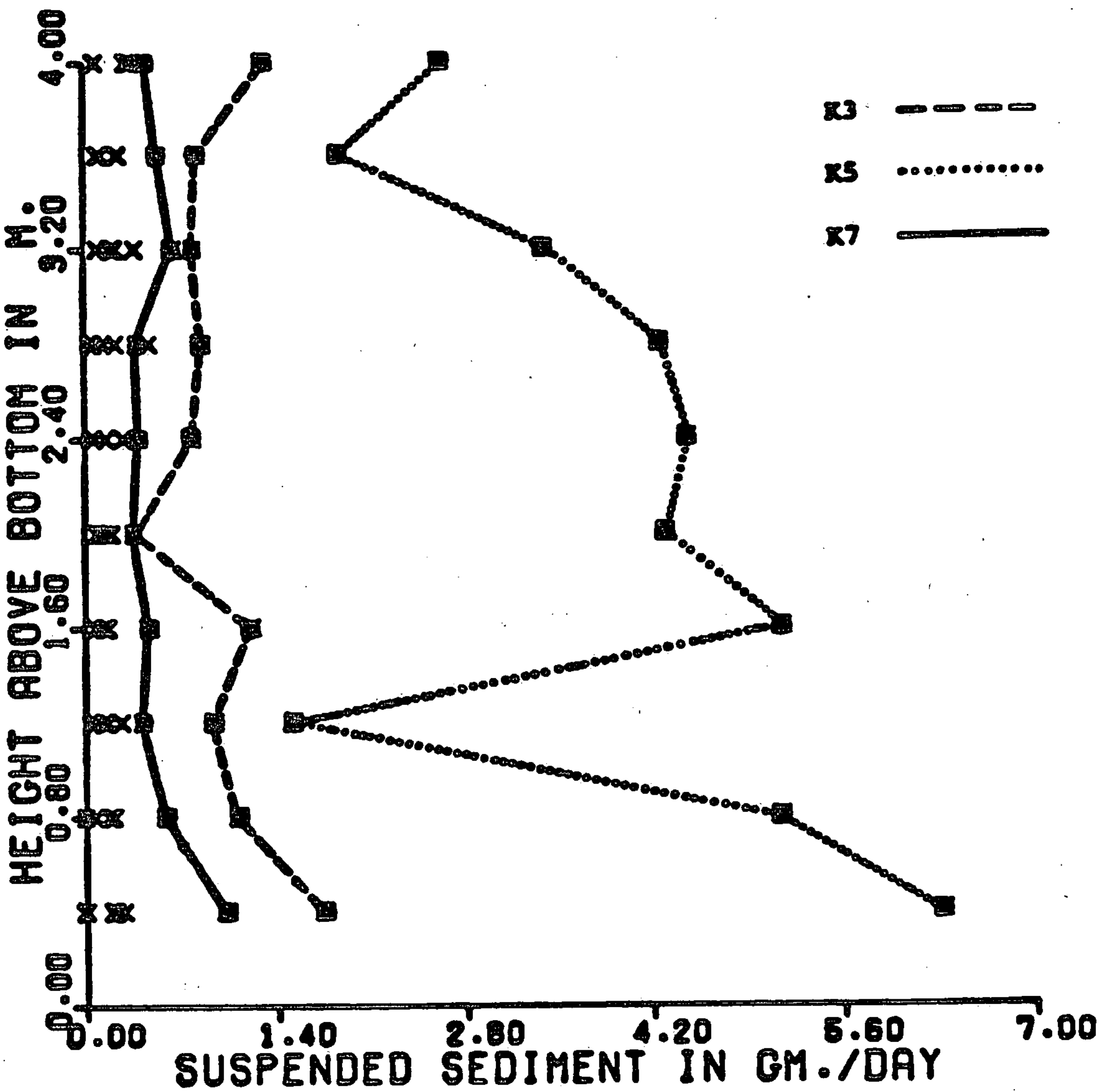
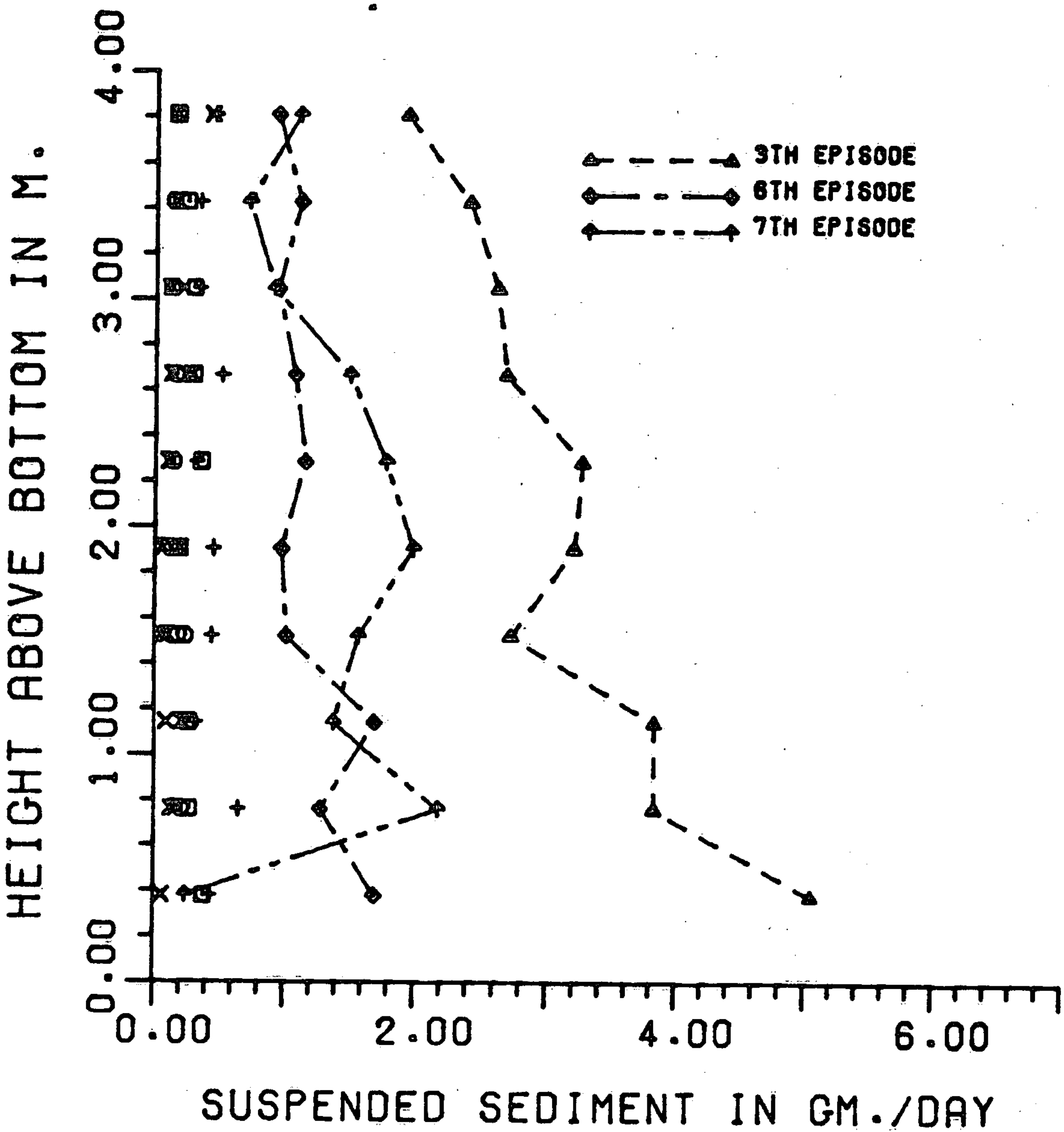

(b)
HEIGHT ABOVE BOTTOM IN m
4
3
2
1
0
0
20
40
60
80
100
120
PERCENTAGE SAND

Figure 4



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 5


3TH EPISODE
6TH EPISODE
7TH EPISODE
HEIGHT ABOVE BOTTOM IN M.
0.00
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3.00
4.00
0.00
2.00
4.00
6.00
SUSPENDED SEDIMENT IN GM./DAY

Figure 6

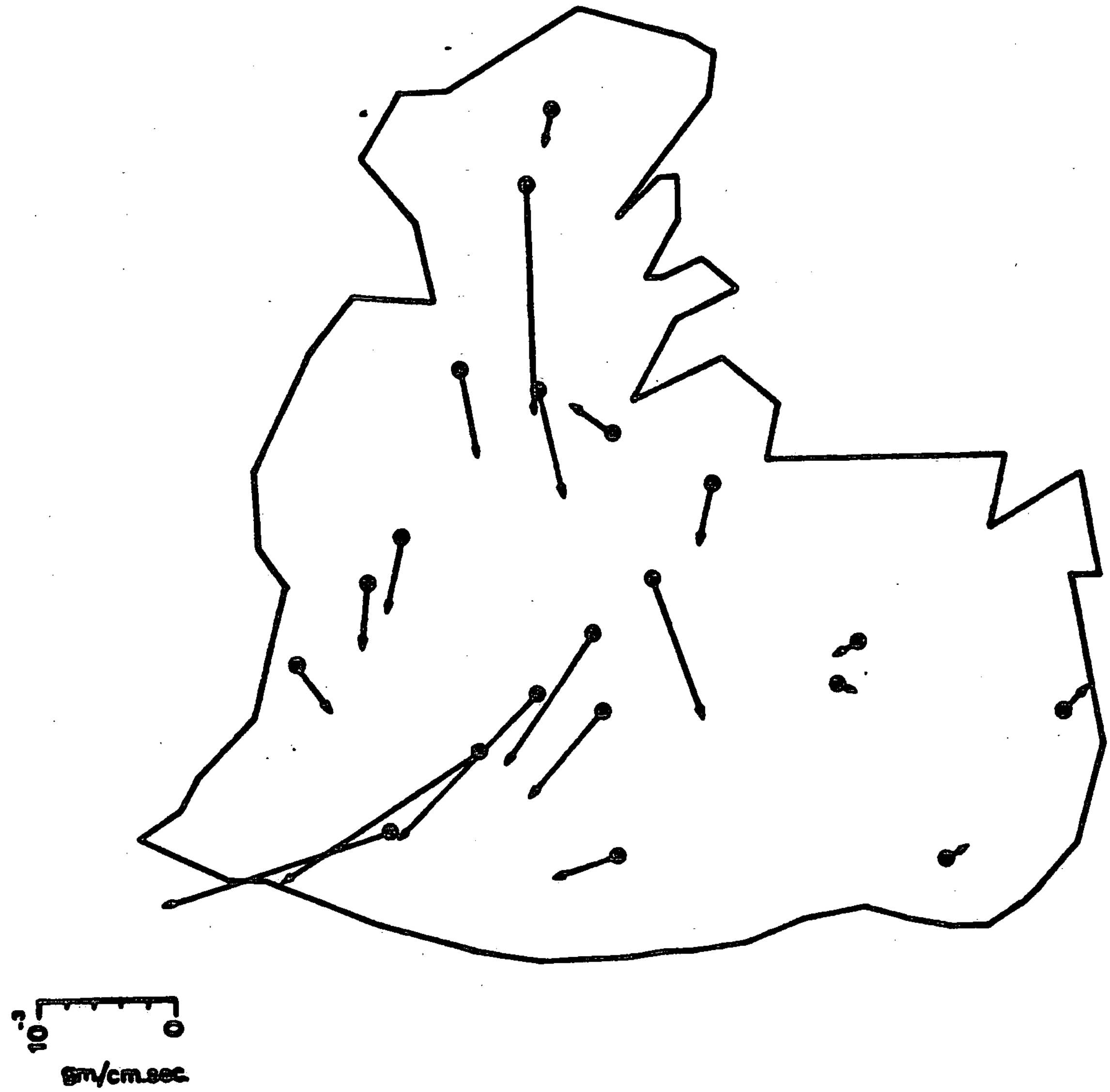


Figure 7

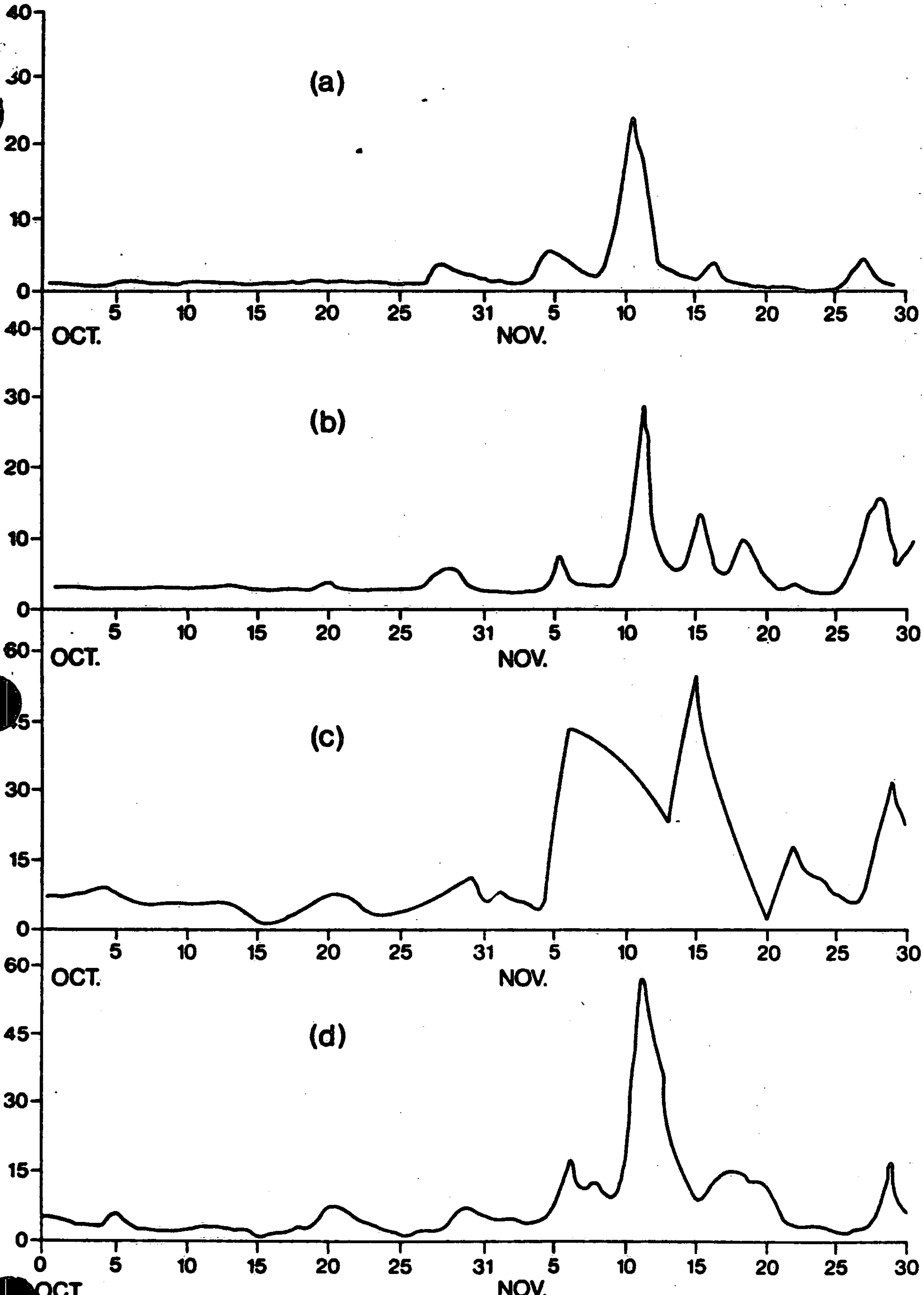
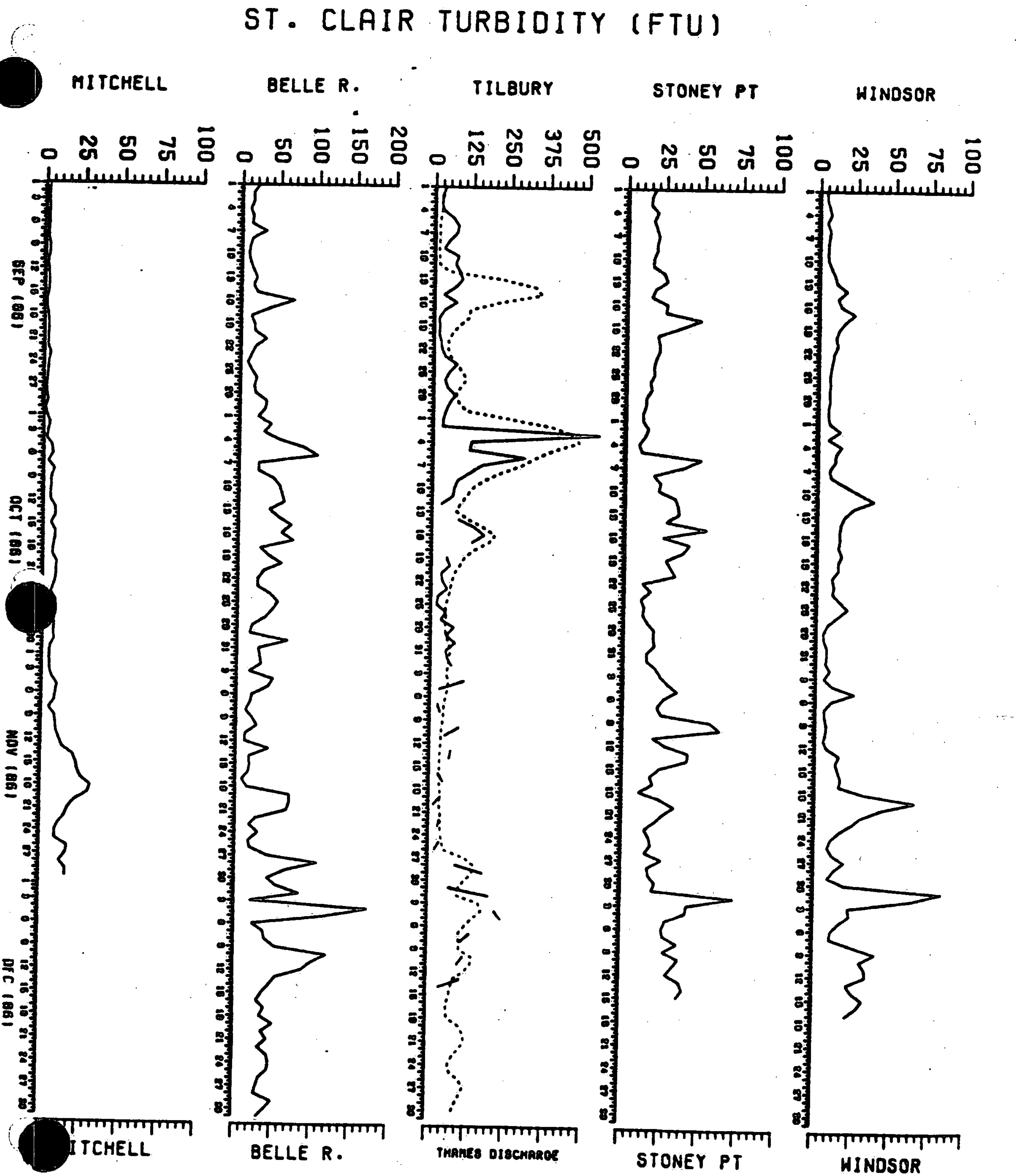


Figure 8

P. HAMBLIN



ST. CLAIR TURBIDITY (FTU)
MITCHELL
BELLE R.
TILBURY
STONEY PT
WINDSOR
SEP (86)
OCT (86)
NOV (86)
DEC (86)
THAMES DISCHARGE

Figure 9

LAKE ST. CLAIR 1986

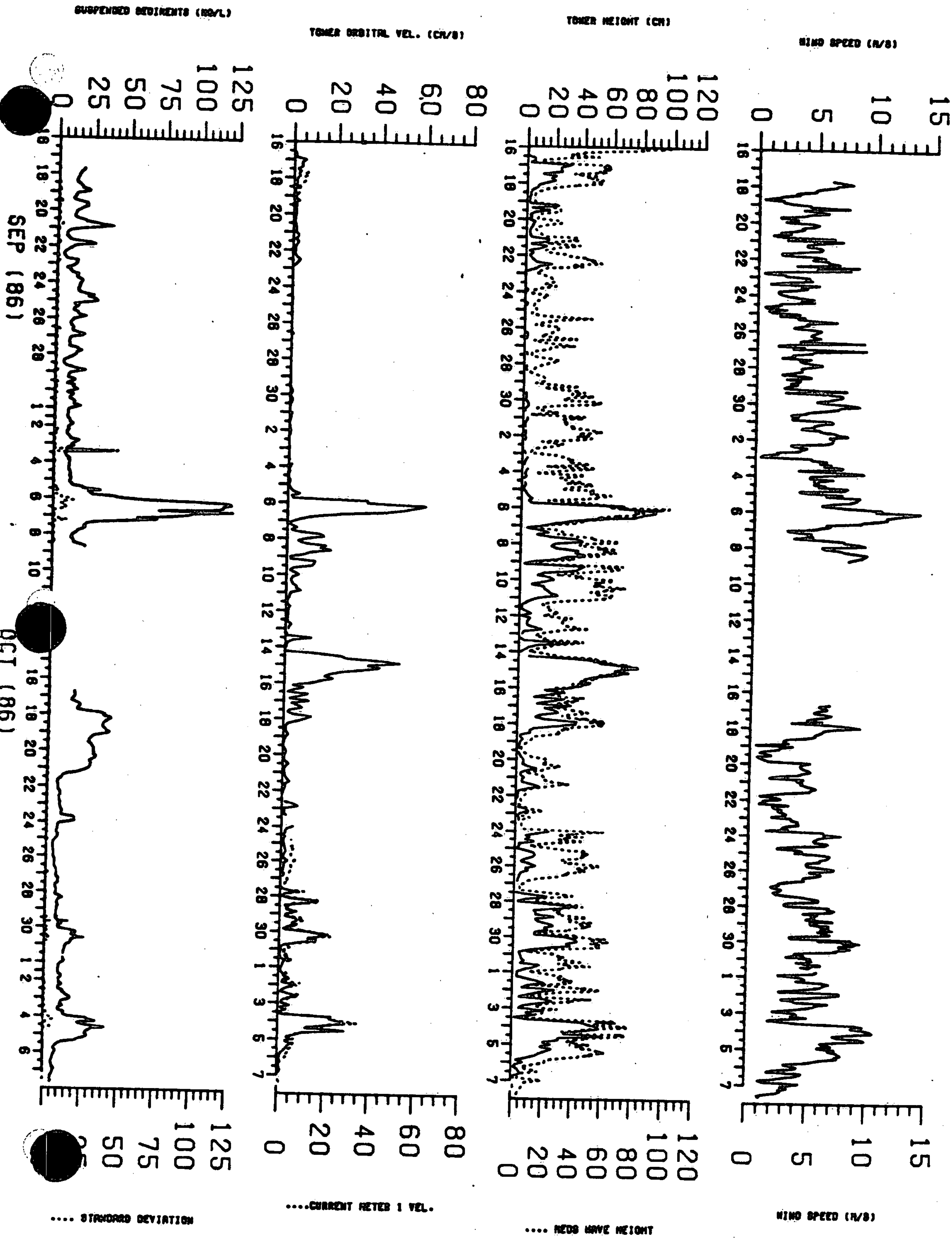


Figure 10

TOTAL SUSPENDED SEDIMENTS (MG/L)

MAIN TOWER (STN 501) LAKE ST. CLAIR 1896

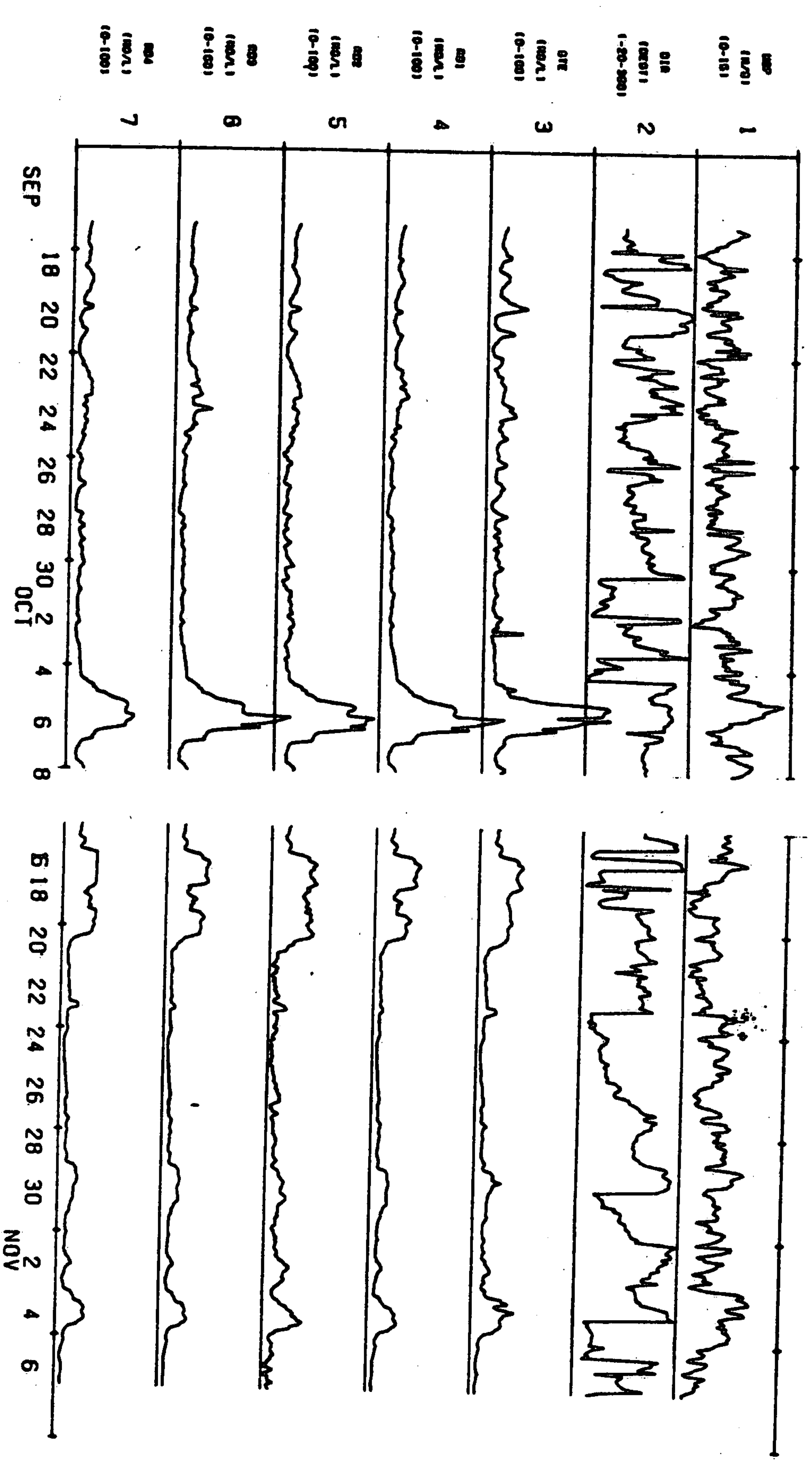


Figure 11

STD DEVIATION OF EXCTINCTION COEFFICIENT

MAIN TOWER (STN 501) LAKE ST. CLAIR 1896

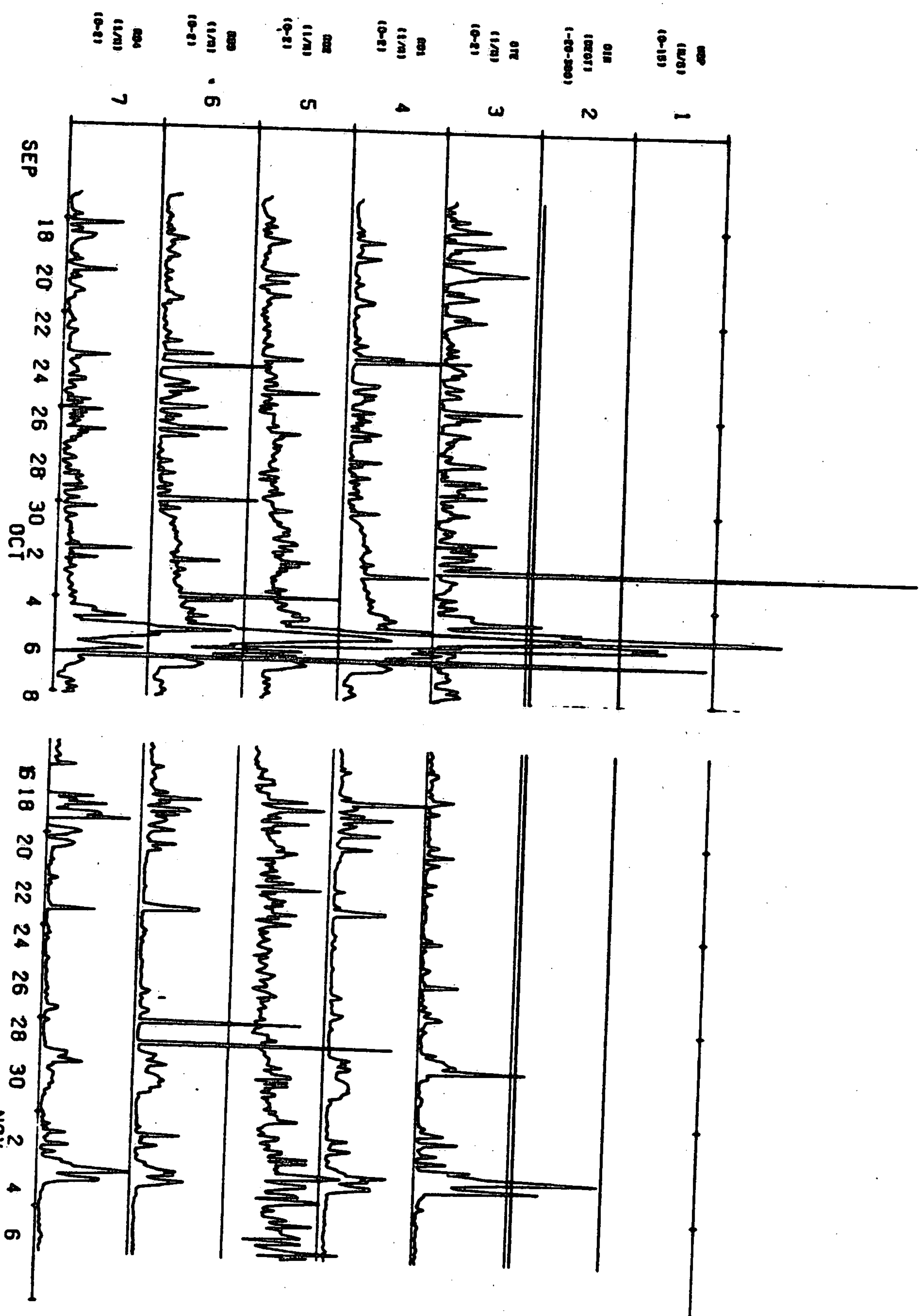
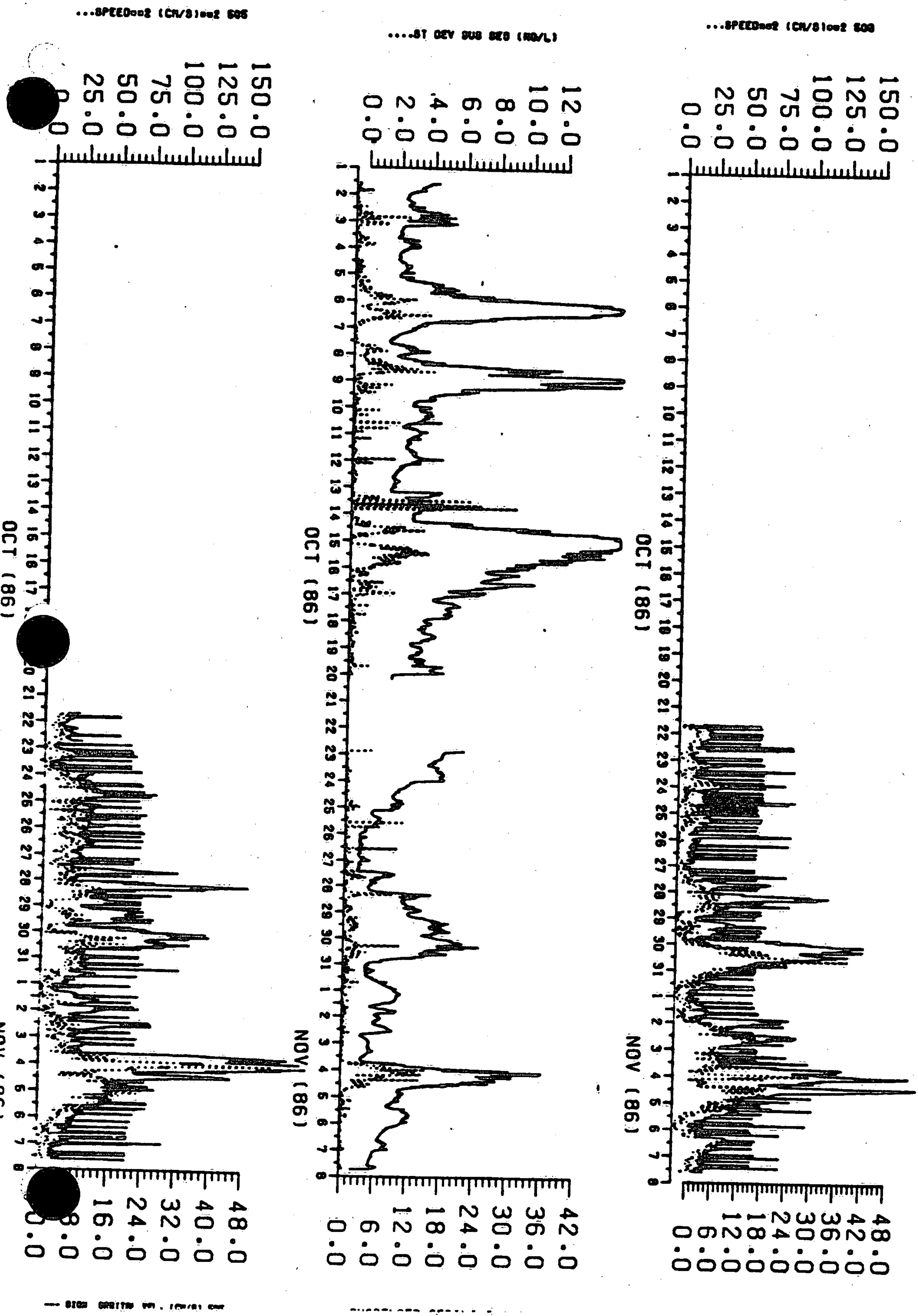


Figure 12

Figure 13

ORBITAL MOTION AND SUSPENDED SEDIMENT STN 505 506



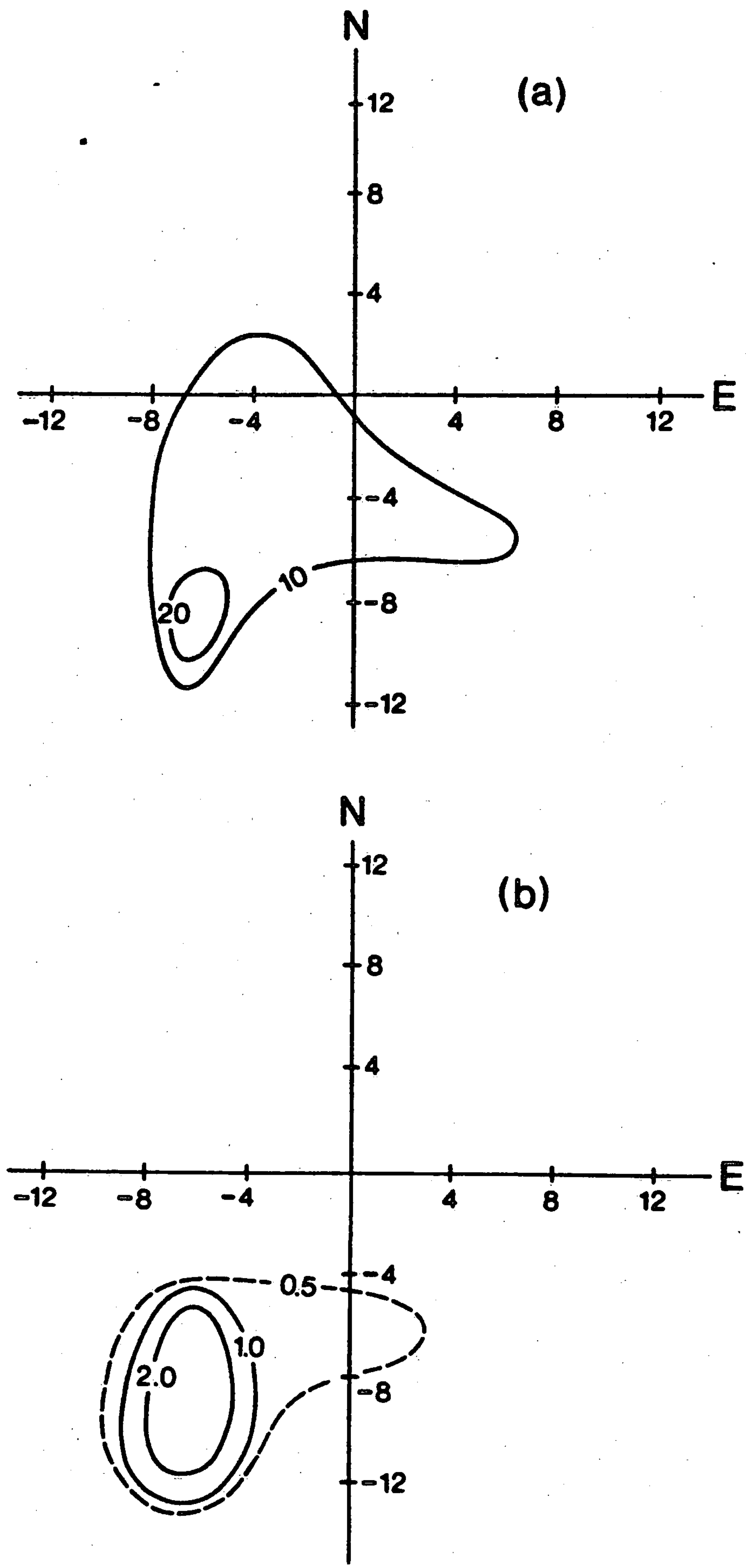


Figure 14

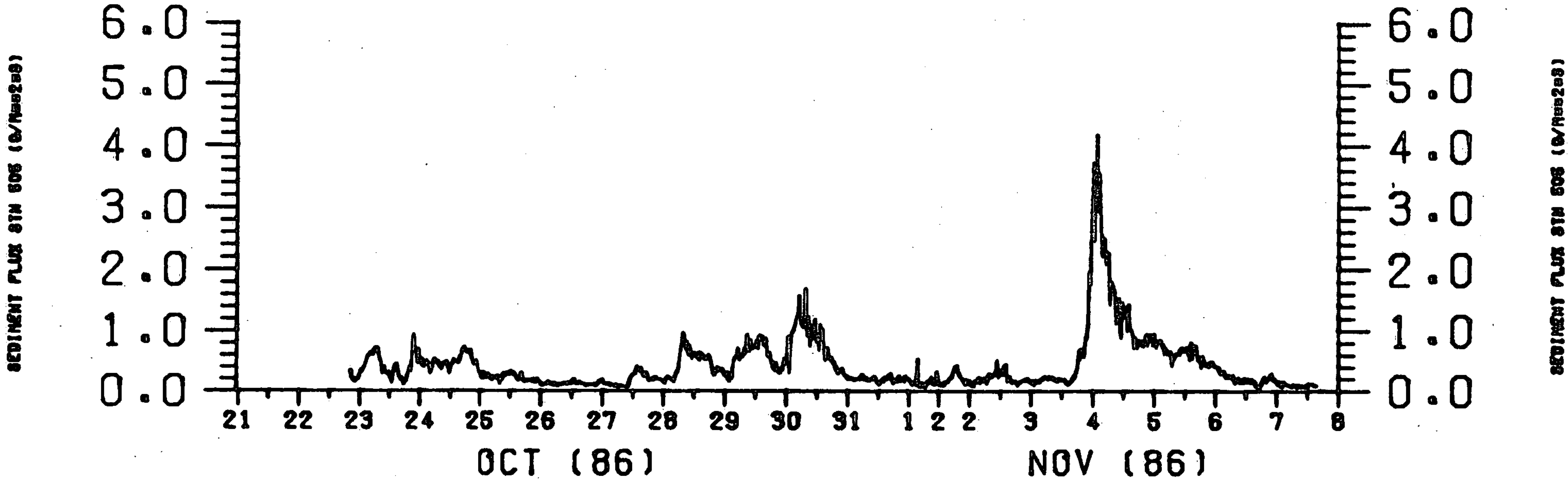

6.0
5.0
4.0
3.0
2.0
1.0
0.0
21 22 23 24 25 26 27 28 29 30 31 1 2 2 3 4 5 6 7 8
OCT (86)
NOV (86)

Figure 15

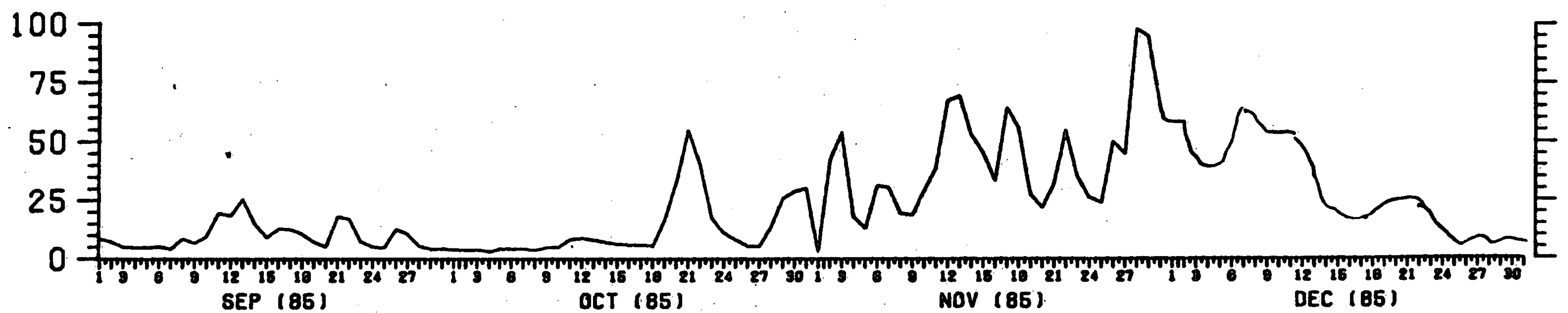
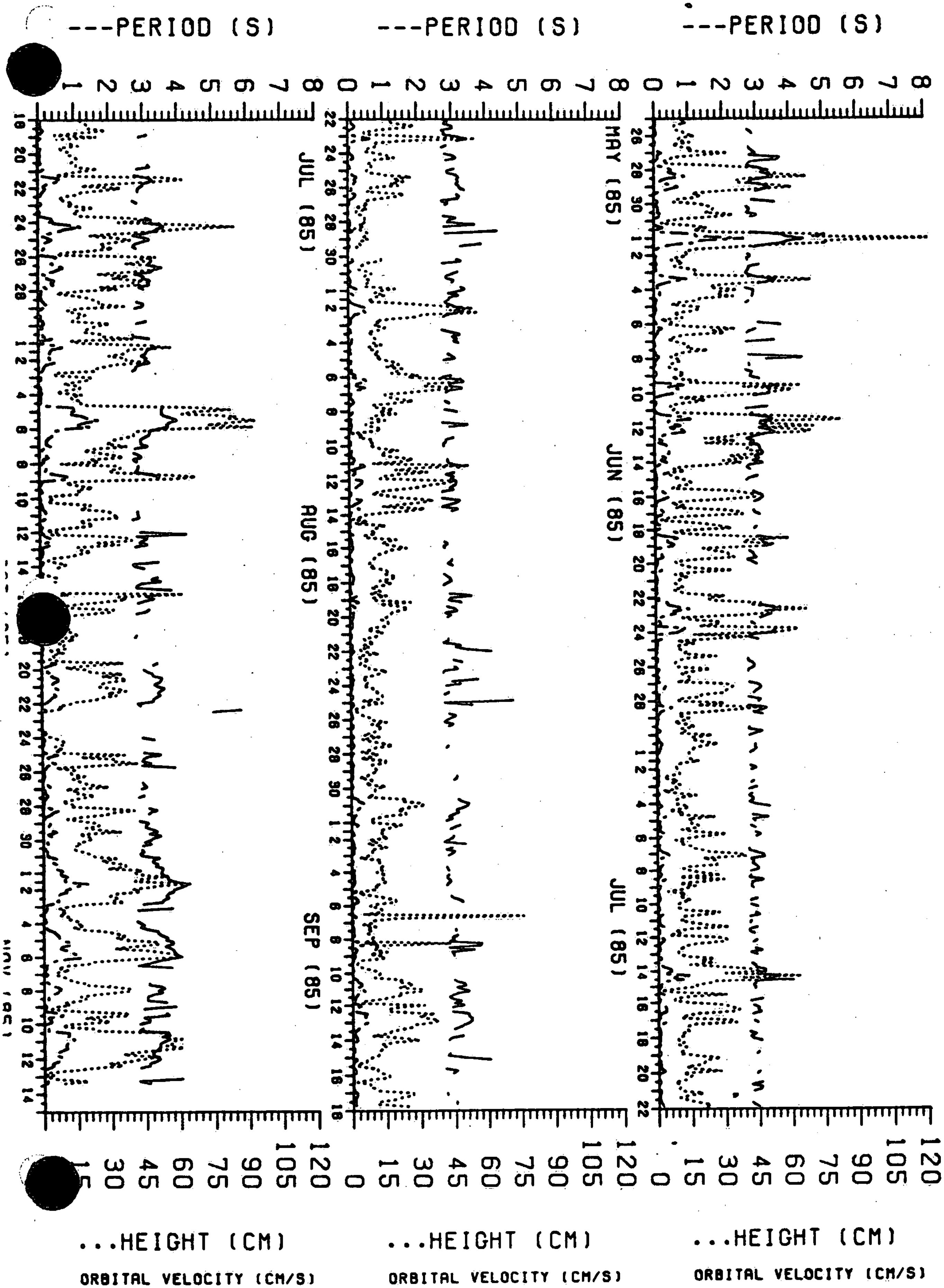


Figure 16

Figure 17

WAVE CHARACTERISTICS LAKE STCLAIR



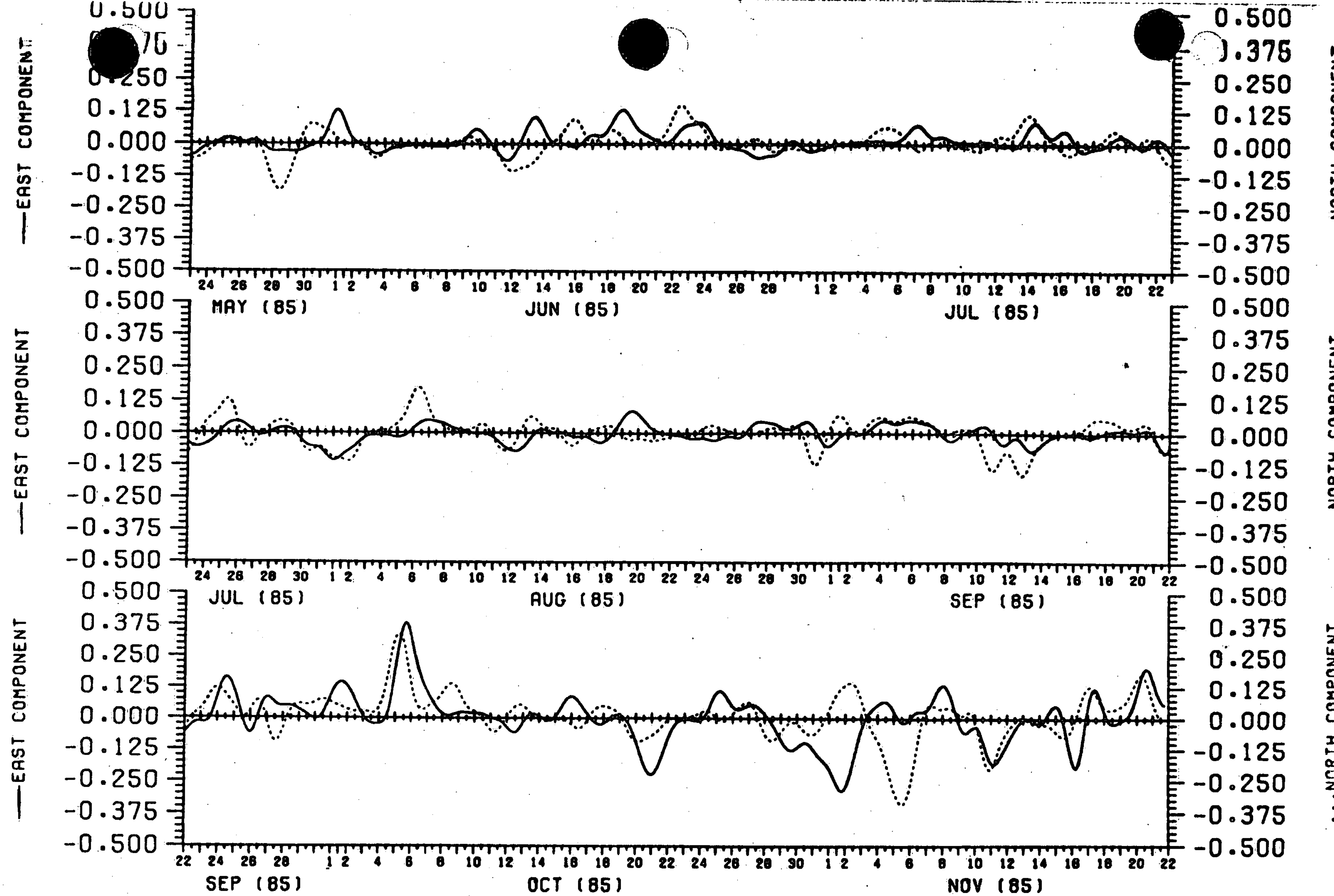
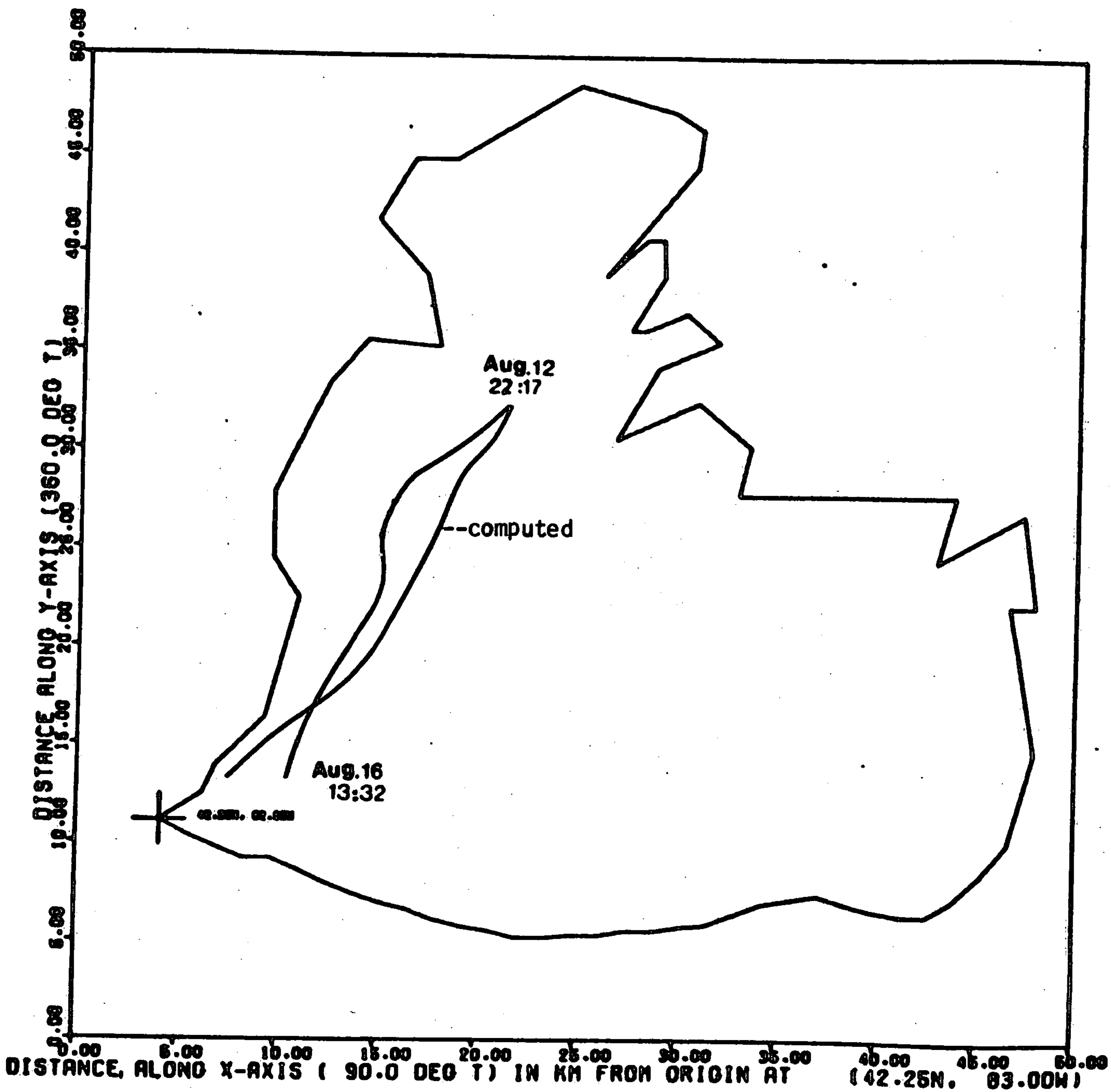

—EAST COMPONENT
...NORTH COMPONENT
MAY (85)
JUN (85)
JUL (85)
AUG (85)
SEP (85)
OCT (85)
NOV (85)

Figure 18



Lake St. Clair

Figure 19

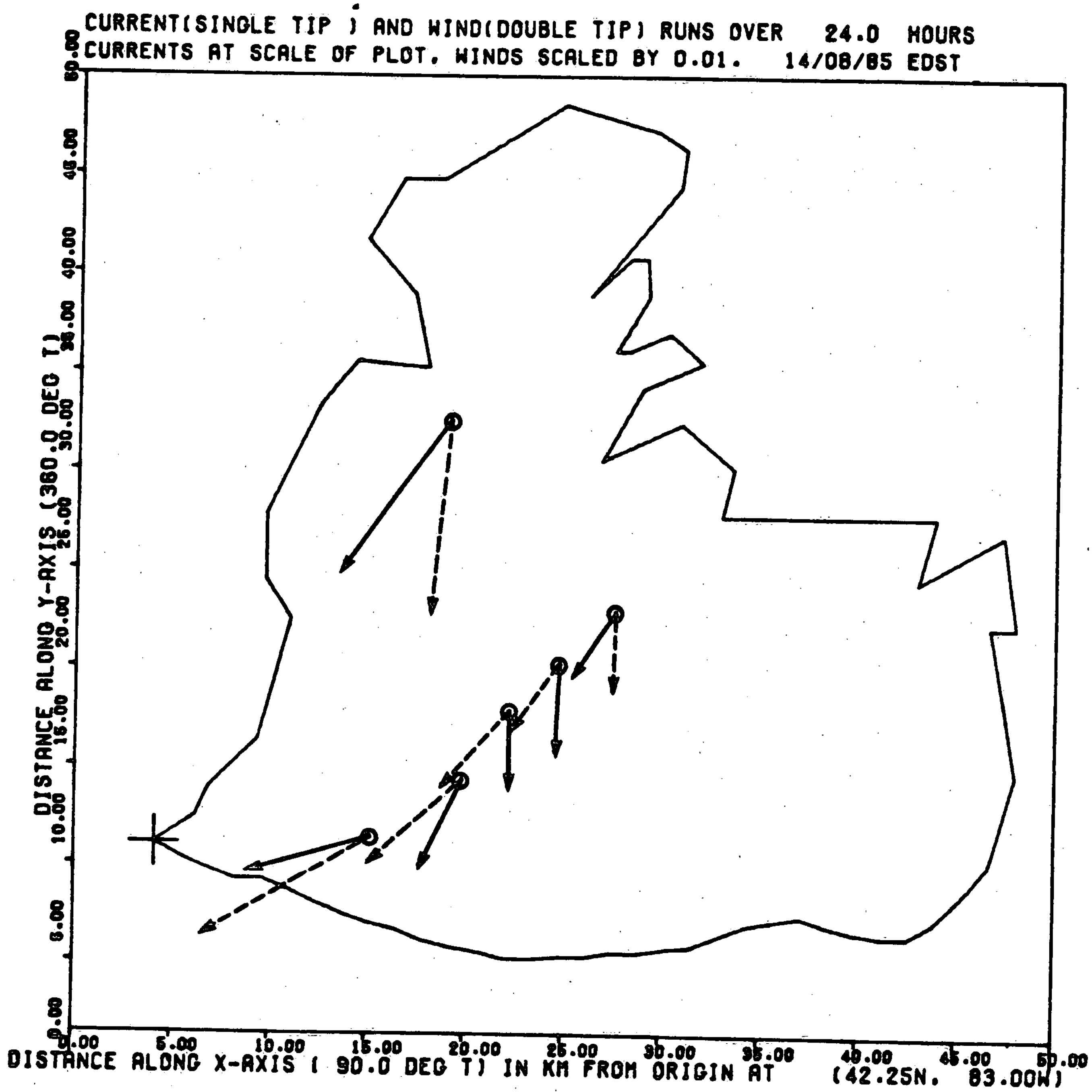

CURRENT(SINGLE TIP) AND WIND(DOUBLE TIP) RUNS OVER 24.0 HOURS
CURRENTS AT SCALE OF PLOT. WINDS SCALED BY 0.01. 14/08/85 EDST
DISTANCE ALONG Y-AXIS (360.0 DEG T)
DISTANCE ALONG X-AXIS (90.0 DEG T) IN KM FROM ORIGIN AT (42.25N. 83.00W)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00

Figure 20

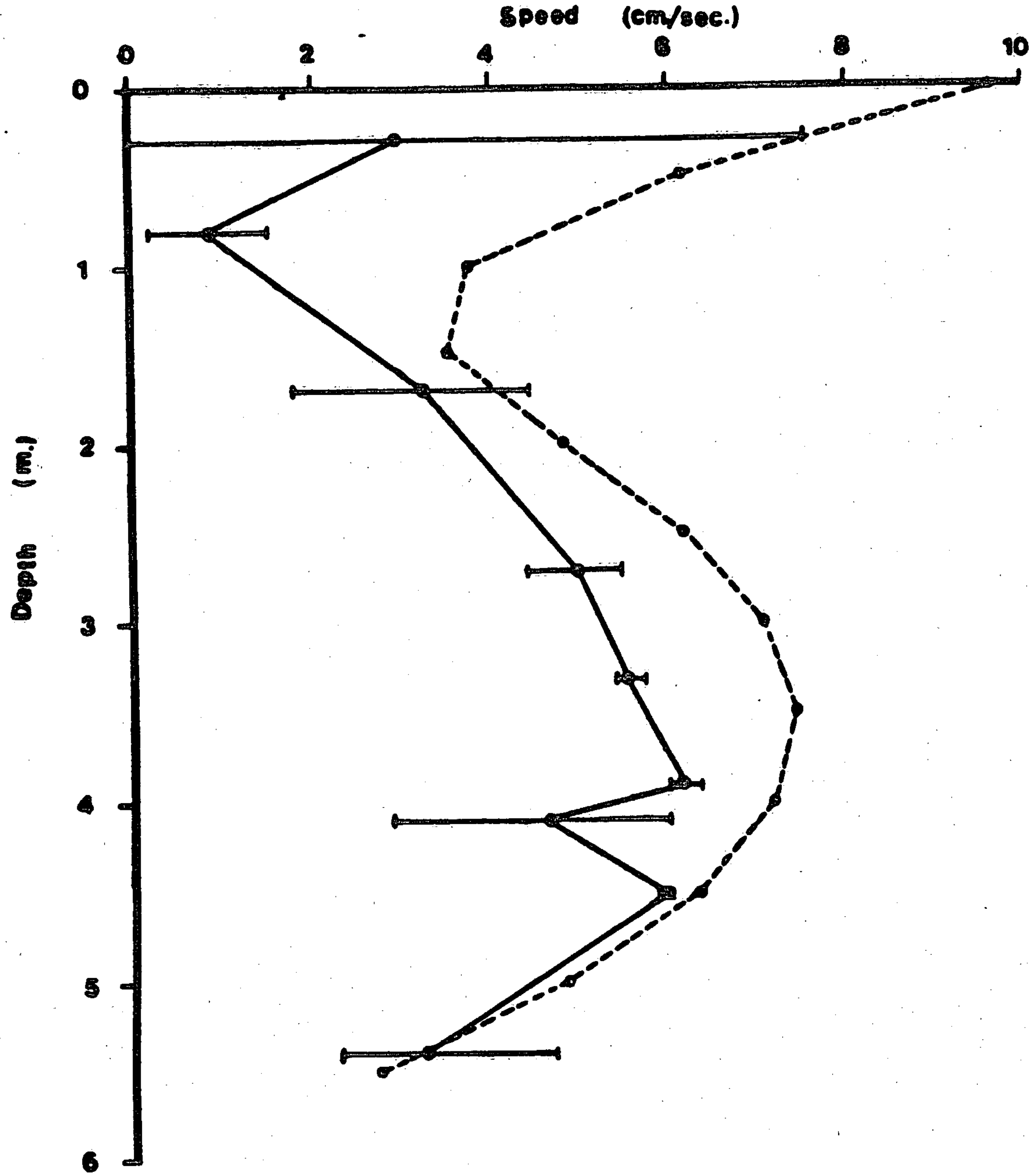


FIGURE 21 a COMPARISON BETWEEN THE OBSERVED (SHOWEN AS SOLID LINES) AND CALCULATED (SHOWEN AS DASHED LINES) VALUES FOR THE VERTICAL CURRENT SPEED NEAR THE MAIN TOWER ON SEPT. 17-1985.

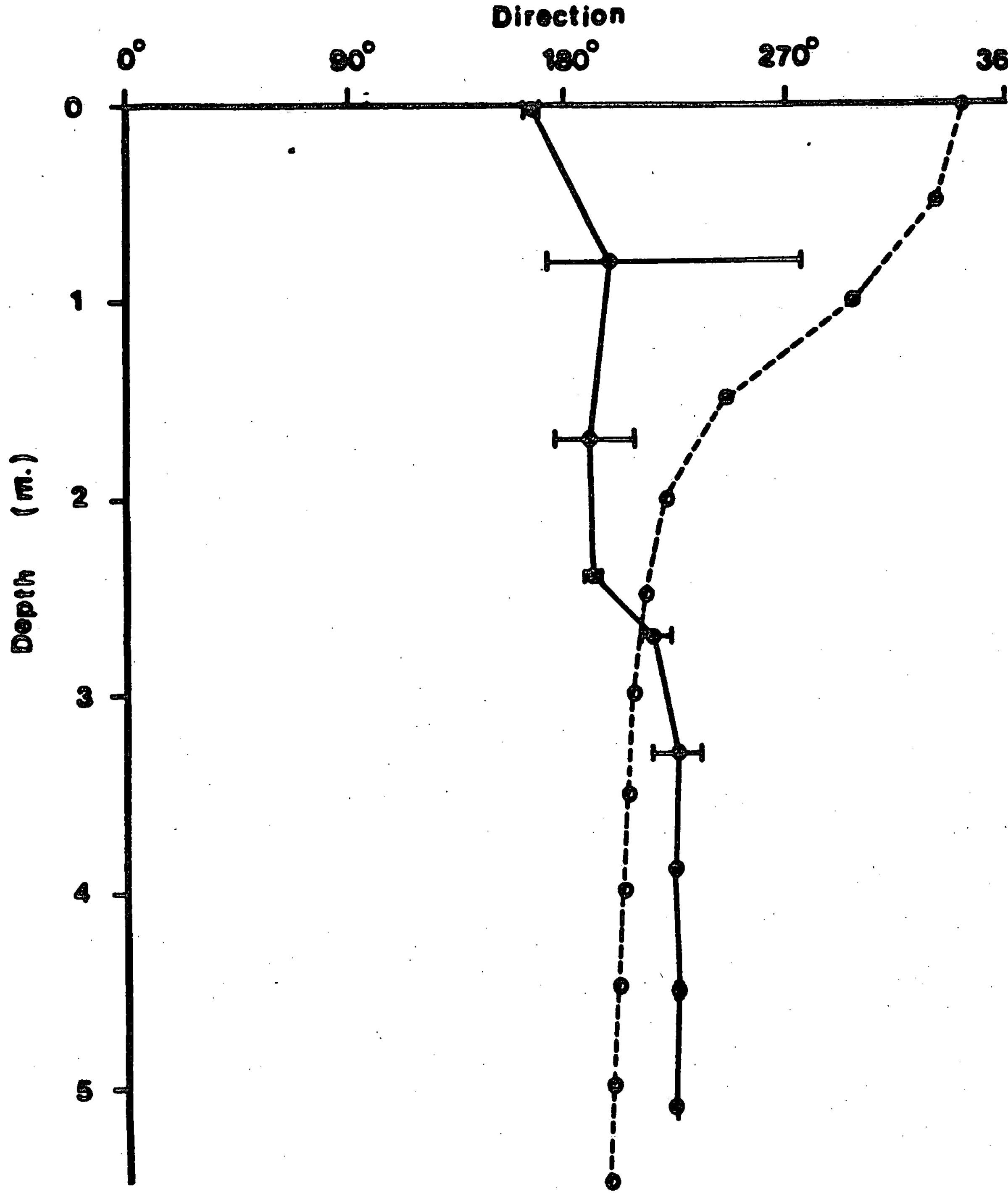


FIGURE 21b · COMPARISON BETWEEN THE OBSERVED (SHOWEN AS SOLID LINES) AND CALCULATED (SHOWEN AS DASHED LINES) VALUES FOR THE VERTICAL CURRENT DIRECTION NEAR THE MAIN TOWER ON SEPT 17-1985.

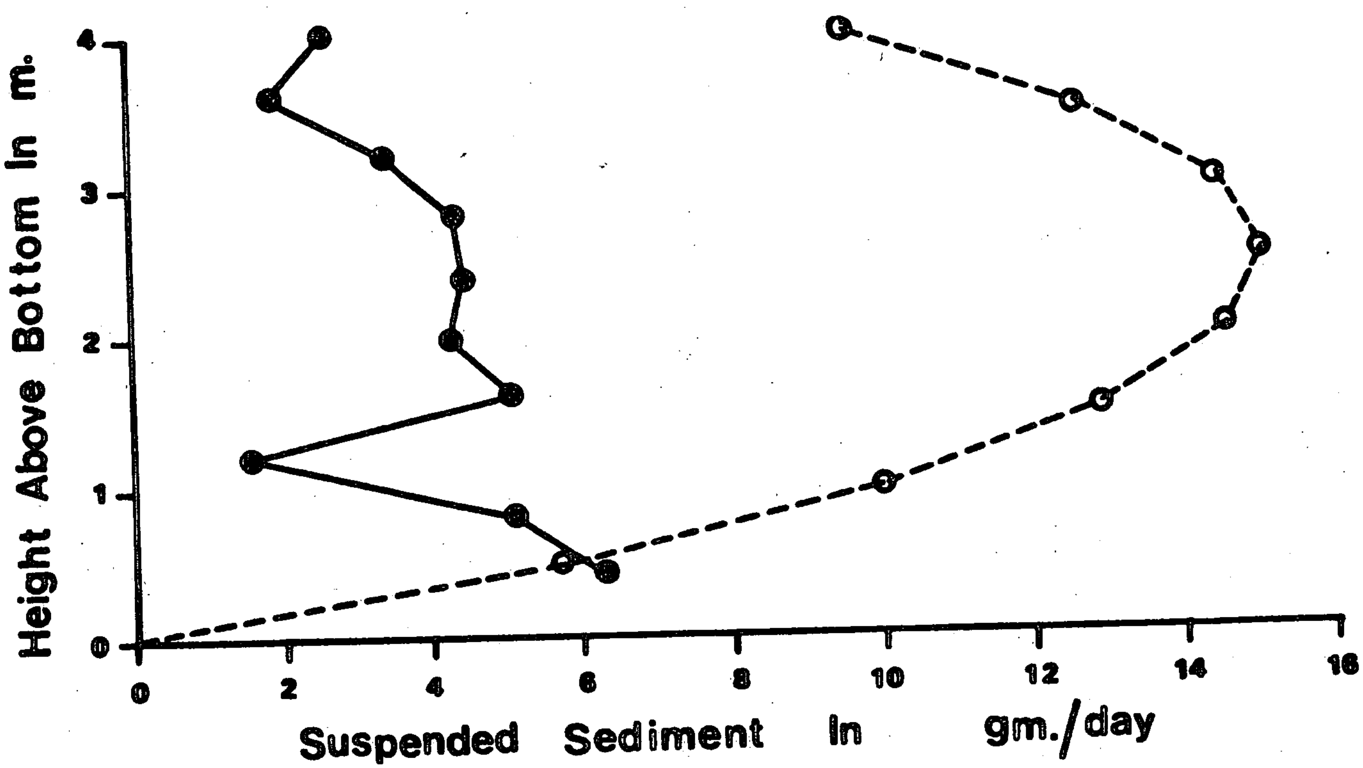


FIGURE 22 COMPARISON BETWEEN THE COLLECTED (SHOWEN AS SOLID LINES) AND CALCULATED (SHOWEN AS DASHED LINES) MASS OF SUSPENDED SEDIMENT WITH DEPTH.

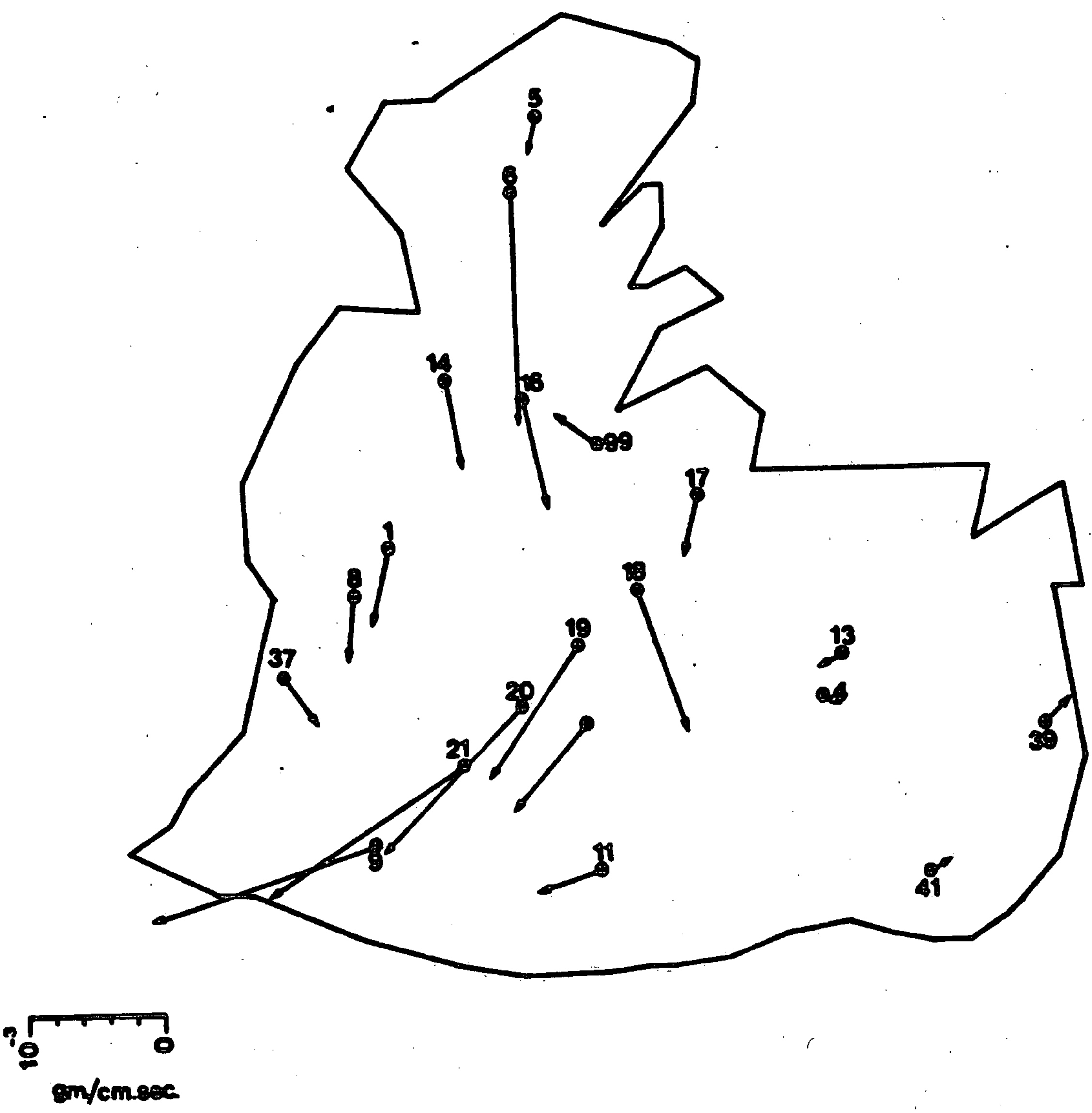


FIGURE 23 CALCULATED HORIZONTAL SEDIMENT TRANSPORT FOR SEPT. 14-1985.