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DYE TRACER STUDIES AT THE KENOSHA, MANITOWOC, MILWAUKEE, AND KEWAUNEE HARBORS CONFINED DISPOSAL FACILITIES

by

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Dye tracer studies were performed at four dredged material confined disposal facilities (CDFs) to locate the points or areas of outflow or seepage from the CDFs. The studies were conducted for the US Army Engineer District, Detroit, at Kenosha, Wisconsin, on 8-9 May 1984; at Manitowoc, Wisconsin, on 30-31 May 1984; at Milwaukee, Wisconsin, on 17-19 September 1984; and at Kewaunee, Wisconsin, on 13-16 May 1985.

The fluorescent dye Rhodamine WT was added to the water in the CDFs and allowed to disperse throughout the CDFs. Following the dispersion, the dye concentration was measured along the entire length of the interior and exterior of the dikes and filter cells of the CDFs. Using a mass balance technique and the measured dye concentrations, the relative outflow was estimated for various points and reaches along the dikes and filter cells. Discrete points of significantly higher outflow were identified at the Kenosha and Manitowoc facilities, where the dikes were constructed entirely of riprap and steel sheet piles. Reaches of significantly higher seepage, but not discrete points of outflow, were found at the Milwaukee and Kewaunee facilities, where the dikes had cores of sand or crushed limestone.

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PREFACE

This report was prepared by the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), in fulfillment of reimbursable order numbers FH NCE-IA-84-0098 and GA NCE-IA-85-0065. The field work was accomplished by Mr. Stephen A. Pranger and Ms. Kathy Smart of the Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), EL, WES.

The report was written and prepared by Mr. Stephen A. Pranger and Dr. Paul R. Schroeder of the WREG. The work was accomplished under the direct supervision of Dr. Michael R. Palermo, Chief, WREG, and under the general supervision of the late Mr. A. J. Green, Chief, EED, Dr. Raymond L. Montgomery, Chief, EED, and Dr. John Harrison, Chief, EL. COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

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DYE TRACER STUDIES AT THE KENOSHA, MANITOWOC, MILWAUKEE AND KEWAUNEE HARBORS CONFINED DISPOSAL FACILITIES

PART I: INTRODUCTION

Background

The Kenosha and Manitowoc Confined Disposal Facilities (CDF's) were designed and built by the U. S. Army Engineer Chicago District between 1974 and 1976 to contain material dredged from the respective harbors (Fig. 1). Both sites were constructed with steel sheet piles surrounded by riprap.

The Milwaukee Harbor Confined Disposal Facility was designed and built by the U. S. Army Engineer Chicago District between 1972 and 1974 to contain material dredged from the Milwaukee Harbor. The south dike consists of cofferdams (cells of steel sheet piles filled with granular material) while the north and east dikes were constructed of a sand and crushed stone core protected by riprap on both sides.

The Kewaunee Harbor Confined Disposal Facility was designed and built by the U. S. Army Engineer Detroit District during 1981 and 1982 to contain material dredged from the Kewaunee Harbor. The entire dike was constructed with a prepared limestone core covered by layers of stone and protected by riprap of increasing size on the lakeward side.

There has been some concern by the Wisconsin Department of Natural Resources (WDNR) and the Detroit District that a portion of the flow was passing through specific leaks in the dikes instead of filtering through the dikes and/or sand filters during active disposal operations. The Detroit District which now has operational and monitoring responsibility for the sites, requested that the U. S. Army Engineer Waterways Experiment Station (WES) conduct dye tracer studies to determine the potential leakage as well as evaluate the effectiveness of the sand filters in discharging the effluent from the CDF's. The purpose of this report is to describe the results of the dye tracer studies conducted at the four confined disposal facilities. This report includes a description of the sites and operational conditions during the studies, techniques and approaches used, and a discussion of the results.

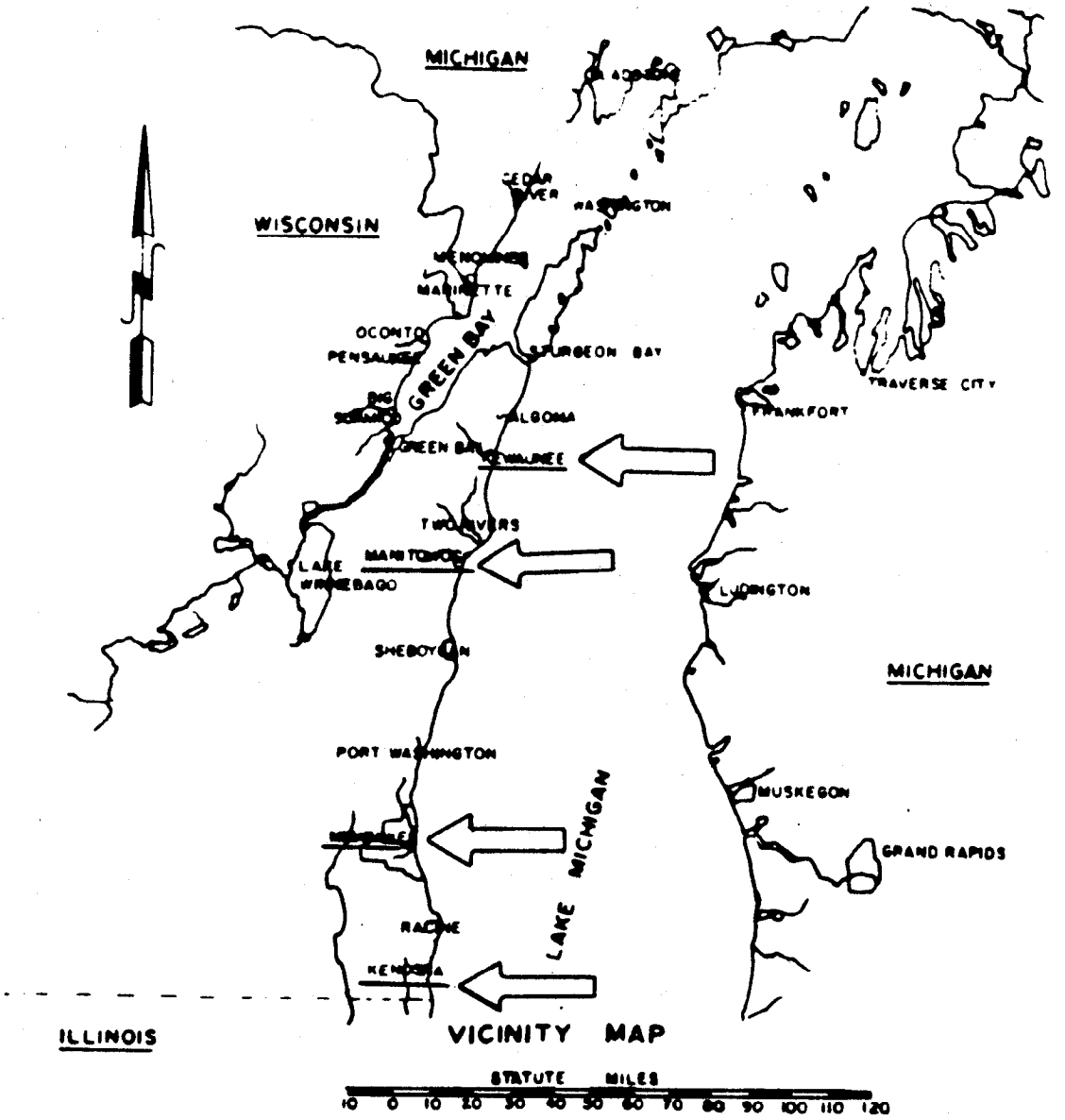

Figure 1. Vicinity Map of Kenosha, Manitowoc, Milwaukee and Manitowoc Harbors.

Objectives and Approach

The initial objectives of the studies were:

a. Identify potential locations of excessive flow through the dikes,

b. Estimate the fraction of the total flow being discharged through the leakage points, and/or through each reach of the dikes,

c. Estimate the fraction of the total flow being discharged through the filters, and

d. Estimate the mean detention time of the CDF's.

Tests were developed to estimate the quantity of outflow passing through the dike during hydraulic dredging when the flow rate is sizable and easily detectable. High flow rates were necessary to mask other factors that would affect the flow such as fluctuations in the water level of the lake outside the CDF's. The dredging operations at Kenosha and Manitowoc were performed by hydraulic dredges while dredging at Milwaukee and Kewaunee was accomplished by clamshell dredges. Therefore, the studies at Milwaukee and Kewaunee were not performed in conjunction with disposal activities; instead, water was pumped continuously into these sites using three 6-in. water pumps to simulate hydraulic dredging during the studies. The field studies were conducted on 8-9 May 1984 at Kenosha, on 30-31 May 1984 at Manitowoc, on 17-19 September 1984 at Milwaukee and on 13-16 May 1985 at Kewaunee.

To accomplish the study objectives, Rhodamine WT, a fluorescent dye commonly used in dispersion studies, was added to the water in the CDF's at the inflow points and/or along the dike interiors and allowed to disperse throughout the disposal areas. Water samples were then taken periodically as follows:

a. Grab samples at the inlet to the filter cells,

b. Grab and continuous flow sampling near the effluent side of the filter cells,

c. Continuous flow sampling around the outside perimeter of the dikes,

d. Grab samples inside and outside the dikes at points where dye was observed or detected, and

e. Grab samples inside and outside the dikes at each 100-foot marker when dye plumes could not be located precisely or were not sustained during the entire study.

Continuous flow sampling was conducted from a boat using a continuous flow through fluorometer. Water was pumped through the fluorometer from along the dike as the boat slowly travelled the perimeter of the CDF. The fluorescence of the water was measured as a function of location along the dike. The fluorescence was converted to dye concentration by subtracting the background fluorescence and multiplying the remaining fluorescence by the response factor to convert a unit of fluorescence to concentration.

Grab samples were analyzed for dye concentration both in the field and later in the laboratory. The grab samples were collected in vials that could be used directly in the field fluorometer to measure the fluorescence of the samples. The fluorescence of the samples were later measured in the laboratory on another instrument to verify the field data.

A procedure was developed to estimate the percent of total outflow at the dye plume locations and at the filter cells. Visual inspection and sampling outside the CDF's were performed in order to determine the approximate locations of any dye plumes. Grab samples were then taken at approximately the same time both inside and outside the dikes at each plume location and at the filter cells. Using a technique based on conservation of mass, the percent of the total flow through the dikes could be estimated at each plume location. Derivation of the equations used in this technique is presented in Appendix E. This procedure was modified to evaluate the Milwaukee and Kewaunee CDF's and to estimate the relative percent of total flow through 100-foot reaches of the dikes.

The mean detention times of the CDF's were not calculated since the accuracy of such determinations where many points of outflow exist is questionable. To determine the mean detention time, the dye concentration and flow rate must be measured continuously at each point of outflow. These measurements were impossible due to the existence of numerous outflow points. However, the mean detention times were not required in order to locate and quantify the outflow conditions or to achieve the goals of the study.

PART II: KENOSHA HARBOR CONFINED DISPOSAL FACILITY

Site Description

The CDF at Kenosha Harbor, Wisconsin, is a diked portion of the harbor area as shown in Figure 2. The diked area is approximately 1100 feet long by 1000 feet wide. Previous disposal operations had formed a delta of dredged material along the north dike. The east and south dikes are exposed to Lake Michigan and the two filter cells are located in the east dike near the southeast corner. A typical cross-section of the Kenosha dikes is shown in Figure 3 and the filter cells cross-section is shown in Figure 4. Two areas of concern had been noted by Detroit District personnel: (1) near the filter cells in the containment area's southeast corner, and (2) in the northeast corner where the east and north (harbor channel) dikes meet.

Site Activities Summary

On 8 May 1984, at 1200 hours, 107 pounds of Rhodamine WT dye was poured into the site at the discharge end of the inflow pipe which was located near the north dike. The dye accompanied the flow into the northeast corner and then south along the east dike before dispersing throughout the rest of the site.

An automatic sampler collected water samples in the area between the front portions of the filter cells. Sampling at the filter cell began at 1200 hours and continued until the next morning. Dye plumes emanating from the east dike were distinctly visible when the sampling outside the containment area was started at 1300 hours. Continuous sampling was conducted outside the east and south dikes during the remainder of the afternoon.

Four large plumes were identified along the east dike and a small plume was found along the south dike. The approximate locations of the dye plumes are denoted as L1 through L5 in Figure 2. The dye concentrations from continuous sampling are presented in Tables A-2 to A-4 in Appendix A and are plotted in Figures 6 through 8.

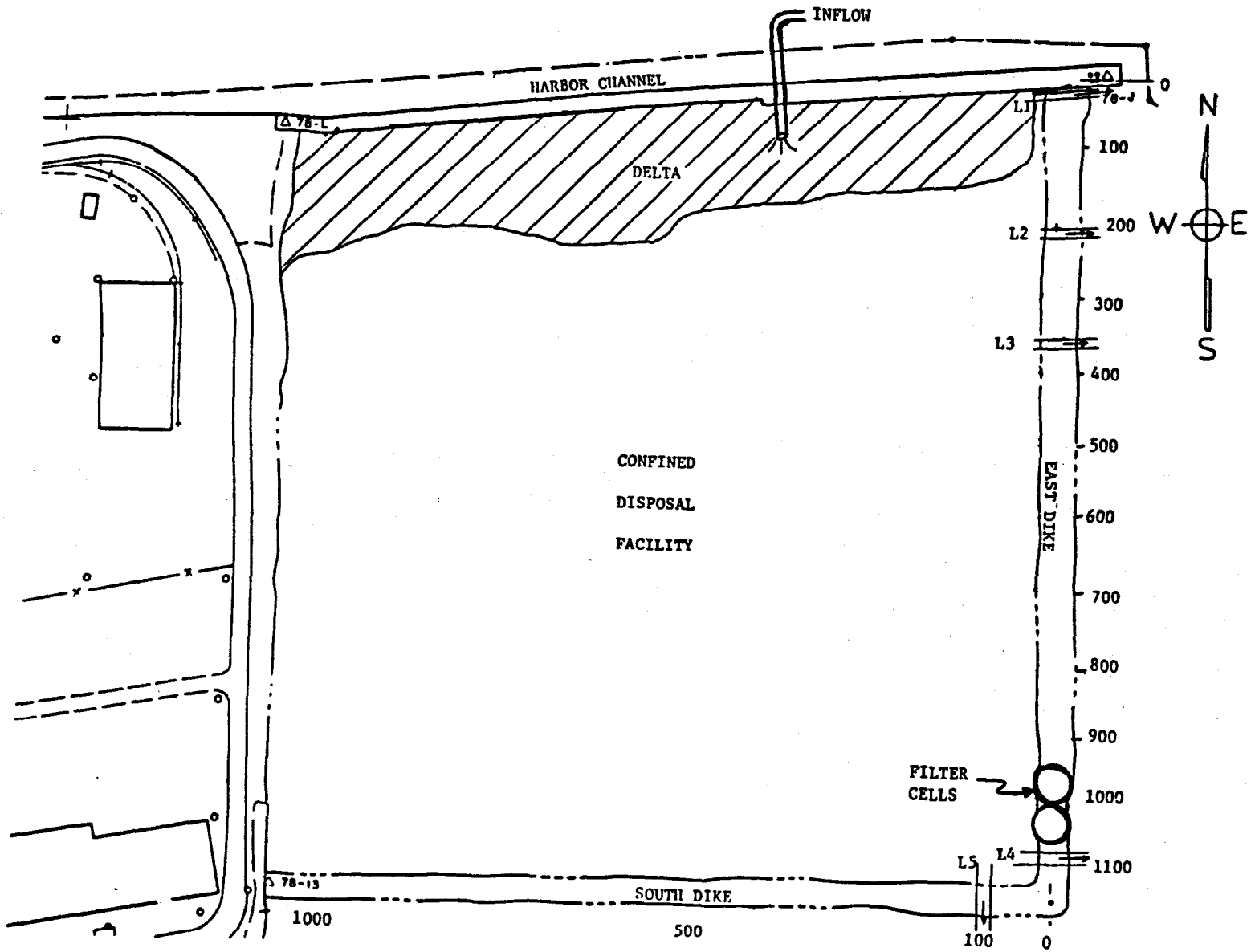

Figure 2. Kenosha Harbor Confined Disposal Facility.

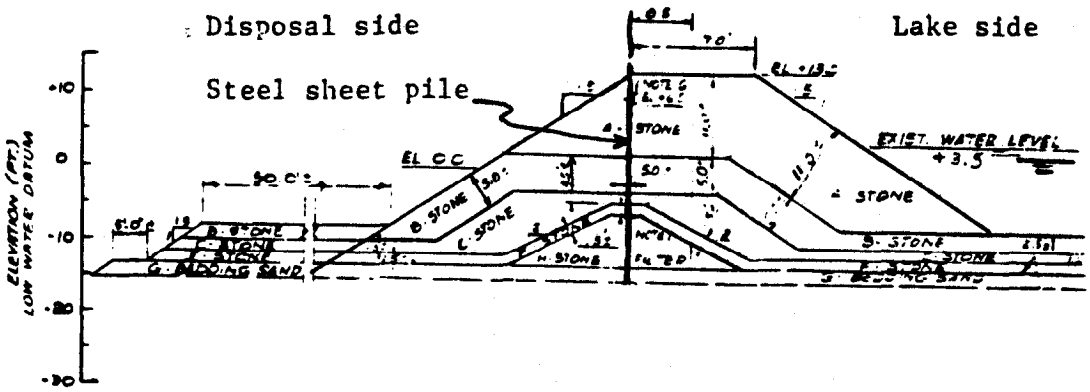

Figure 3. Typical Cross-Section of Kenosha and Manitowoc CDF Dikes.

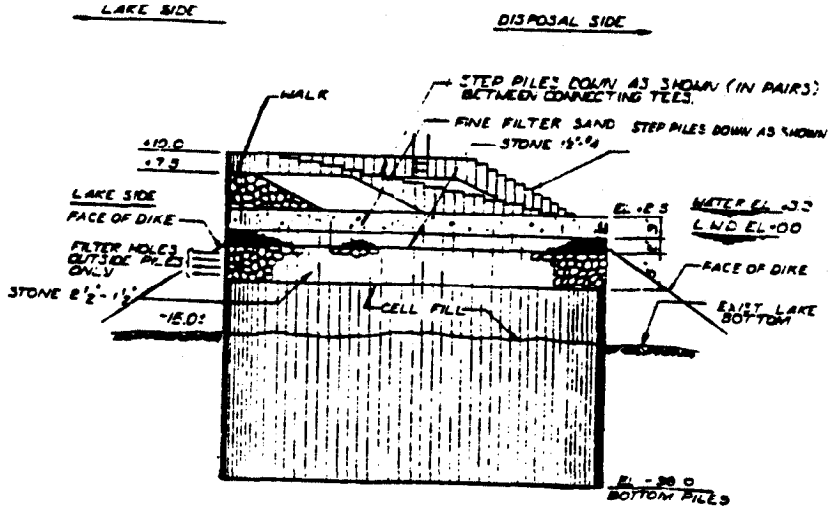

Figure 4. Typical Cross-Section of Kenosha and Manitowoc CDF Filter Cells.

Results and Discussion

The amount of dye added to the area was expected to result in an average concentration of approximately 40 ppb based on complete mixing of the estimated site volume. Figure 5 shows the dye concentration at the inlet to the filter cells as a function of elapsed time since dye was added. During the first four hours the dye moved along the east dike towards the filter cells and then dispersed. After six hours had elapsed, the dye concentration at the filter cell inlet leveled off. These dye concentrations are tabulated in Table A-1 in Appendix A.

Figures 6 and 7 show data from sampling conducted outside the east dike. Four dye plumes, located at the 0-, 150-, 250- and 400-ft markers, were detected when sampling 25 feet from the dike. However, Figure 7 shows only three peaks in dye concentration at 100 feet from the dike (at location L1 through L3 in Figure 2), which agrees with the visual observations from the dikes. The 40 ppb reading at the zero-ft marker at a distance of 100 feet after only two hours indicates that the outflow is quite significant at this location and the dye plume is large. The fluorescence measurements made past the 500-ft marker were equal to the background readings at both distances from the dike and indicate that no plumes were detected. The dye had already reached the filter cell location (1000-ft marker) inside the containment area when these samples were collected.

At 1500 hours, dye plumes emanating from the southern filter cell and at the 1100-ft marker (L4 in Figure 2) were visible. Figure 8 shows a plume at the 1100-ft marker that was not detected during earlier sampling. This plume was expected since the steel piles were 1-2 feet higher than adjacent piles at this location. By this time the dye inside the area had reached the south dike and was dispersing quickly. A plume along the south dike at the 100-ft marker (L5 in Figure 2) was visible at 1630 hours; however, this was the only plume detected along the south dike.

Samples taken at the plume locations more than 48 hours after the addition of dye had concentrations in the range of 20-40 ppb while the filter cell effluent was approximately 1.0 ppb. The dye plume at the filter cell was visible only for two hours while the plumes along the dikes remained visible for over 48 hours. The filter cell dye plume was visible only when the highly

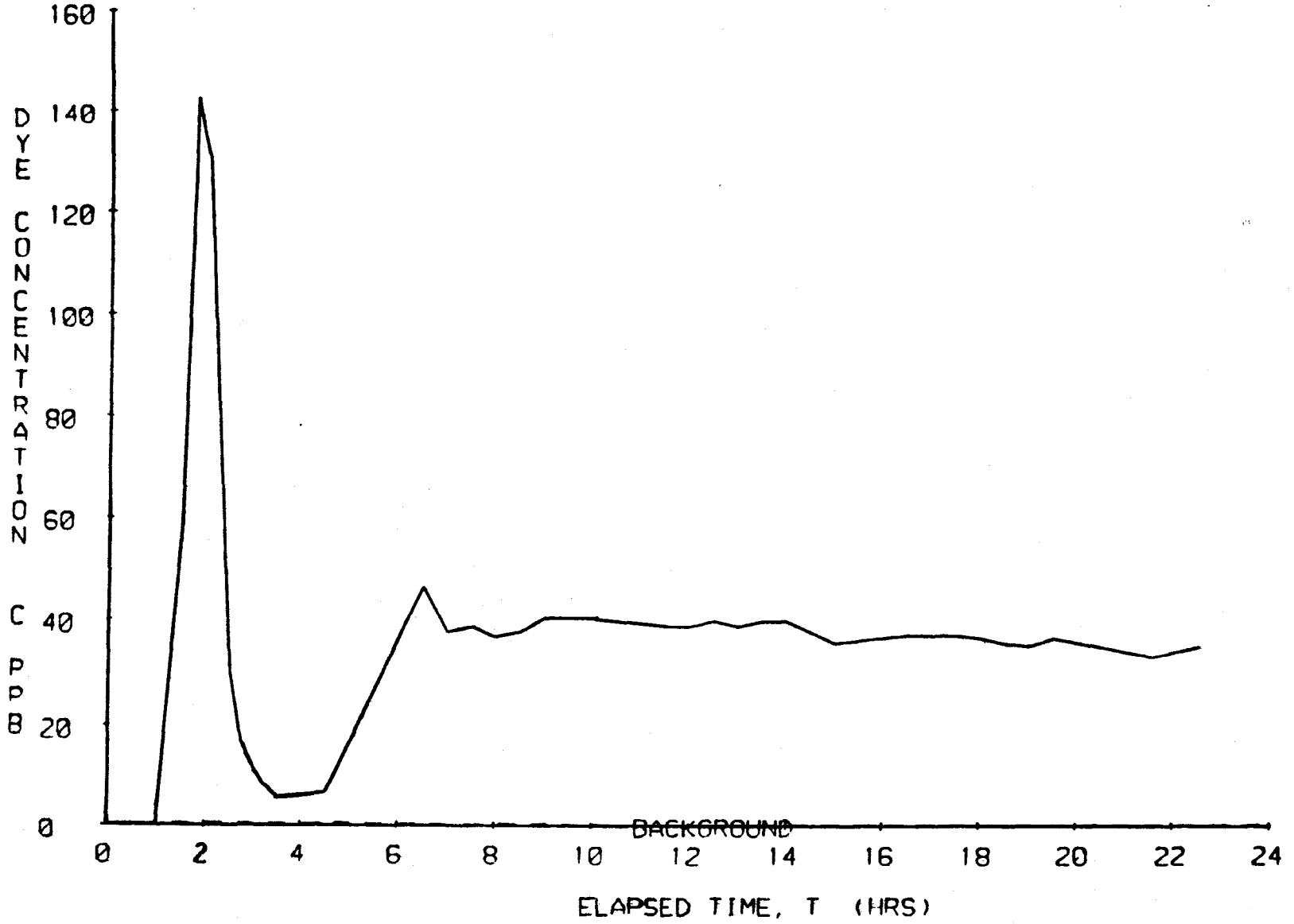

Figure 5. Dye Concentration Inside Kenosha CDF at the Filter Cells.

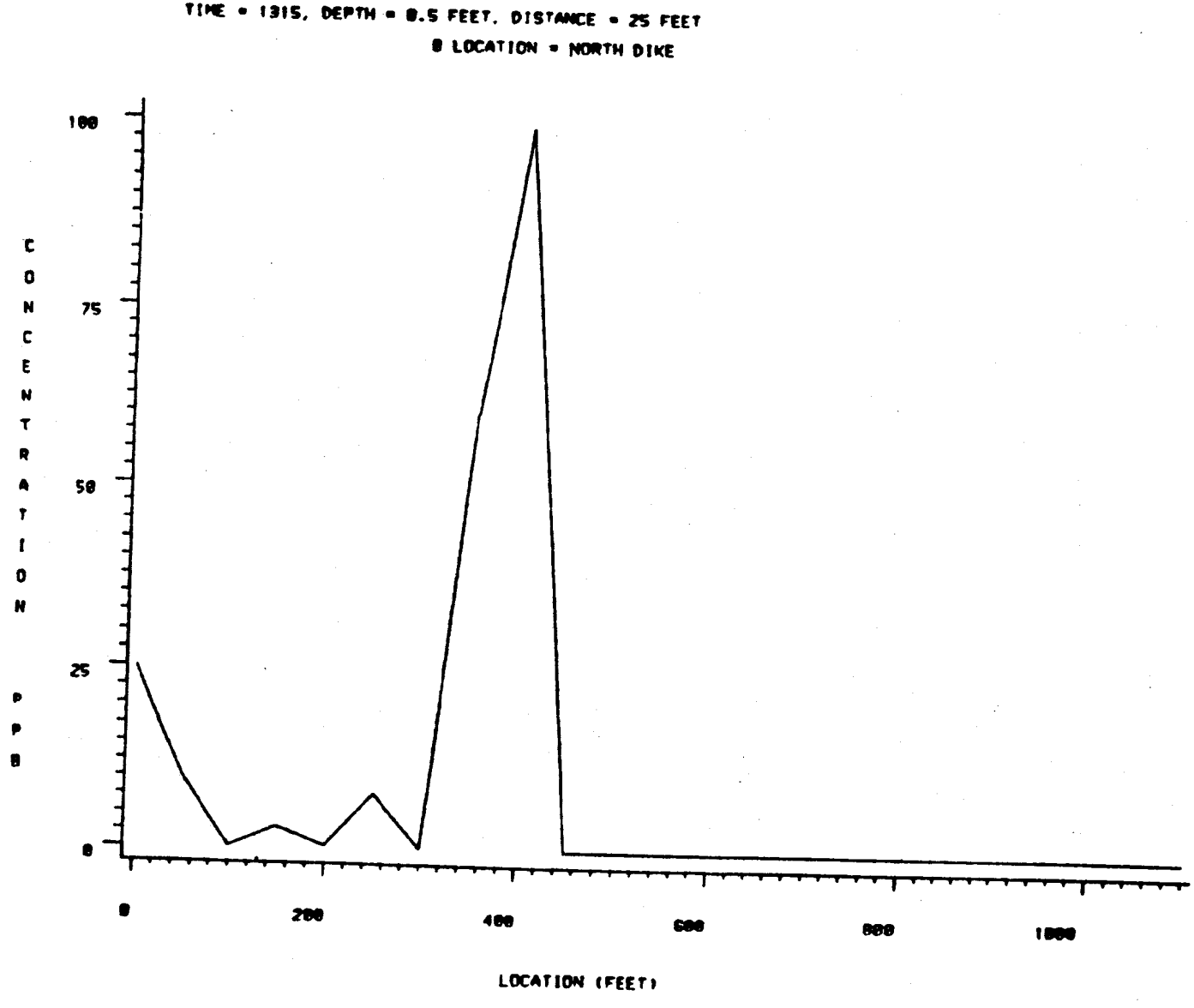

Figure 6. Dye Concentration Along Kenosha East Dike, 1315 Hours, 8 May 84.

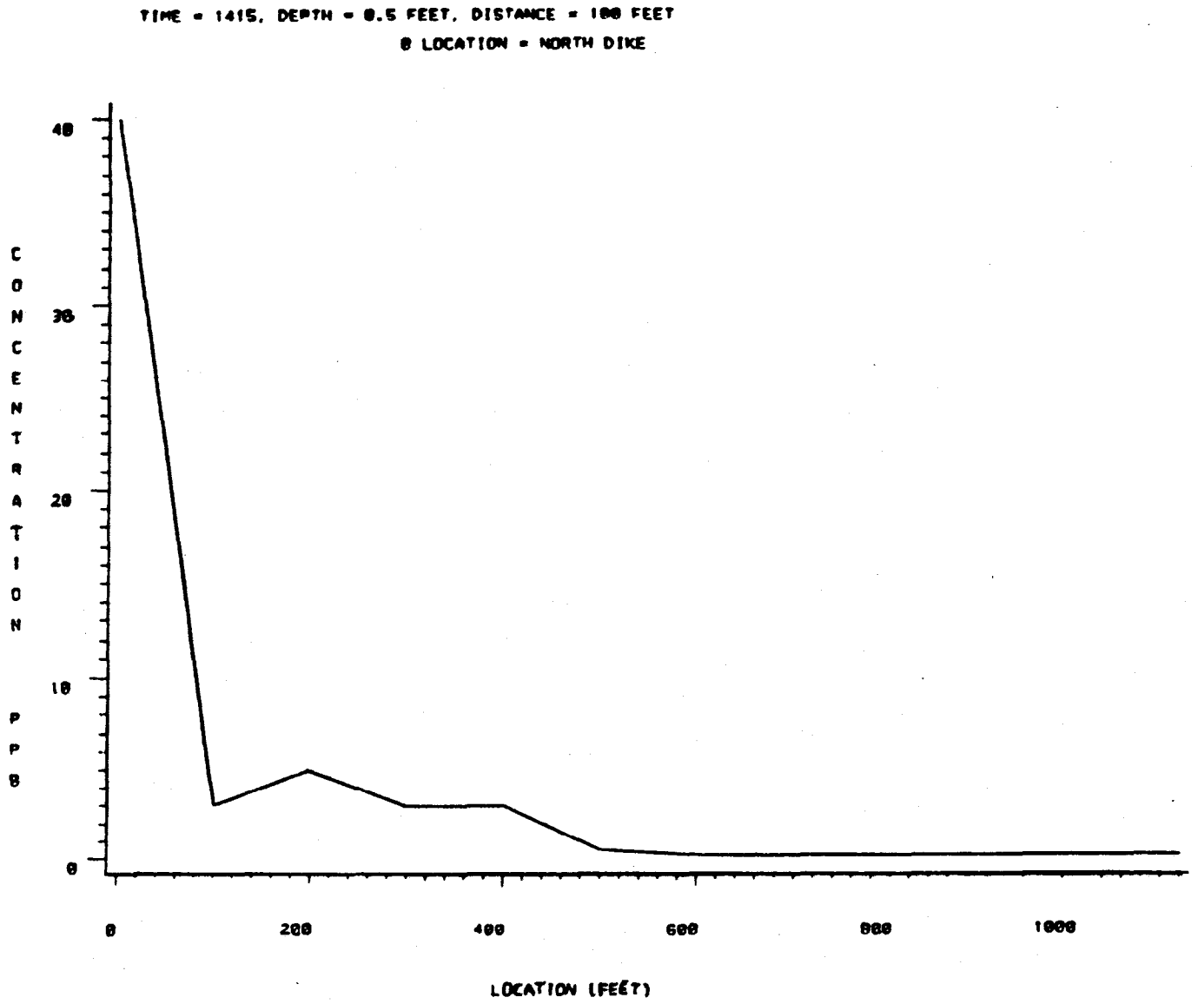

Figure 7. Dye Concentration Along Kenosha East Dike, 1415 Hours, 8 May 84.

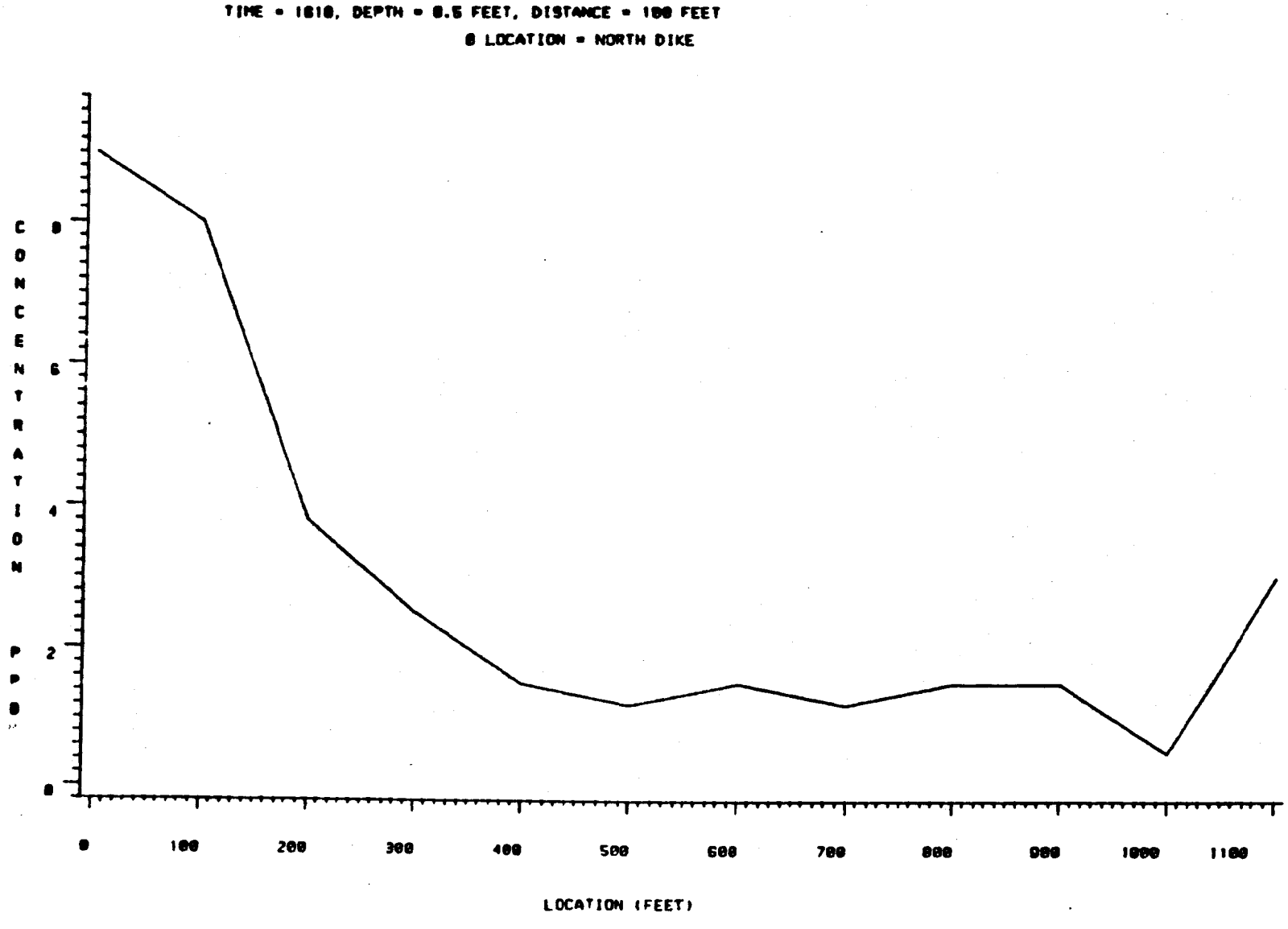

Figure 8. Dye Concentration Along Kenosha East Dike, 1610 Hours, 8 May 84.

concentrated stream of dye initially reached the filter cell prior to dispersion.

Flow Quantification

The flow quantification (relative portion of the flow discharged through the outflow points as compared with the total discharge from the CDF) was estimated using procedures described in Appendix E. The results of the flow quantification study for the Kenosha site are presented in Table 1. Since the filter cell outlet was 70 feet wide and the dye plumes were 15-25 feet wide, relative width weighting factors of 3.0 and 1.0 were used for the filter cell and plumes, respectively, in the flow quantification analysis. The largest outflows were at the East 0-ft and 1100-ft markers. This was not unexpected because of the raised piles at the 1100-ft marker and the existence of a small gap between the channel wall and east dike at the 0-ft marker.

Sampling of the dye concentration inside the Kenosha CDF was insufficient to precisely quantify the inside concentration but certain estimates could be made and conclusions drawn. The inside dye concentration was estimated to be 90 ppb by averaging the four readings (57.0, 142.5, 130.5, 30.0) at the filter cell during the 1330-1430 hours time period when the majority of the outside samples were taken. The dye concentration for the water inside was assumed to be constant and spatially uniform. Based on these approximations, the flow through the filter cell was about 3% of the total, with the flow through the dikes accounting for 97% of the total outflow. Using the extremes of the inside dye concentrations in place of the average and allowing for variation in the dye concentration along the dikes, the flow through the filter cells was estimated to not exceed 10% of the outflow.

Table 1

Kenosha CDF Flow Quantification Data and Results

Plume Number	Location, feet	Dye Concentration, ppb		Percent Flow	
		Inside	Outside	Estimate	Range
1	East[1]-0	90.0	60.0	31.05	20-45
2	East-200	90.0	36.0	10.32	7-16
3	East-350	90.0	34.0	9.40	6-15
4	East-1100	90.0	65.0	40.38	25-60
5	South[2]-100	90.0	25.0	5.94	4-12
Filter Cell	East - 1000	90.0	5.5	2.91	2- 8

[1] 0 = North dike (channel). See Figure 2.

[2] 0 = East dike.

PART III: MANITOWOC HARBOR CONFINED DISPOSAL FACILITY

Site Description

The CDF located at Manitowoc Harbor, Wisconsin, is shown in Figure 9. The site is approximately 1600 feet long and 600 feet wide. As in Kenosha, the Manitowoc site was approximately 25% full before the current dredging operation started. The north and east dikes are exposed to Lake Michigan with the filter cells located in the northeast corner and were similar in design to those at the Kenosha CDF (Figs. 3 and 4). No abnormalities in the dike such as gaps or steel sheet piles were noticed unlike at Kenosha. However, the Detroit District suspected significantly higher outflow from the southeast corner and near the filter cells.

Site Activities Summary

The dredging at Manitowoc Harbor started on the morning of 30 May 1984 and lasted 3 to 4 days. WES personnel arrived at 1430 hours on 30 May and proceeded to inspect the site and pumping arrangements near the south dike. The inflow pipeline extended across a heavily vegetated delta that had been created from previously dredged material. Since the pipeline flow ran across part of the delta, 60 pounds of dye was added to the water in the CDF along the delta's northern edges at 1645 hours. Winds from the south spread the dye towards the filter cell and north dike. An automatic sampler collected water samples at the filter cell during the night of 30 May in order to document the dye dispersion.

At 0830 hours on 31 May, the following was observed:

a. Dye had dispersed throughout the entire site,

b. Dye plumes were visible on the west dike near the 600-foot marker and at the northwest corner, and

c. Small dye plumes had formed outside the east dike where dye had remained in a small reach of water between the delta and the east dike.

Dye had discharged through the west dike during the night resulting in readings of 5-7 ppb in the marina harbor 300 feet away from the dikes. The sidewalk and narrow marina channel trapped the dye in the enclosed area;

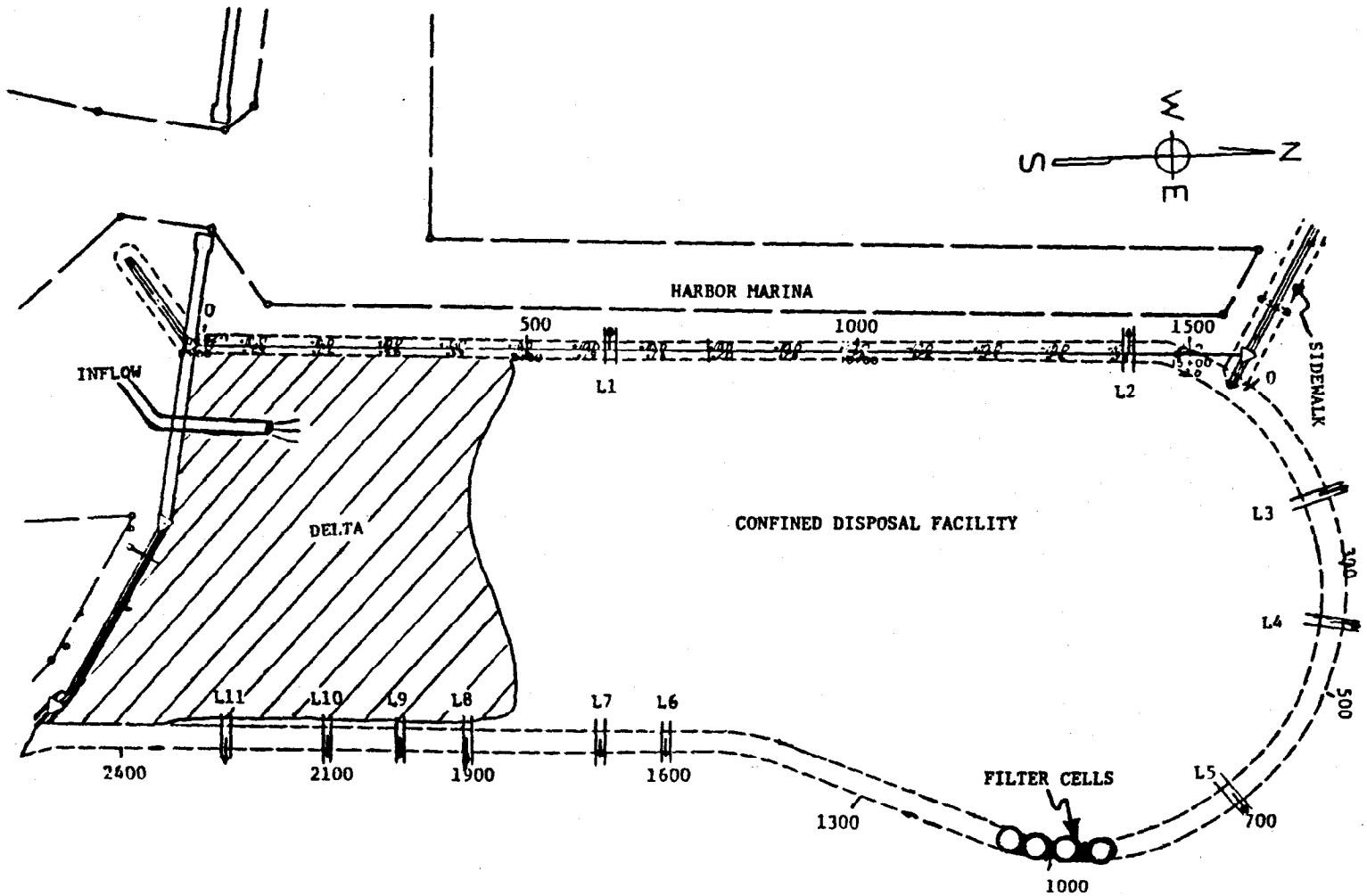

Figure 9. Manitowoc Harbor Confined Disposal Facility.

therefore, background readings were obtained in the lake near the hydraulic dredge. At 1000 hours, sampling was started outside the CDF along the west dike and then proceeded along the north and east dikes.

The morning sampling indicated the dye plume locations (denoted as L1 through L11 in Figure 9) and samples were collected inside and outside the dikes at these points for the flow quantification calculations. Sampling outside the dikes continued throughout the afternoon at various depths and distances around the entire site. Data from selective sampling times are tabulated in Appendix B, (Tables B-2 to B-4), and graphed in Figures 11 and 12.

Results and Discussion

Figure 10 is a plot of the dye concentration inside the CDF at the filter cells. The gradual increase in concentration verifies that the dye dispersed throughout the CDF from the south end (probably due to the wind) and reached the filter cells located in the northeast. An average concentration of 25 ppb would have resulted from complete dispersion of the 60 pounds of dye poured into the site. The plot indicates that the dye was almost completely dispersed after 21 hours and was well dispersed during sampling. The dye concentrations at the filter cell are given in Table B-1 in Appendix B.

A sediment plume was visible at the 625-ft marker (L1 in Figure 9) outside the west dike before the dye was added. A dye plume was also observed near that point when conducting the outside sampling. As Figure 11 shows, a second plume was also detected at the 1400-ft marker (denoted as L2 in Figure 9) near the northwest sidewalk. Concentration values were higher between the 800- and 1200-ft markers than between the 0- and 400-ft markers because the dilution was less in the 800- to 1200-ft range because the area was an enclosed marina while the entrance to the marina at the 0-ft marker provided dilution in the 0- to 400-ft range. Grab samples taken while sampling verified that the dye concentration increased near the 600- and 1400-ft markers.

Readings from continuous sampling were taken every 30 seconds as the boat moved along the north and east dikes. There were no markers placed on these dikes; therefore, the distance covered was calculated in order to plot the data in Figure 12. The two samplings (results shown in Figure 12) were conducted to detect dye plumes as well as to check if there was any

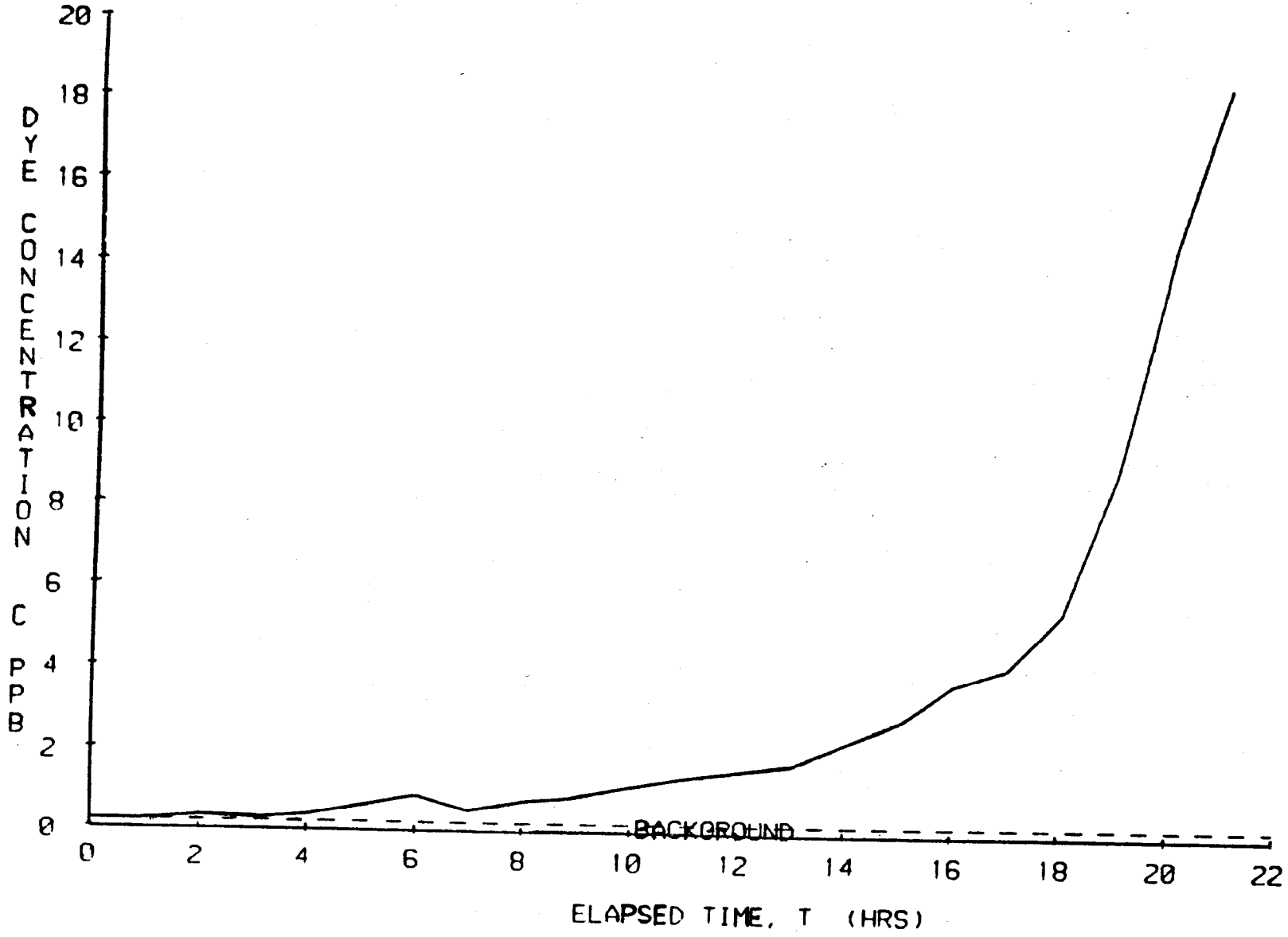

Figure 10. Dye Concentration Inside Manitowoc CDF at the Filter Cells.

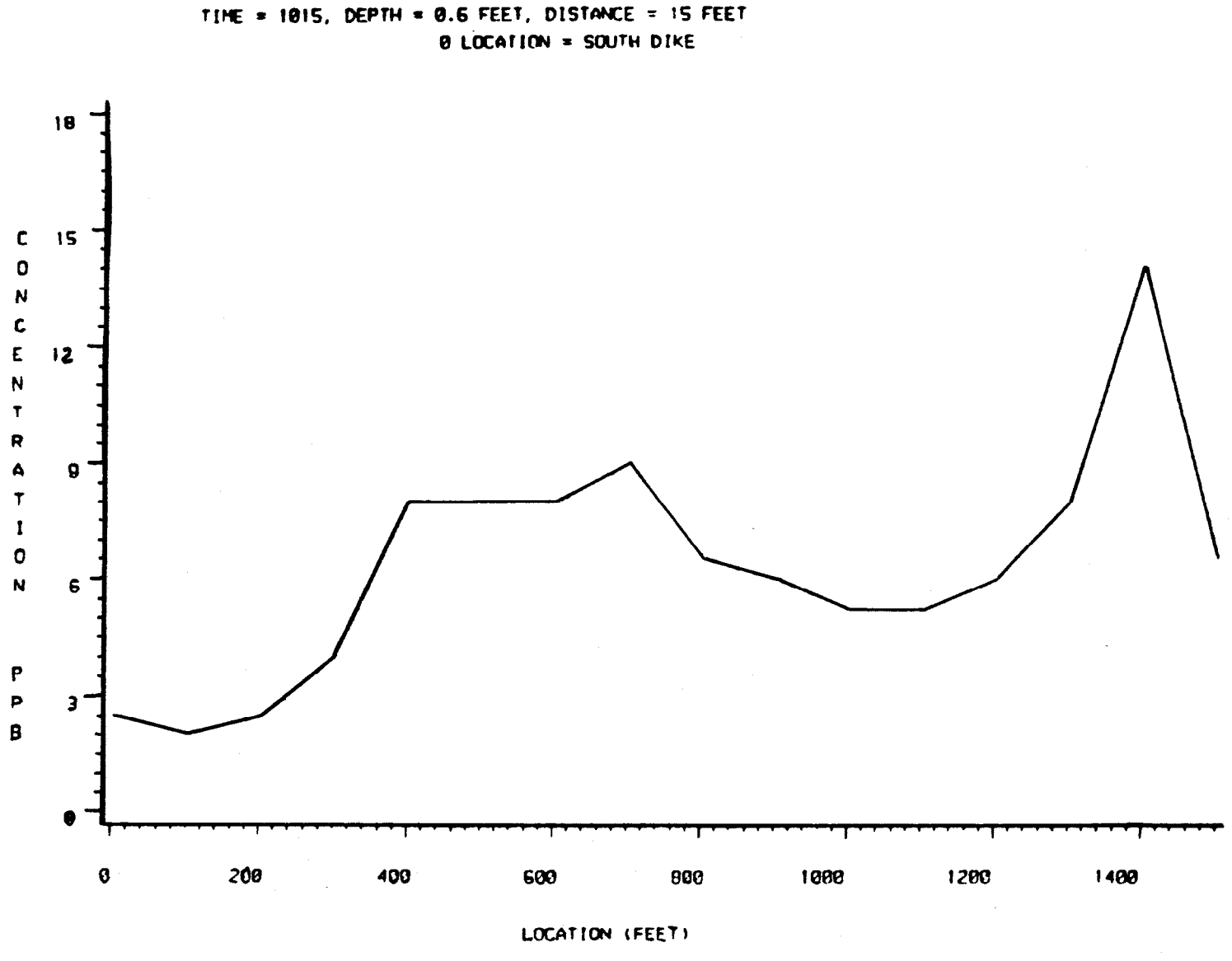

Figure 11. Dye Concentration Along Manitowoc West Dike, 1015 Hours, 31 May 84.

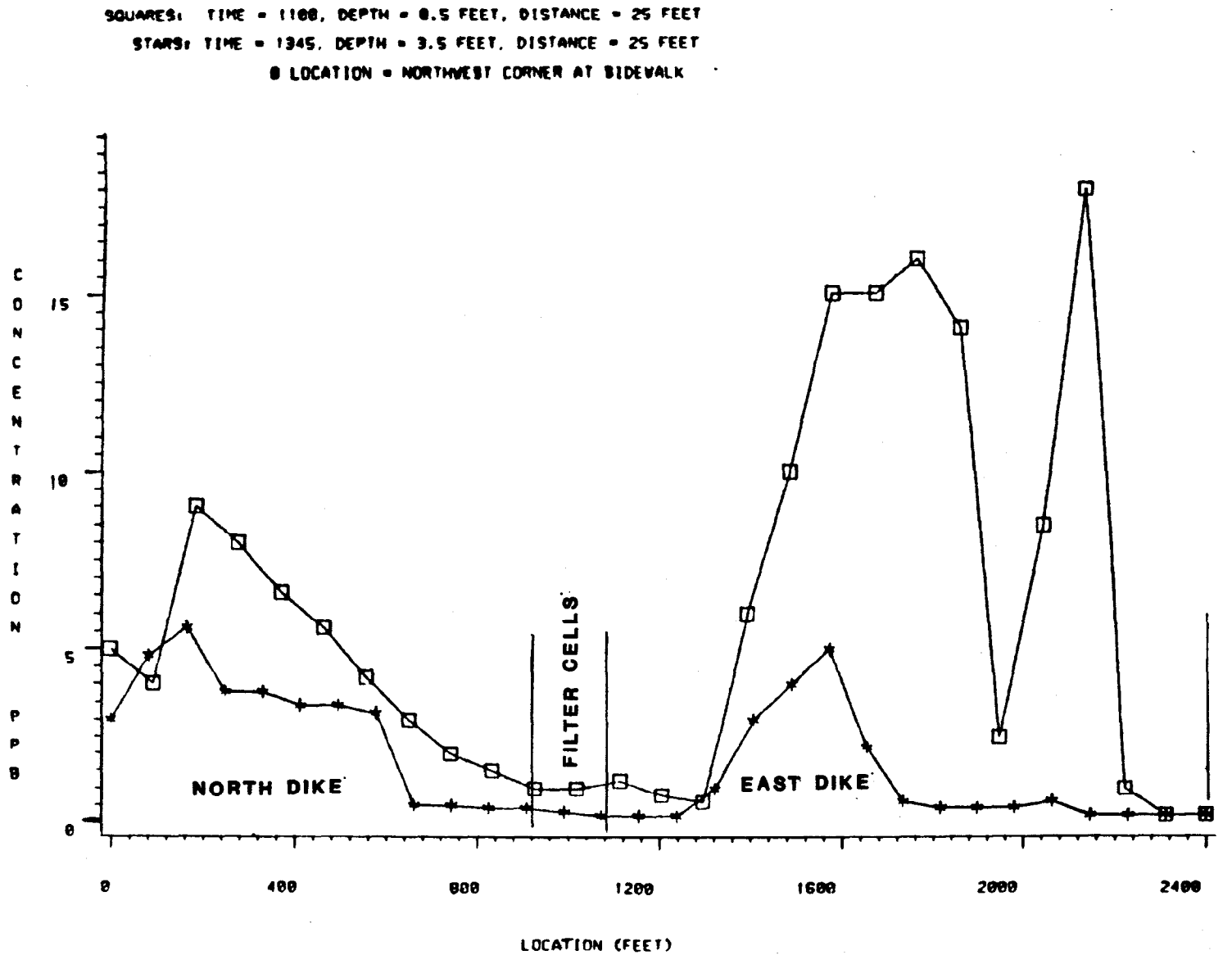

Figure 12. Dye Concentration Along Manitowoc North and East Dikes, 1100 and 1345 Hours, 31 May 84.

correlation between depth and relative concentration. Comparing the sampling conducted at different depths (0.5 ft and 3.5 ft) at a distance of 25 ft from the dike showed that peaks occurred at similar locations at both depths except for an additional peak at the 2100-ft marker at a depth of 0.5 ft and that concentrations were relatively higher at the 0.5 ft depth than at the 3.5 ft depth. The sampling indicated large outflows at several points along the north and east dikes.

Flow Quantification

To quantify the outflow at the Manitowoc site, grab samples from inside and outside the CDF were collected at the filter cell as well as at eleven locations where possible outflows had been identified during the sampling outside the dikes. These locations are marked in Figure 9. The size of the plumes were small except at the 625-ft marker on the west dike. Therefore, the relative width weighting factors used in the flow quantification analysis were: 10.0 for the filter cell, 2.0 for the plume at the west 625-ft marker, and 1.0 for the other plumes. The procedure for the flow quantification analysis is presented in Appendix E and the data and results are presented in Table 2.

The results indicate that the two largest outflows were at locations 200 feet on either side of the northwest sidewalk. The West-625 outflow was fairly large as expected and a point near the delta's northern edge had the highest flow along the east dike at the 1900-ft marker. Based on the results of this evaluation, the flow rate through the filter cells was estimated account for less than 3% of the total flow.

Table 2

Manitowoc CDF Flow Quantification Data and Results

Plume Number	Location, feet	Dye Concentration, ppb		Percent Flow	
		Inside	Outside	Estimate	Range
1	West[1]-625	22.0	8.0	14.97	4-17
2	West-1400	20.0	11.0	16.12	10-20
3	NE[2]-200	18.0	12.0	26.42	22-36
4	NE-400	17.5	7.5	9.81	7-15
5	NE-700	16.0	4.8	5.52	3- 7
6	NE-1600	21.5	1.15	0.63	.3-.8
7	NE-1700	29.5	4.9	2.57	1- 3
8	NE-1900	59.0	29.0	12.90	11-17
9	NE-2000	104.0	23.5	3.89	2- 5
10	NE-2100	230.0	33.5	2.28	1- 3
11	NE-2250	450.0	75.0	2.68	1- 4
12	Filter cell (NE-1000)	18.5	0.5	2.24	1- 3

[1] 0 = South dike.

[2] 0 = Northwest corner at sidewalk. See Figure 9.

PART IV: MILWAUKEE HARBOR CONFINED DISPOSAL FACILITY

Site Description

The CDF is located in the southern portion of Milwaukee Harbor and is basically trapezoidal in shape (Figure 13). Three sides (north, east and south) are exposed to Lake Michigan and the two filter cells are located in the north dike. The design surface area was approximately 50 acres, but previous disposal operations have formed a large delta of dredged material along the south dike, comprising approximately 40% of the initial surface area. In addition, small vegetated deltas have formed at two locations along the east dike (between the 150- and 250-ft markers and the 550- and 875-ft markers).

The exposed dikes at the Milwaukee Harbor CDF were constructed with solid cores above the mean low water elevation unlike the dikes at the Kenosha and Manitowoc Harbors CDF's. The north and east dikes were constructed using a crushed stone and sand core with riprap protection on both sides (Figure 14) and the south dike consists of filled steel sheet pile cells (cofferdams). No outflow along the south dike was expected due to the cell design and the location of the large delta; therefore, this dike was not monitored. The filter cells at Milwaukee (Figure 15) were similar in design to those used at Kenosha and Manitowoc except that the cells at Milwaukee were not covered by riprap.

Site Activities Summary

On 17 September 1984, at 1200 hours, Detroit District personnel began pumping in water at the CDF's northwest corner inlet location through three 6-inch diameter pipes. At 1700 hours, WES personnel arrived at the site and set up automatic water samplers inside and outside the filter cells. Due to the wind direction (towards the north dike) and inlet location (pump discharge point), it was decided to add the majority of the dye (fifty pounds) along the south delta at 1800 hours. In addition, 15 pounds of dye were poured in at the inlet location.

Distances along the dike were measured and marked off every 100 feet during the morning of 18 September. Three plumes (at the 100-, 250- to 350- and 850- to 1000-ft markers) were visually detected along the east dike during

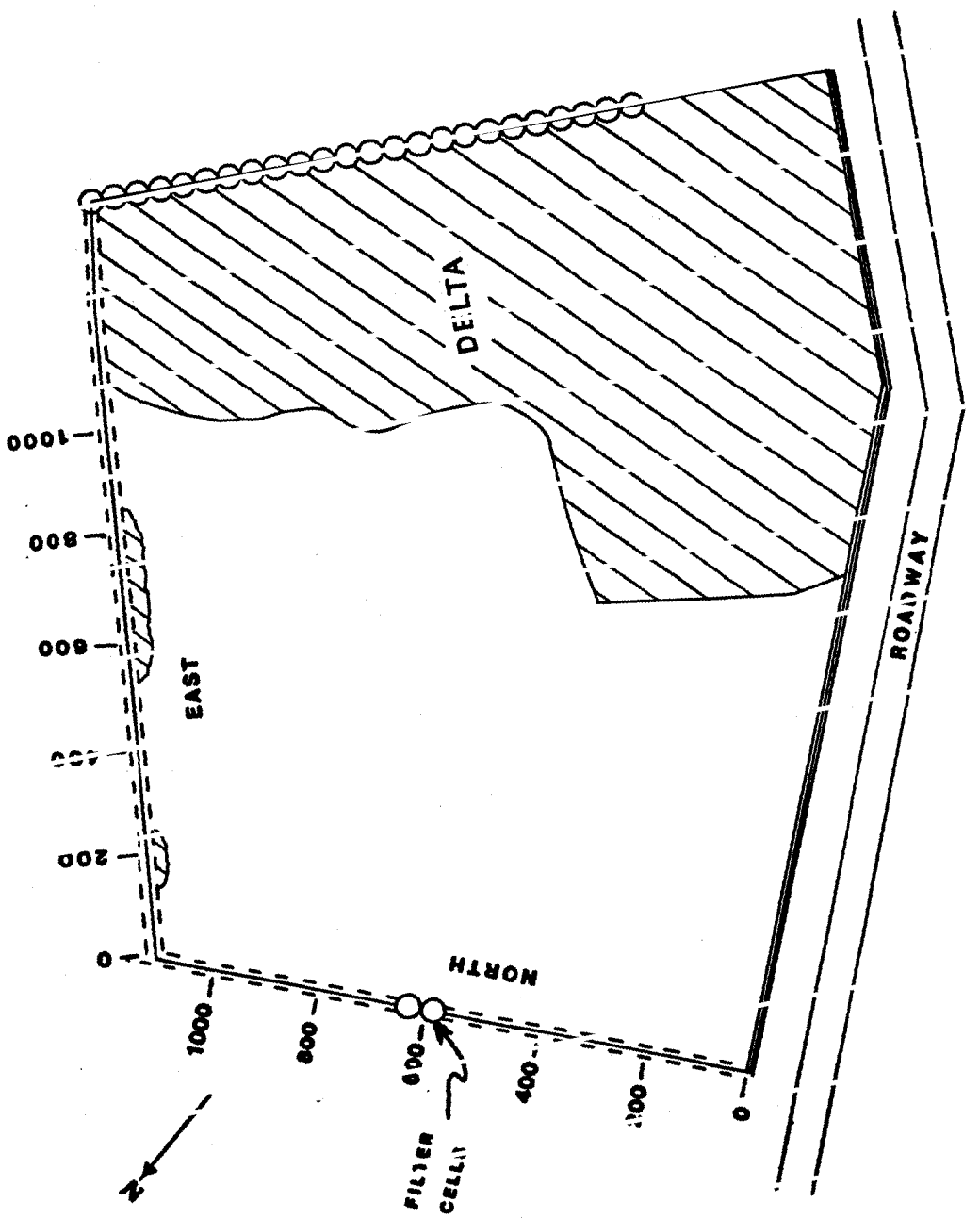

Figure 13. Milwaukee Harbor Confined Disposal Facility.

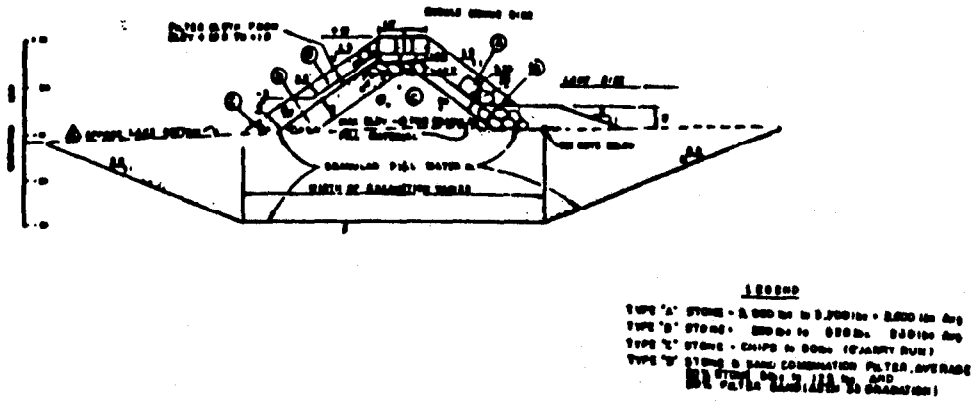

Figure 14. Typical Cross-Section of Milwaukee CDF North and East Dikes.

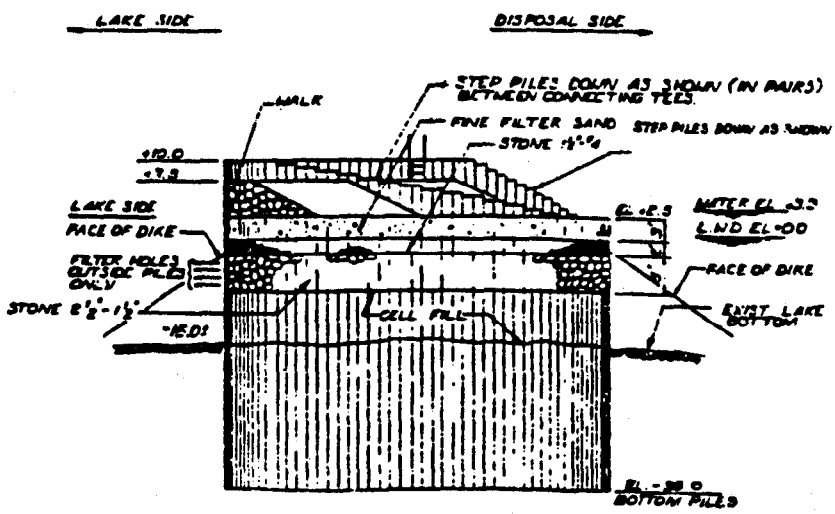

Figure 15. Typical Cross-Section of Milwaukee CDF Filter Cells.

this period. The winds had shifted towards the east, which may account for the fact that no plumes were visible along the north dike at this time. However, the pump operators mentioned that dye was observed flowing through the northwest corner shortly after adding dye at the inlet which was located in this corner.

Upon completion of the marker placements, continuous sampling was conducted outside the CDF's north and east dikes. Dye plumes were detected at various locations along the east dike, including one large visible plume near the 900-ft marker. Along the north dike plumes were detected only near the northeast corner. After completion of the continuous sampling, grab samples were obtained at the dye plume locations.

On the morning of 19 September, with winds blowing towards the north, dye plumes were visible along the north dike; however, dye plumes along the east dike were not readily visible at this time. Later in the morning when the winds shifted, the east dike dye plumes were again visible, though not as prominently as on 18 September. Grab samples were then obtained at all plume locations as well as along the entire length of the north and east dikes. Continuous sampling outside the CDF was conducted during the afternoon and the test was concluded at 1600 hours. Results of selected sampling periods from both days are tabulated in Appendix C, (Tables C-3 to C-9), and graphed in Figures 18 through 24.

On both 18 and 19 September, dye plumes were more visible outside the dike towards which the wind was blowing. This is understandable considering that the wind would cause a head to build up on the downwind dike while there was no net build up of head in the CDF. Consequently, the head on the downwind dike would be greater inside the CDF than outside while the opposite was true for the upwind dike. This produces a differential head across the dikes that would drive water and dye out of the CDF along the downwind dike while water would seep into the CDF along the upwind dike. The rate of flow is dependent on the differential head across the dike and therefore the concentration of the dye outside the CDF would be dependent on the wind speed and direction.

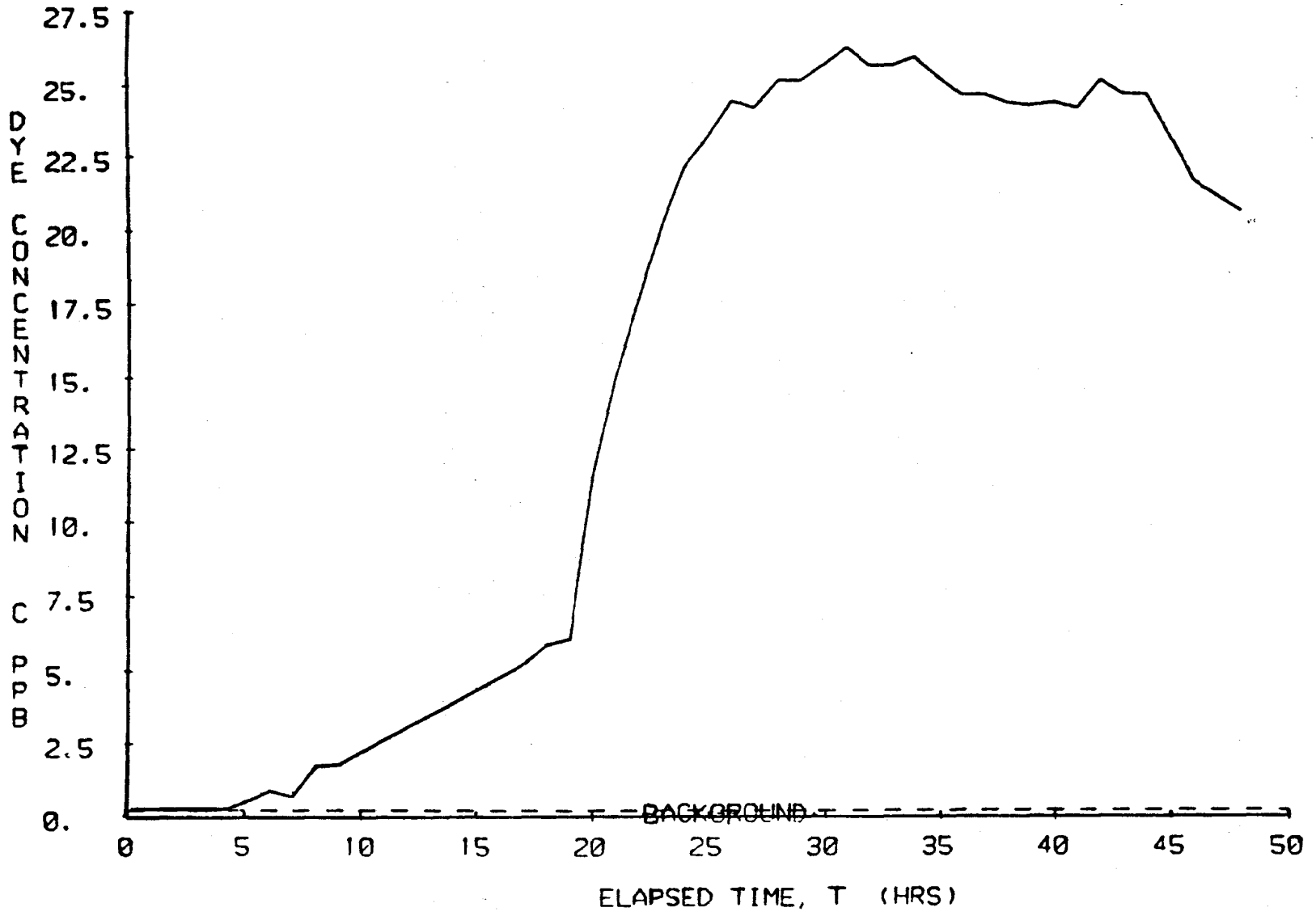

Figure 16. Dye Concentration at the Milwaukee Harbor Filter Cells Inlet.

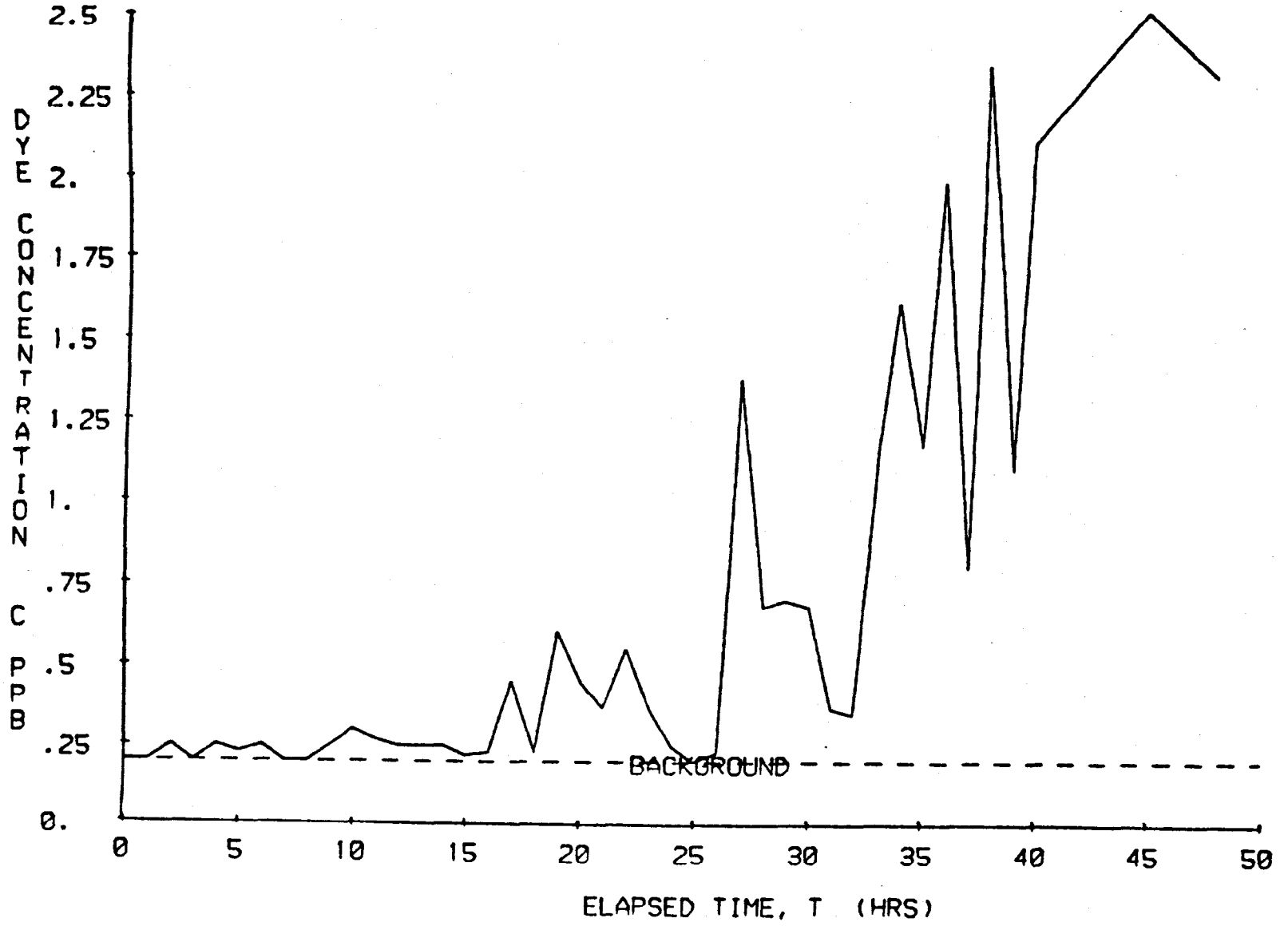

Figure 17. Dye Concentration at the Milwaukee Harbor Filter Cells Outlet.

Results and Discussion

Plots of the dye concentration inside and outside the CDF's filter cells are presented in Figures 16 and 17, respectively. The curves indicate that the dye dispersed throughout the CDF and then passed through the filter cell. The concentrations on the inside approached the test design average of 30 ppb while the concentrations outside the filter cell remained below 3 ppb. The data is presented in Tables C1 and C2 in Appendix C.

The dye concentrations of grab samples that were obtained outside of the CDF during the morning of 18 September are presented in Figure 18. The concentration peaks correspond to the locations where dye plumes were visible when the winds were blowing towards the east dike.

Figures 19 through 22 are plots of the data obtained from the continuous sampling outside the CDF on 18 September. The first sampling time (Figures 19 and 20) indicated plumes at the northeast corner as well as at three locations along the east dike. Figure 20 clearly demonstrates the effects of the inside deltas. The dye concentrations decreased essentially to zero outside the CDF along the delta located in the 550- to 875-ft range. The decrease in concentration outside the delta located at the 200-ft marker was not as pronounced due to the smaller size of the delta.

Samples from the second sampling time (Figures 21 and 22) were collected at different depths than the first time; however, the results are similar to the first sampling time (Figures 19 and 20). Dye plumes were detected in the same ranges as before and the dye concentration decreased outside the deltas.

Figures 23 and 24 present the data from sampling after 36 hours had elapsed since addition of the dye. The winds had shifted towards the north dike and plumes along this dike became more readily visible. Dye plumes were detected all along the north dike as indicated by Figure 23. Along the east dike (Figure 24), plumes were detected at the same areas noted previously but the dye concentrations were much lower than before when the wind was blowing toward this dike.

By comparing Figures 19 through 24, it can be concluded that several regions of higher outflows exist and that general seepage occurs along the north and east dikes. However, visible detection of the dye plumes seemed to depend on the direction of the wind. This differs from the Kenosha and

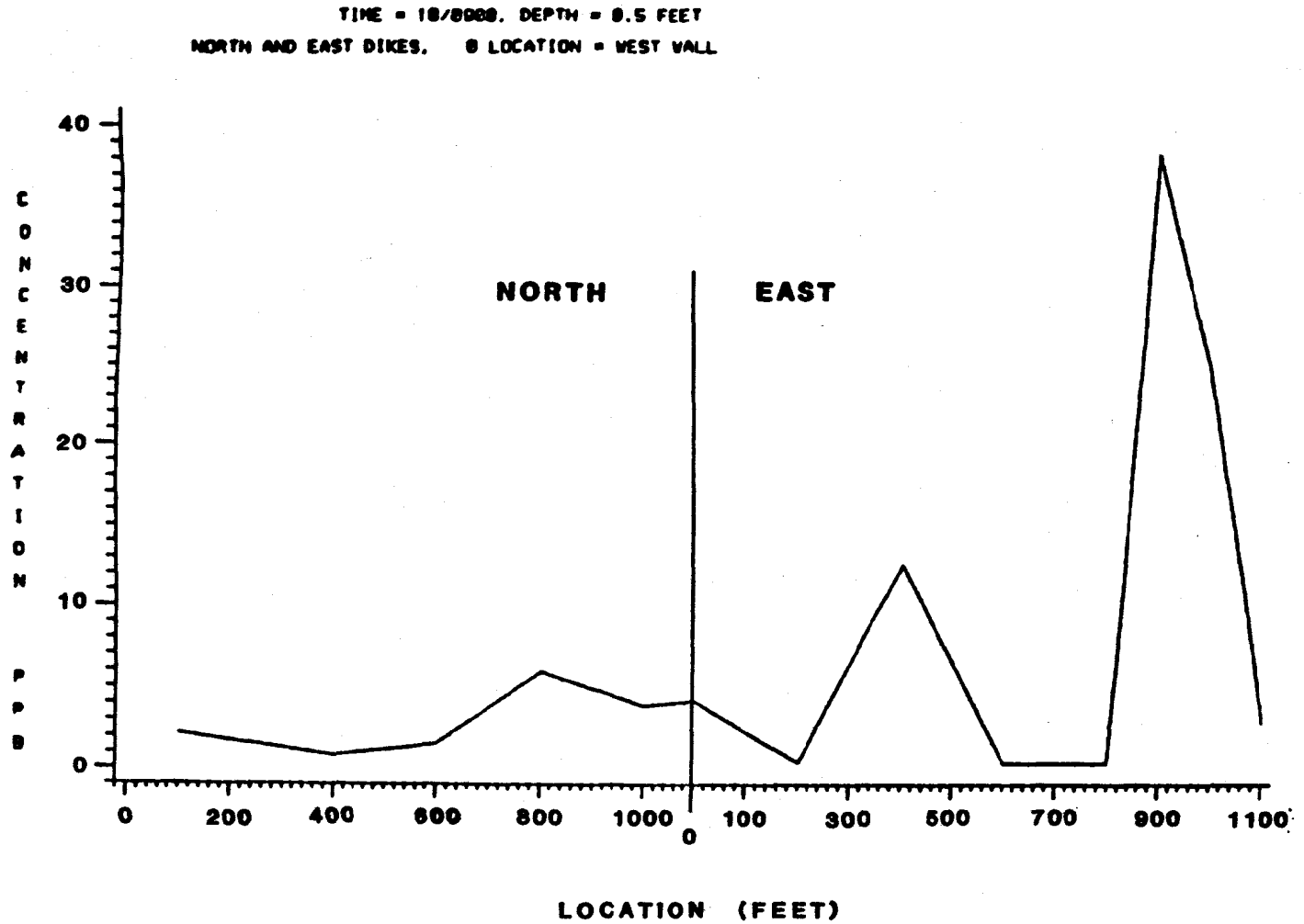

Figure 18. Dye Concentration Along Milwaukee North and East Dikes at 0900 Hours, 18 Sep 84.

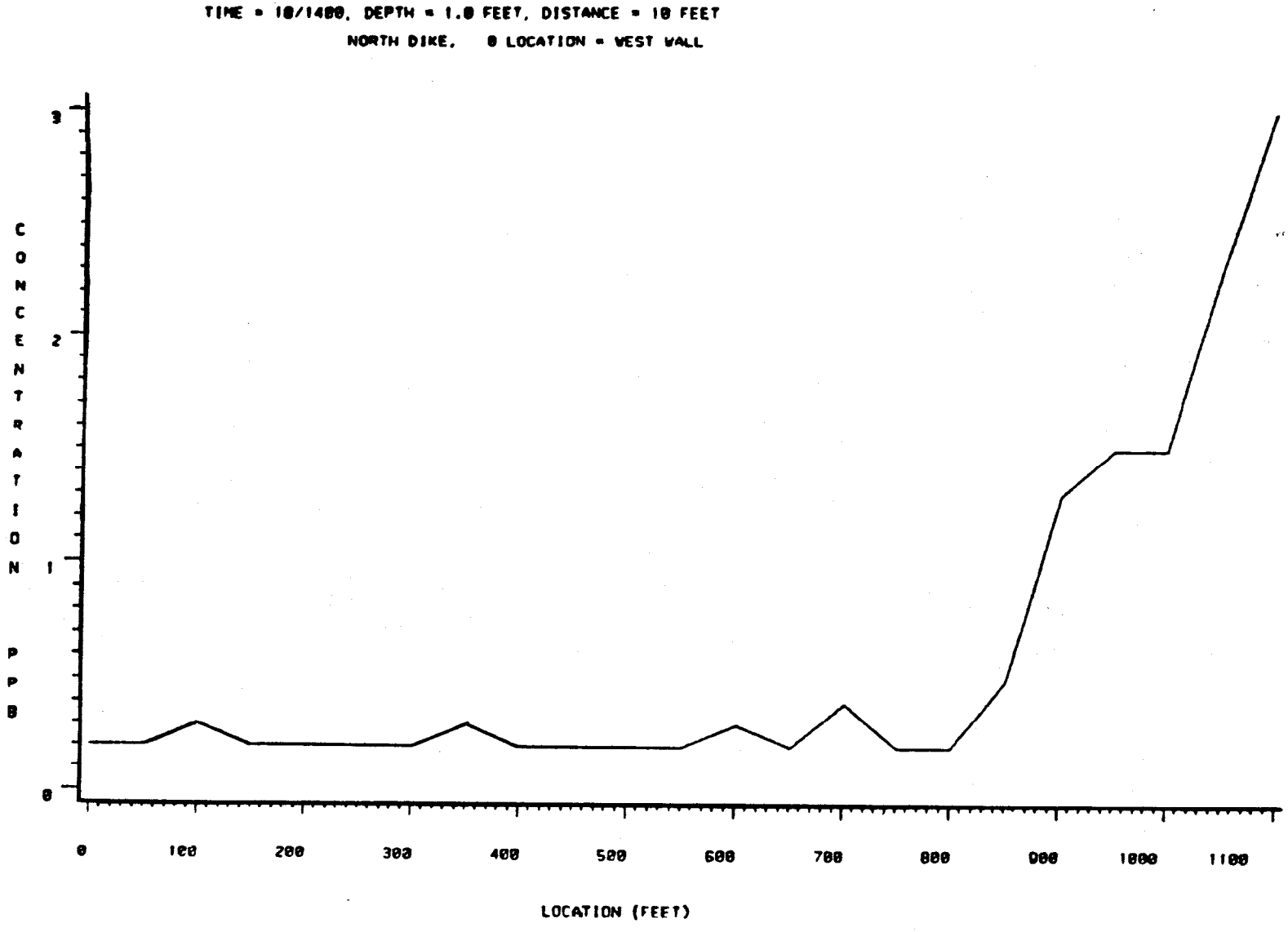

Figure 19. Dye Concentration Along Milwaukee North Dike at 1400 Hours, 18 Sep 84.

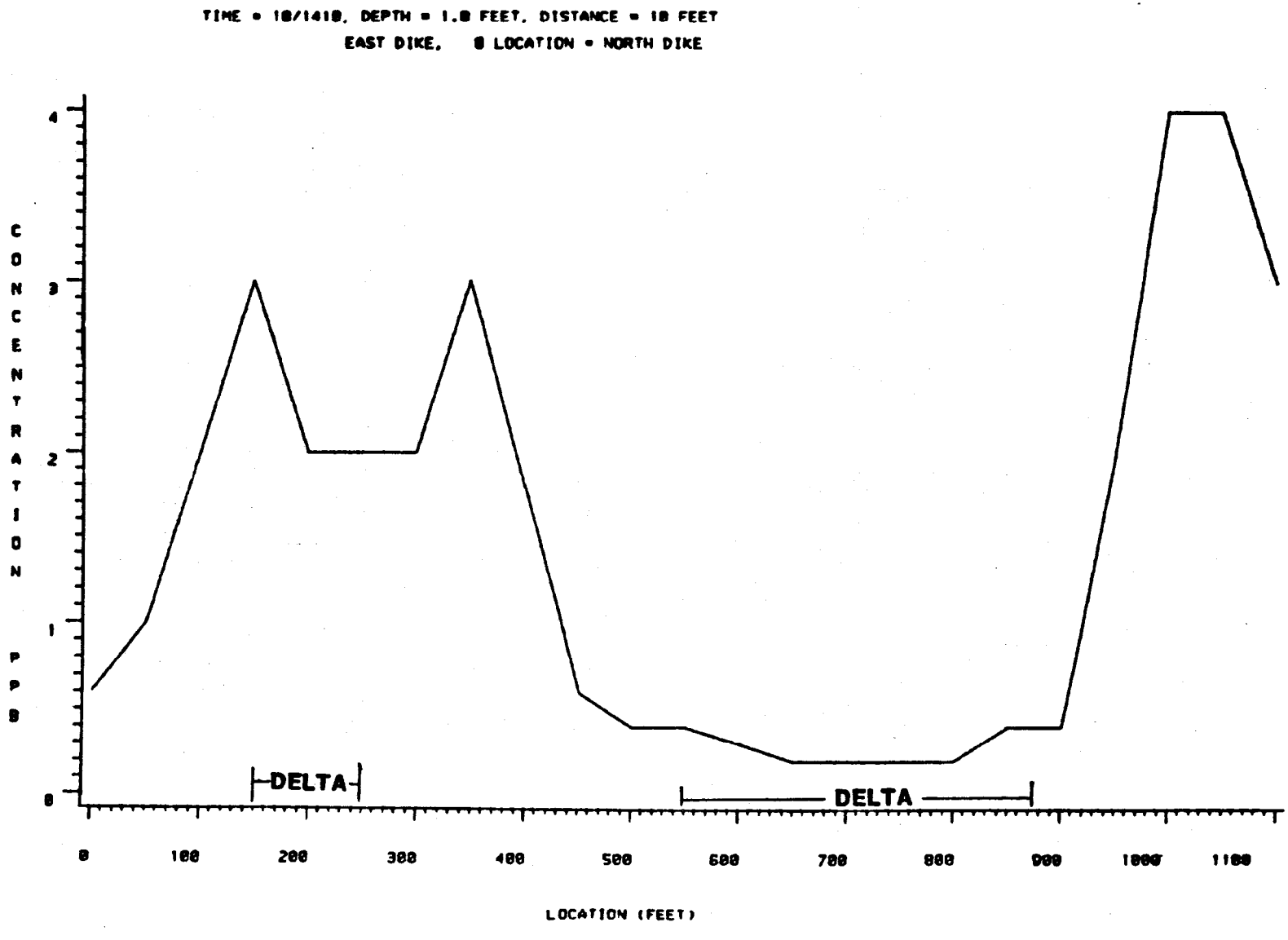

Figure 20. Dye Concentration Along Milwaukee East Dike at 1410 Hours, 18 Sep 84.

Figure 21. Dye Concentration Along Milwaukee East Dike at 1440 Hours, 18 Sep 84.

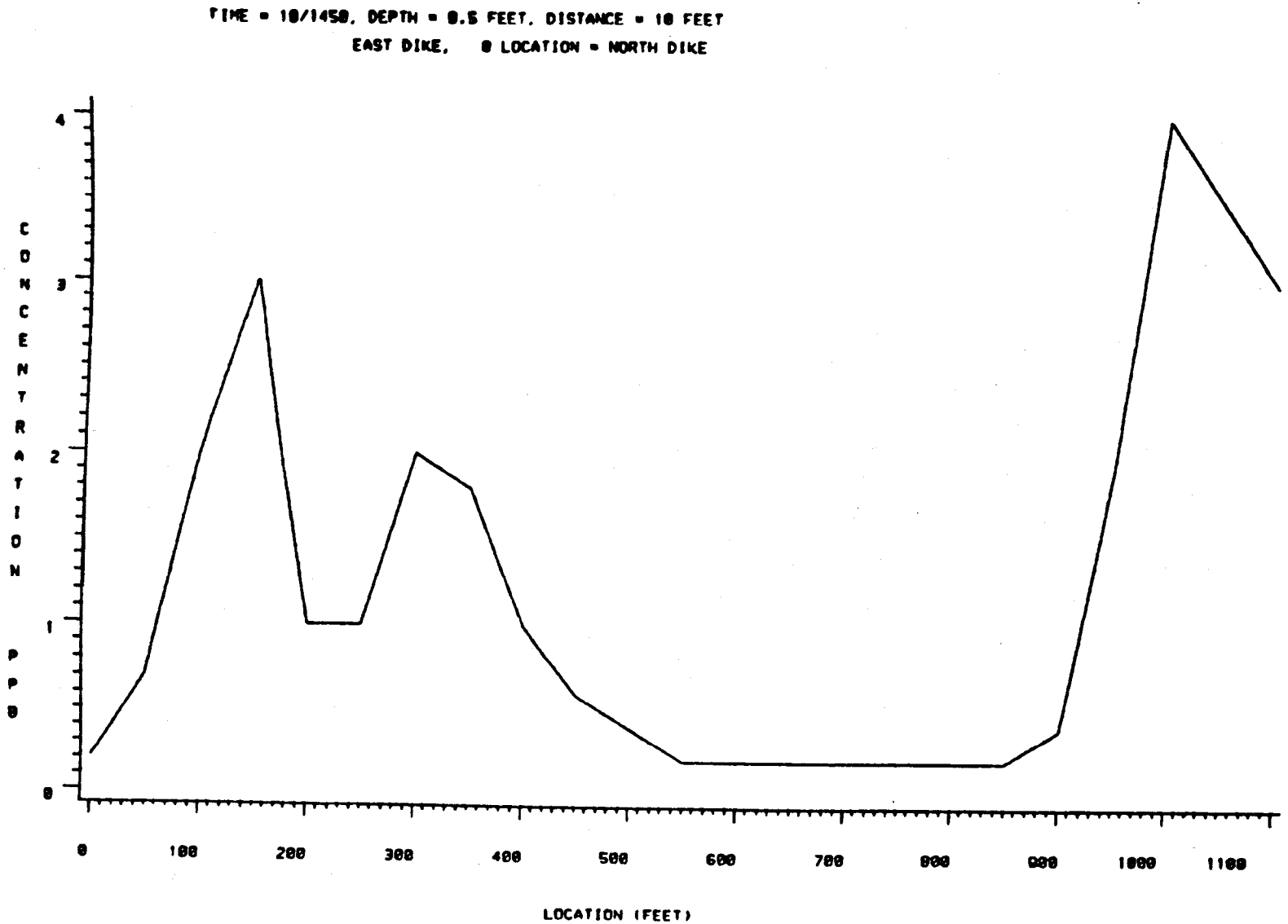

Figure 22. Dye Concentration Along Milwaukee East Dike at 1500 Hours, 18 Sep 84.

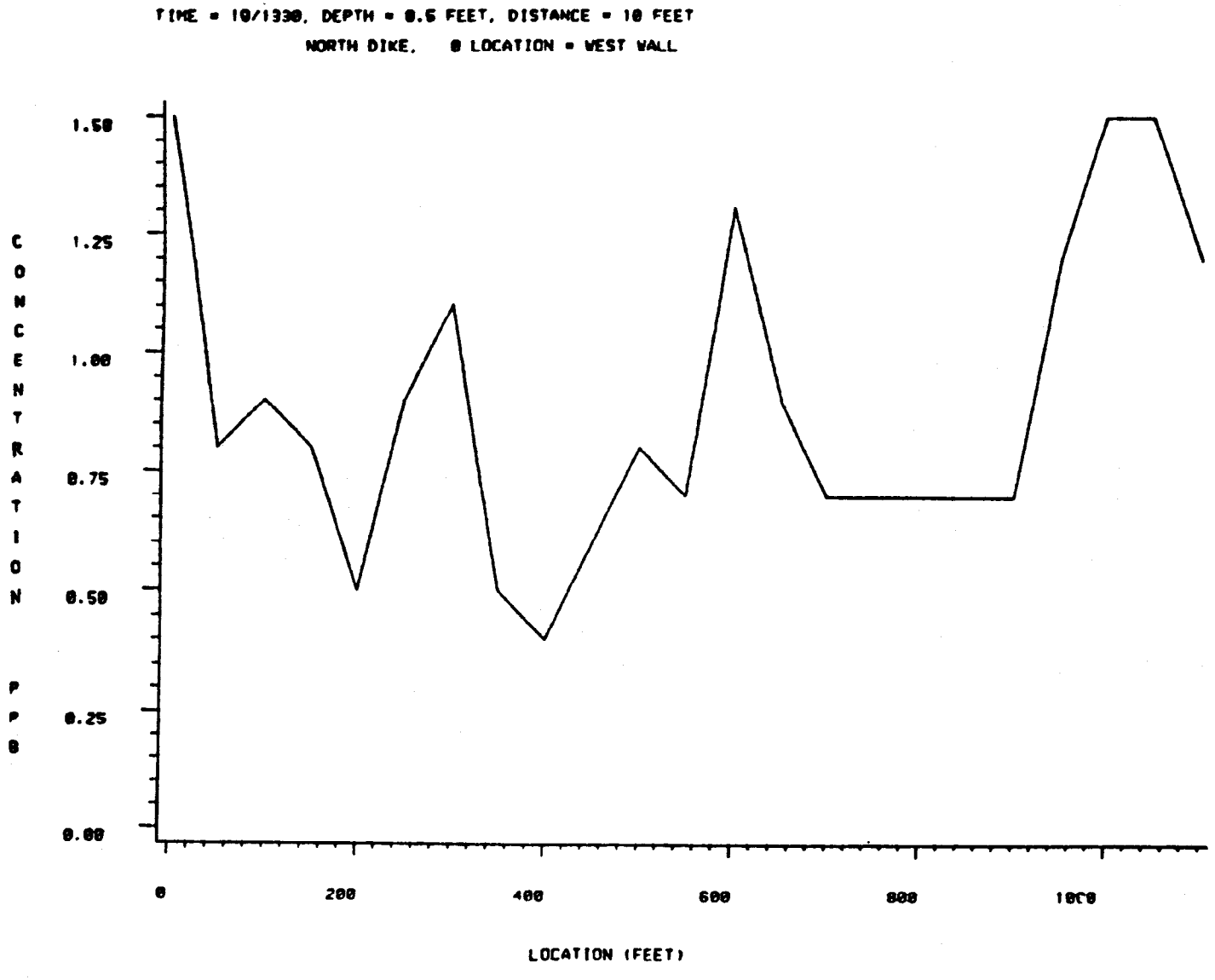

Figure 23. Dye Concentration Along Milwaukee North Dike at 1330 Hours, 19 Sep 84.

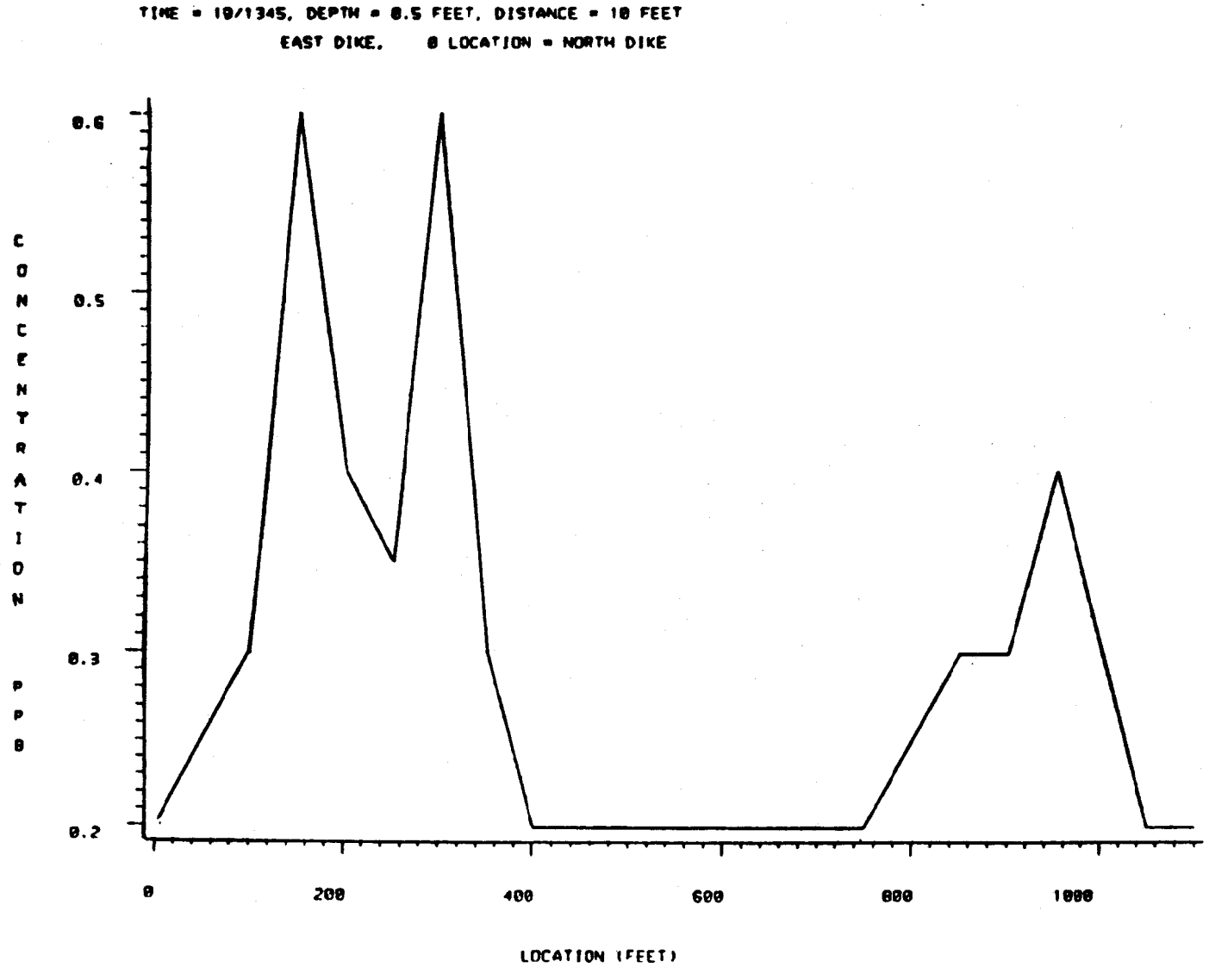

Figure 24. Dye Concentration Along Milwaukee East Dike at 1345 Hours, 19 Sep 84.

which had distinctive plumes that remained clearly visible throughout the duration of the study.

Although discrete plumes were not as distinguishable as those at Kenosha and Manitowoc, similarities between the sites were noted. Two areas of greater than average seepage or outflow occurred on either side of the northeast corner. This is similar to the pattern observed near the Manitowoc sidewalk junction and the Kenosha southeast corner. Greater than average seepage was also detected at the northwest corner of the Milwaukee CDF which is similar in construction to the northeast corner of the Kenosha CDF where a similar but more pronounced problem also occurred.

Dye was detected continuously outside the filter cells at the Milwaukee CDF, unlike the Kenosha and Manitowoc CDF's. This indicates that the filter cells at Milwaukee did pass a portion of the flow. More flow may have been discharged through the filter cells at Milwaukee than at Kenosha and Manitowoc for two reasons:

(1) The substantial width of the solid core dikes provided more resistance to seepage than the steel sheet pile and riprap dikes, and

(2) The filter cells were not covered with riprap, exposing more surface area for discharging water.

Flow Quantification

The percent of the total flow discharged through filter cells and the amount of flow passing through the dikes were estimated using a modification of procedures employed in the Kenosha and Manitowoc studies. The first modification was that reaches of 100 feet of dike were used instead of discrete dye plume locations. This was necessary due to the physical characteristics of the dike (solid core) and the difficulty in pinpointing the plume locations. It is apparent that the flow passed through the dike along its entire length instead of rushing through discrete points as at Kenosha and Manitowoc. This necessitated the use of average concentrations along the inside as well as along the outside of each 100-ft reach.

Due to the apparent wind effect on the magnitude of the flow, data were used from samples collected when the wind was blowing towards the respective dike. This procedure yields average seepage rates for all reaches in relative

Table 3

Milwaukee CDF Flow Quantification Data and Results

Reach Number	Location, feet	Dye Concentration, ppb		Percent Flow Estimate
		Inside	Outside	
1	North 0-100	24.1	1.07	6.22
2	100-200	24.1	0.73	3.73
3	200-300	24.1	0.83	4.46
4	300-400	24.1	0.66	3.23
5	400-500	24.1	0.60	2.80
6	500-600	24.1	0.93	5.19
7	Filter Cells	24.1	0.97	5.48
8	700-800	24.1	0.70	3.52
9	800-900	24.1	0.70	3.52
10	900-1000	24.1	1.13	6.67
11	1000-1100	24.1	1.40	8.70
12	East 0-100	50.0	1.20	3.37
13	100-200	50.0	2.33	7.36
14	200-300	50.0	2.00	6.17
15	300-400	50.0	2.26	7.10
16	400-500	50.0	0.93	2.45
17	500-600	50.0	0.37	0.56
18	600-700	50.0	0.23	0.10
19	700-800	50.0	0.20	0.00
20	800-900	50.0	0.33	0.43
21	900-1000	50.0	2.13	6.64
22	1000-1100	50.0	3.66	12.29

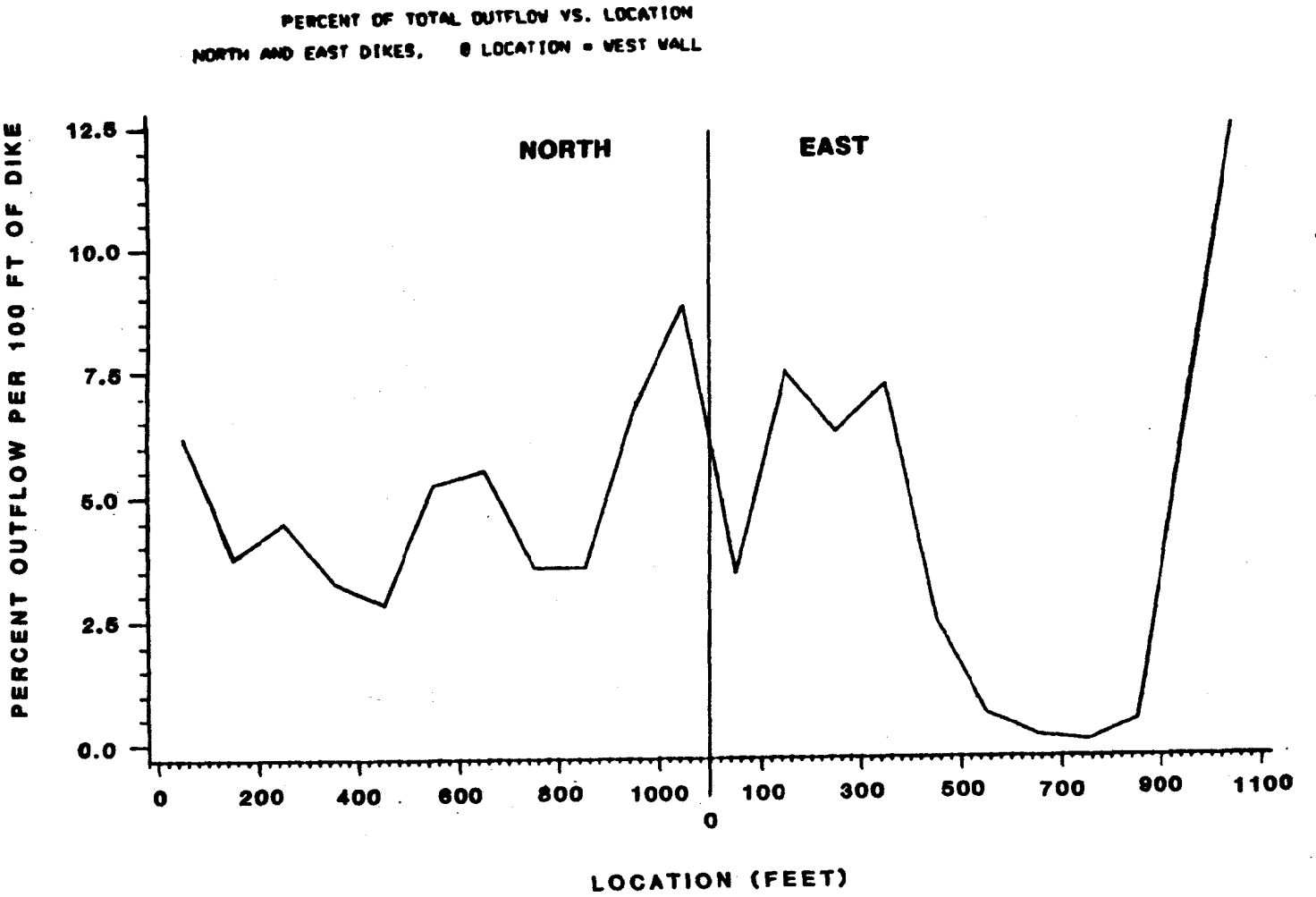

Figure 25. Percent of Total Outflow Along Milwaukee North and East Dikes.

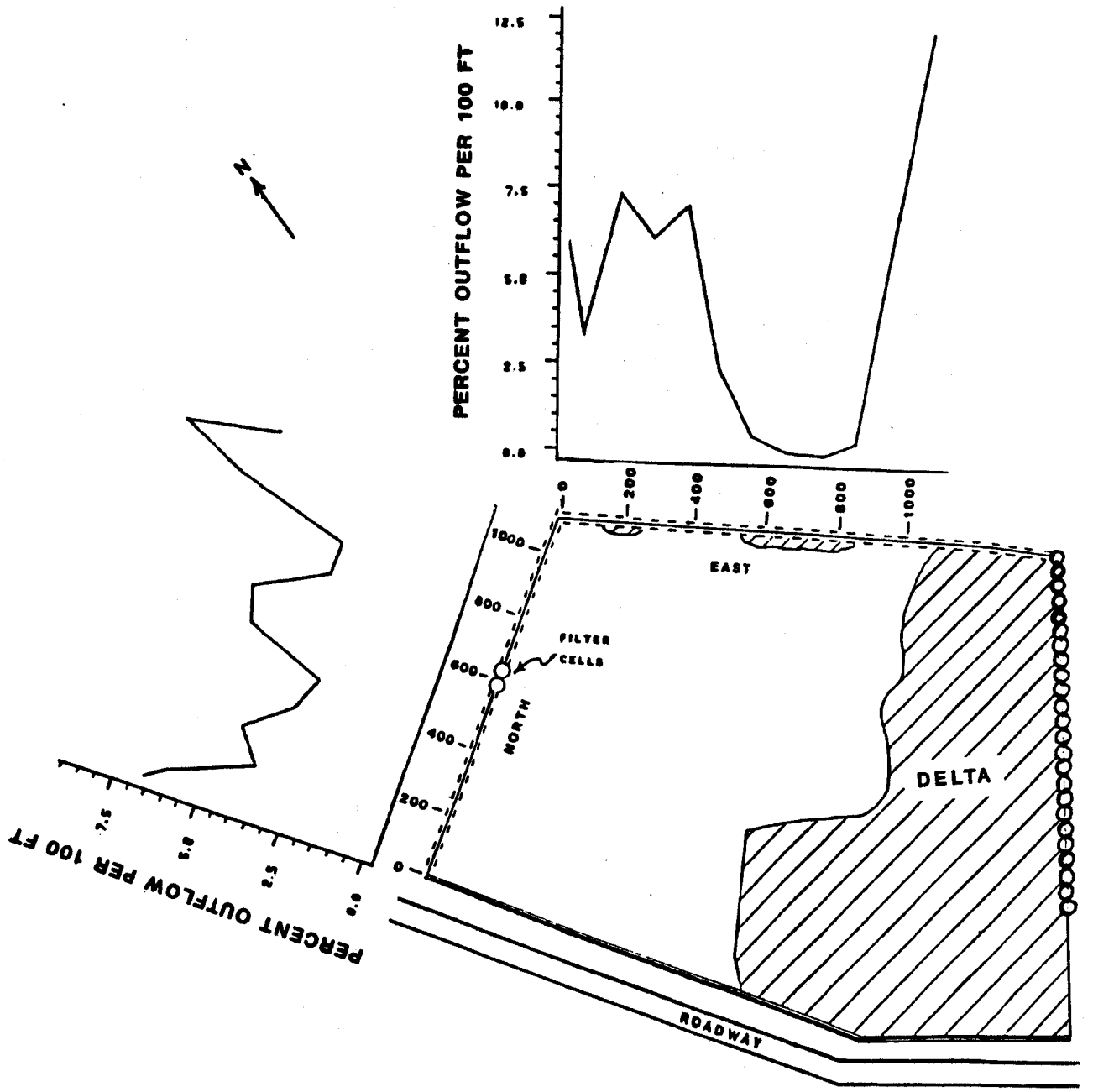

Figure 26. Percent of Total Outflow at the Milwaukee Harbor CDF.

terms (percent of total outflow) since the flow conditions were the same along both dikes. The results of the flow quantification calculations are presented in Table 3, graphed in Figure 25 and combined with the site map in Figure 26. The quantities of flow through the reaches presented in Table 3 represent average flow and the actual percentages would vary depending on wind speed and direction.

Figures 25 and 26 indicate that the large east delta (centered at the 1800-ft marker) significantly reduced the flow through the dike. These figures also indicate that the area of greatest seepage occurred between the east dike delta and edge of the south delta. Overall, the filter cell accounted for 5 to 10% of the outflow and flow through the dikes accounted for over 90% of the total outflow. The seepage rate through the filter cells was approximately equal to the average seepage rate through an equal length of dike, indicating that the solid core retards flow as well as the filter cell and therefore filters water in a similar manner as the filter cells. Reaches having substantial higher seepage rates may not filter as well as the filter cells.

PART V: KEWAUNEE HARBOR CONFINED DISPOSAL FACILITY

Site Description

Kewaunee Harbor is Wisconsin's fourth largest Great Lakes port in terms of total tonnage. Contaminated material from maintenance dredging of the harbor is placed in the Kewaunee Harbor CDF located less than one mile to the northeast. Three sections of the CDF (north, east and south) are exposed to Lake Michigan and four filter cells are located in the northeast section of a curved dike (Figure 27). The CDF is semicircular in shape (800-ft radius) and contains a design surface area of approximately 28 acres.

Dredged material from previous disposal operations has formed a large vegetated delta that covers approximately 30% of the original surface area as shown in Figure 27. The large delta extended halfway down the southwest breakwater dike, thus stopping flow through that portion of the dike. In addition, small deltas were formed at two locations due to recent clamshell operations (between the 350- and 550-ft markers and the 725- and 875-ft markers on the semi-circular dike).

Dikes at the Kewaunee Harbor CDF consist of a prepared limestone core covered by layers of graded stone and protected by riprap on the lakeside. The breakwater dike was constructed by placing a layer of graded stone and prepared limestone along the disposal side of a previously constructed breakwater (Figure 28). The main circular dike contains a clay lining which extends from elevation +6.0 to +10.0 feet (0.0 = International Great Lakes Datum 1955) on the disposal side to resist seepage (Figure 29). The four sand filter cells were similar in design to those used at the previous CDF's, except that the Kewaunee CDF had adjustable weir boards with a bottom elevation of approximately +6.0 feet (Figure 30). The water level elevation at the start of the test was approximately +4.3 feet.

During previous disposal operations, silt plumes were noted in the southwest corner (0-ft marker) as well as on both sides of the filter cells. A dye tracer study at the Kewaunee Harbor CDF had been planned for September 1984; however, the test was delayed in order to conduct repairs that would reduce the flow rate through the dikes in these areas. A clay layer covered with stone was placed across a reach extending 100 feet in both directions from the southwest corner. Due to construction problems, clay was not used to

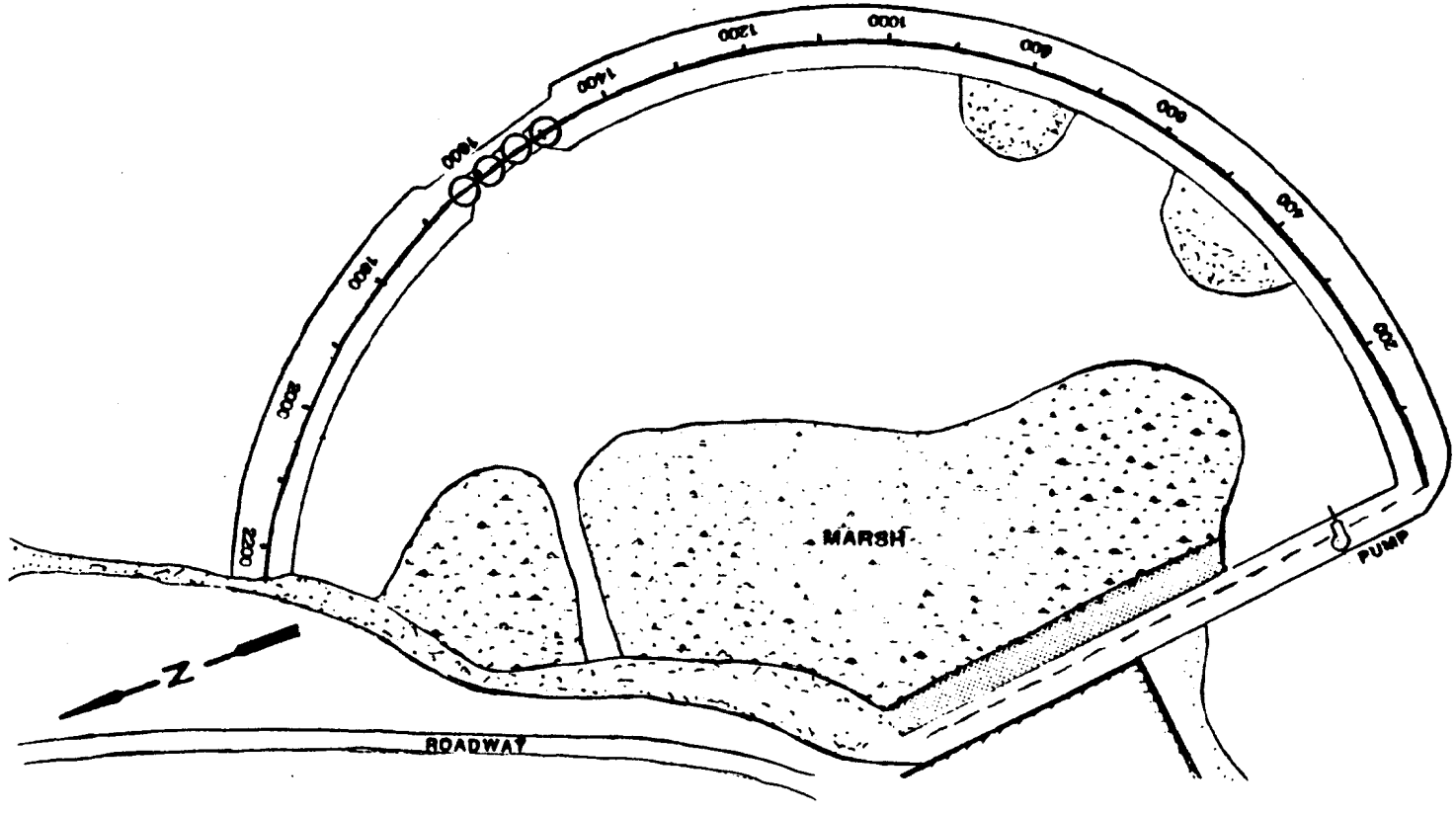

Figure 27. Kewaunee Harbor Confined Disposal Facility.

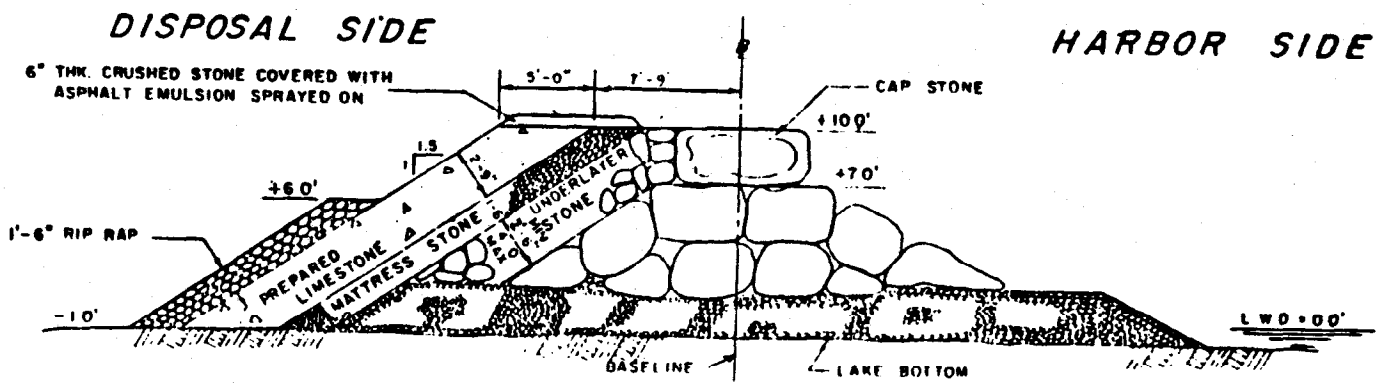

Figure 28. Typical Cross-Section of Kewaunee CDF Breakwater Dike.

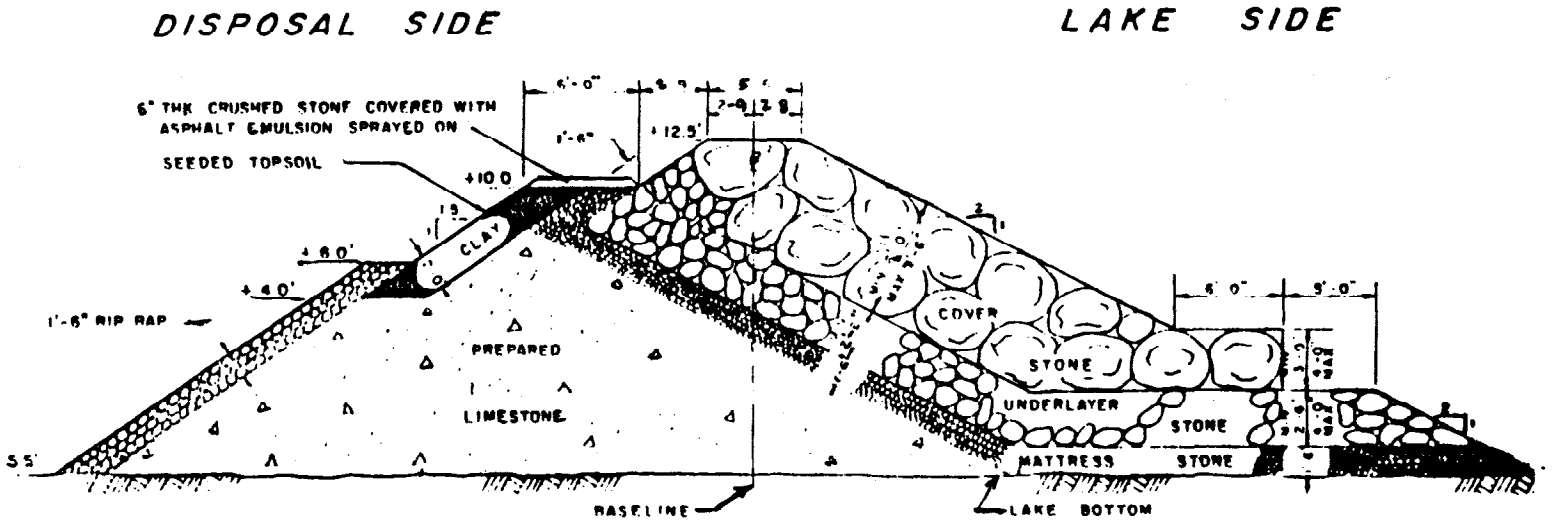

Figure 29. Typical Cross-Section of Kewaunee Harbor CDF (Circular) Dike.

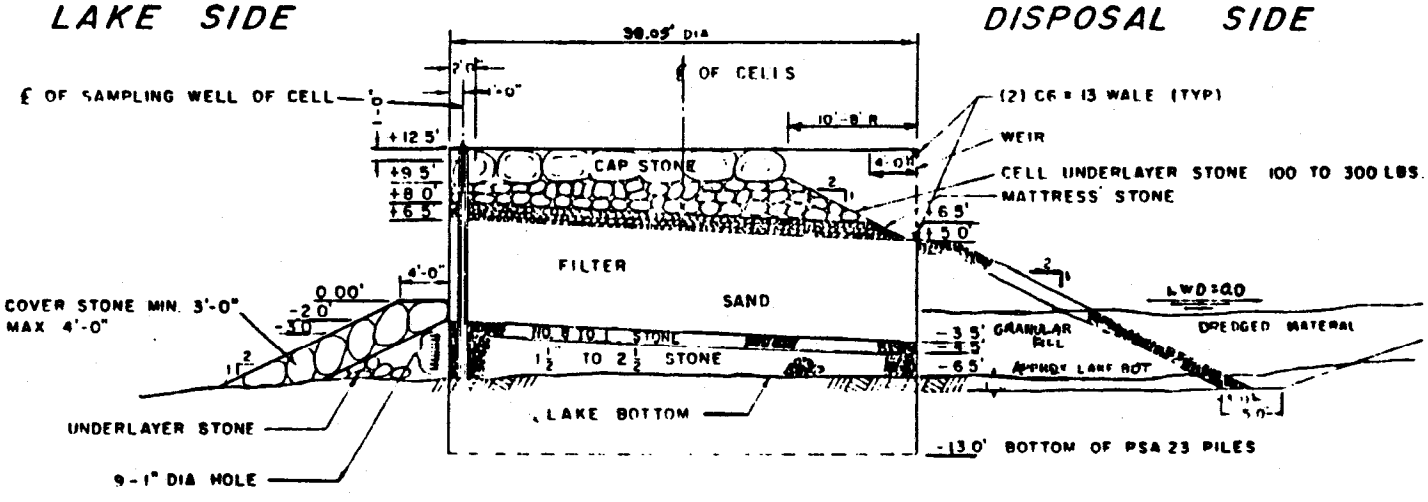

Figure 30. Typical Cross-Section of Kewaunee Harbor CDF Filter Cells.

seal the dikes around the filter cells. Instead, the repair was made using sand and graded stone and extends 100 feet on both sides of the filter cells.

Site Activities Summary

Dye was added by Detroit District personnel along the inside edge of the dikes at 0700 hours on 10 May 1985, approximately 3 1/2 days before water was pumped into the site to simulate hydraulic dredging. This early addition allowed the dye to disperse throughout the entire CDF before pumping started. On 13 May, at 1500 hours, WES personnel arrived on site and collected samples inside and outside the CDF and set up automatic water samplers at the filter cells. This preliminary sampling indicated that the dye was well dispersed inside the CDF (average concentration = 75.0 ppb). Dye was also detected at various locations outside the breakwater and circular dikes before pumping started.

Detroit District personnel had placed three pumps with 6-inch diameter pipes approximately 150 feet north of the southwest corner and began pumping at 1530 hours on 13 May. Detroit District personnel had observed dye outside the CDF when placing the water pumps. Upon consultation with the Detroit District office, a 10 to 15 foot wide dirt berm (consisting of previously dredged material) was placed along the breakwater dike interior as a corrective measure on 14 May near the water pumps.

No dye plumes were detected visibly outside the CDF during the morning sampling on 14 May, even though the dye was clearly visible inside the CDF. A visible boundary between the dyed water and the clear inflow water was observed inside the CDF near the 150-ft marker. During the remainder of the study, this boundary moved laterally as lake water was added to the CDF.

Flag markers were placed every 100 feet along the circular dike and staff gauges were installed at the 200-, 1000- and 2000-ft markers, with the 0-ft marker established at the southwest corner (junction of the circular and breakwater dikes).

Due to northeasterly winds of 10 to 15 mph and the resulting rough water with 1 to 2 foot waves, continuous sampling from the boat outside the CDF was not practical. The morning and afternoon sampling consisted only of grab samples at each 100-ft marker. However, analysis of these samples indicated that dye was present outside of the CDF.

Diminished winds and a directional change to southerly allowed continuous sampling to be conducted outside the CDF on 15 May. Grab samples were also collected in the morning and afternoon during this day. During the boat sampling, dye was detected at various locations along the circular dike and verified when the grab samples were analyzed. The visible boundary between the dyed and clear water inside the CDF had moved to between the 400- and 500-ft markers. The water level inside the CDF had risen since the previous day but was still below the inlet to the filter cells.

Sampling on 16 May was conducted during the morning with slight winds from the west southwest. The water level inside the CDF had fallen from the level of the previous day. Dye was detected in more locations than in previous sampling runs outside the CDF. Following the morning sampling, the pumps were shut down at 1000 hours.

In summary, the following observations were made:

a. Water levels inside the CDF rose initially and then fell when the winds and waves diminished. However, the water level inside the CDF did not rise to an elevation that would have allowed flow through the filter cells.

b. Dye was detected along the entire outside length of the circular dike but concentrations decreased to background near the pump-in point due to greatly increased dilution on the inside.

c. Dye plumes were detected in approximately the same locations on all 3 days by both sampling methods.

Results and Discussion

Wind speed and direction readings are presented in Table 4. The wind direction and strength varied considerably during the study and affected the dye tracer study operations. Table 5 contains the water level readings inside the Kewaunee CDF during pumping operations and the lake water levels collected at Kewaunee Harbor by NOAA. During the first 40 hours of pumping, the water levels inside and outside the CDF rose as strong winds came in from across the lake. The outside water level reached a maximum of +4.7 feet IGLD (+ 7.0 inches above the study datum) at 0500 on 15 May. The water level inside the CDF during a similar period also increased by about 7 inches. As the wind speed decreased and shifted direction, both water levels decreased during the remainder of the study. In general, the water level inside the CDF rose only by about 1 to 2 inches during the study while pumping continuously

Table 4

Observed Wind Speed and Direction Readings at Kewaunee CDF

Date - Time	Direction	Wind Speed (fpm)*
13 May - 1530	Southwest	600
14 May - 0900	North Northeast	1000-1200
- 1300	North Northeast	800
15 May - 0830	South	500
- 1100	South	1000
- 1300	South	600-800
16 May - 0830	West Southwest	200

* 100 fpm = 1.14 mph

Table 5

Water Elevations[1,2] at Kewaunee CDF

Date - Time	Outside[3]	Inside		
		200	1000	2000
14 May 1400	+ 3.0 in.	+ 4.0 in.	+ 4.0 in.	+ 4.0 in.
15 May 0830	+ 4.0	+ 7.0	+ 7.0	+ 7.0
1330	+ 4.0	+ 7.25	+ 7.25	+ 7.5
16 May 0830	+ 3.0	+ 4.25	+ 4.50	+ 4.25

1 Water levels are approximate.

2 0 elevation = water level at 1500 hours, 13 May = + 4.1 feet (IGLD)

3 U.S. Department of Commerce, NOAA. 1985. "Great Lakes Water Levels at Kewaunee, Wisconsin (Station 7068)," May 1985 report, National Oceanographic and Atmospheric Administration, Rockville, Md.

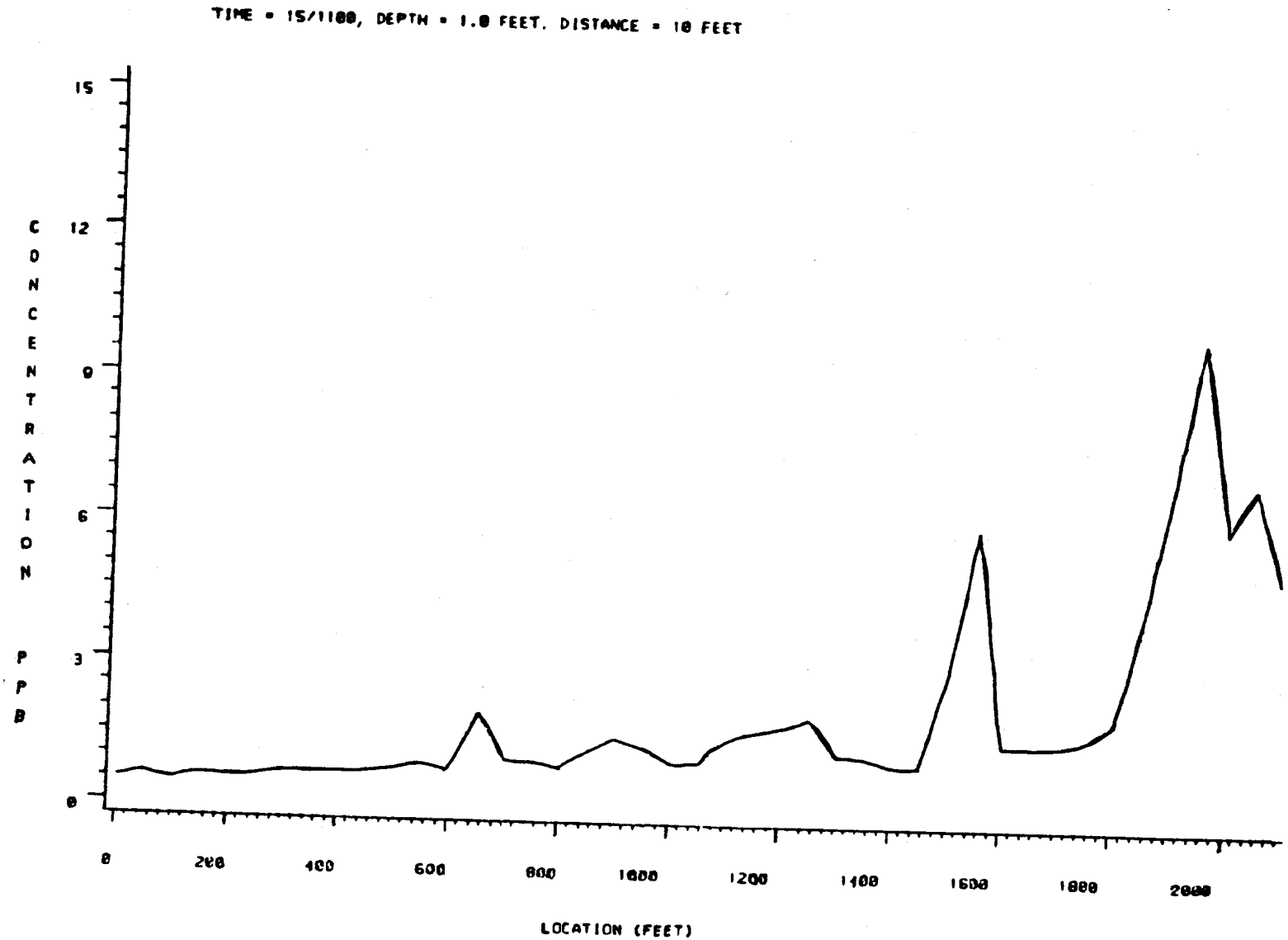

Figure 31. Dye Concentration Along Kewaunee Dike at 1100 Hours, 15 May 85.

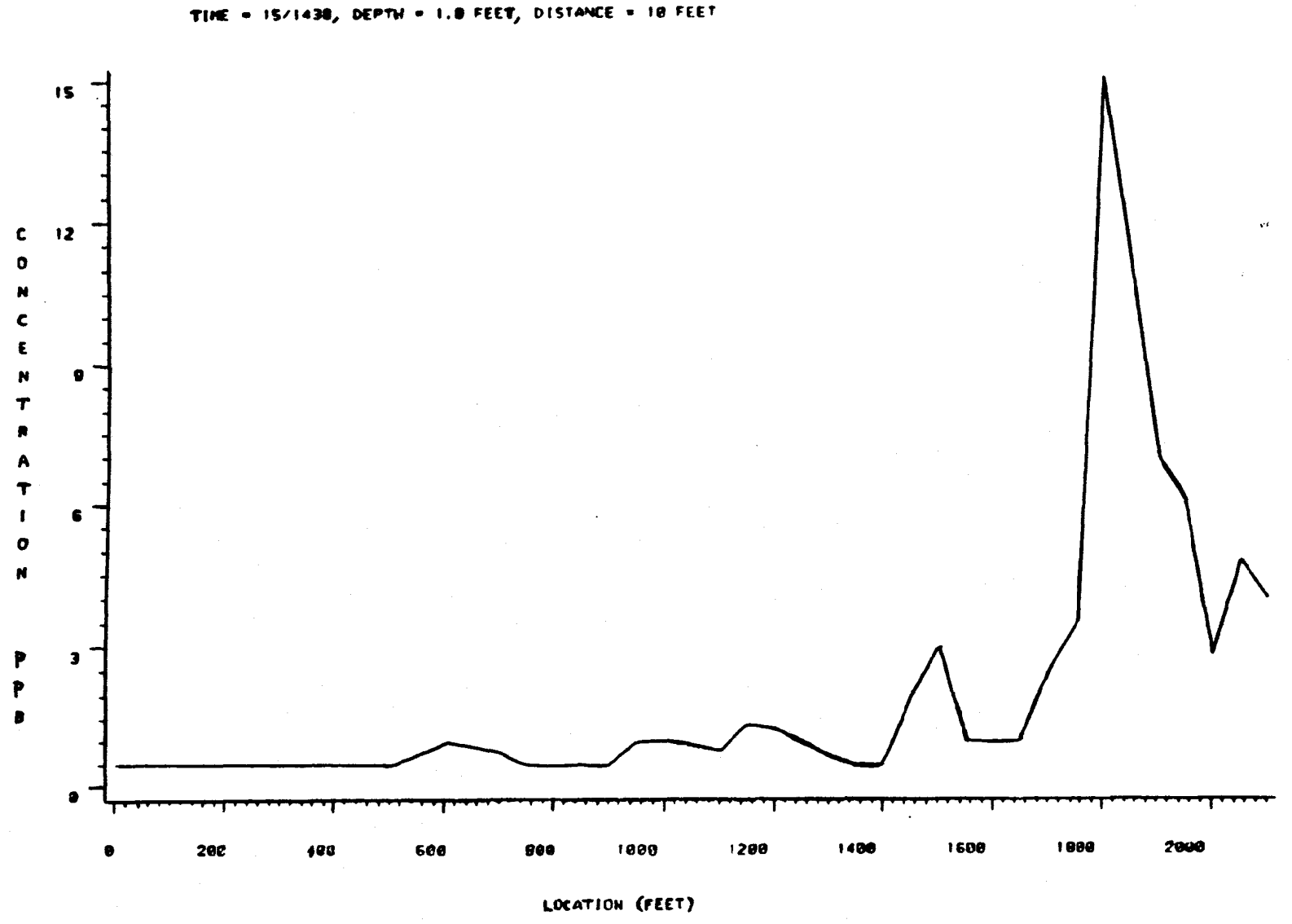

Figure 32. Dye Concentration Along Kewaunee Dike at 1430 Hours, 15 May 85.

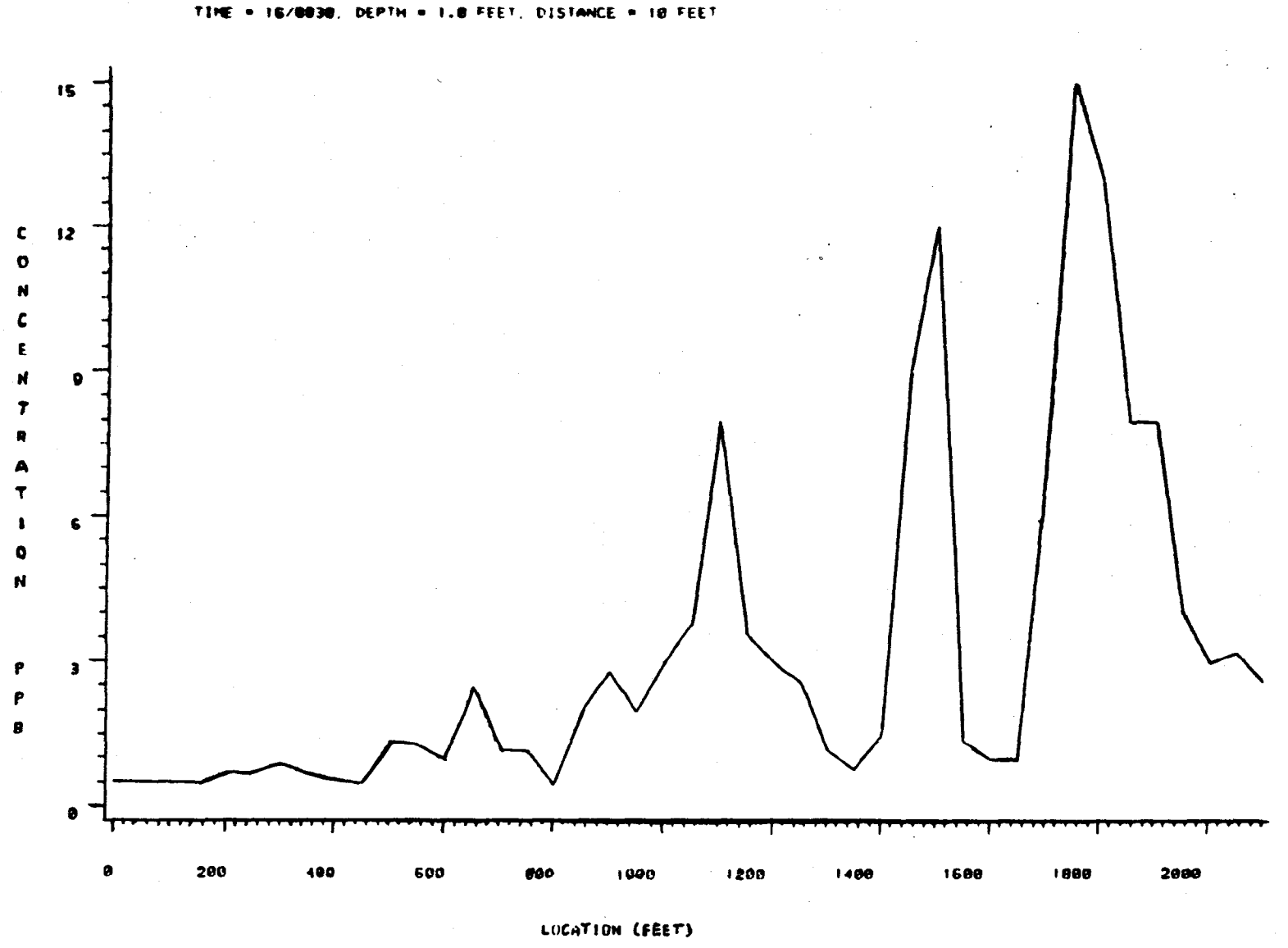

Figure 33. Dye Concentration Along Kewaunee Dike at 0830 Hours, 16 May 85.

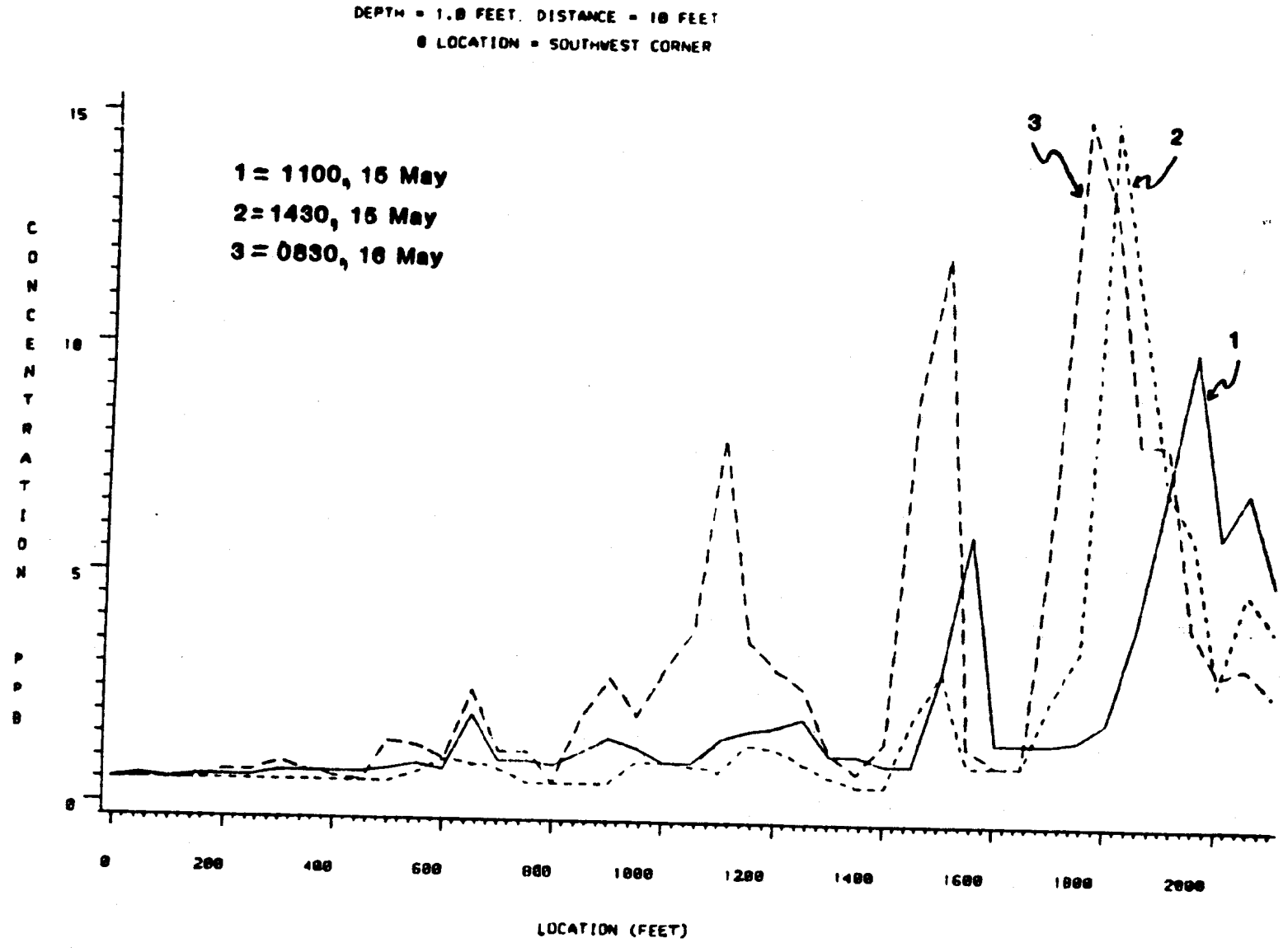

Figure 34. Composite of Dye Concentrations Along Kewaunee Dike.

at a rate of about 8 inches/day. Only a small head was required to discharge this flow, indicating that the dikes are very permeable.

Data from the continuous sampling conducted outside the CDF is tabulated in Appendix D, (Tables D-1 to D-3), and graphed in Figures 31 through 33. Results of the three sampling periods are combined in a composite graph in Figure 34. Figures 31, 32 and 33 indicate that dye was not detected near the southwest corner. This is a result of two factors: (1) fresh water greatly diluted the inside concentrations between the 0- and the 500-ft markers, and (2) a delta was located between the 350- and 550-ft markers.

Dye plumes were detected at each sampling time in the reaches on either side of the filter cell. Another plume was detected near the 1100-ft marker only on 16 May. Figure 34 combines the results of the three sampling times and graphically illustrates that the plumes occurred in approximately the same locations.

An interesting pattern may also be noted concerning the shifting of the peaks between the three sampling times. The three largest plumes (1100-1250, 1400-1550 and 1700-1900) shifted to the south (towards the zero marker) as the study progressed. A possible explanation for this observation is the shifting of the winds from southerly to westerly as well as the decreased wind velocity. The strong southerly winds may have induced a current towards the north or from lower to higher ft markers and as the wind changed direction and lessened in strength, the dye plumes apparently returned to the actual locations of seepage, closer to the zero marker.

Flow Quantification

Percentages of the total outflow passing through the individual 100-ft reaches were estimated using a modification of procedures used in previous studies. Since there was no flow through the filter cells and dye plume locations could not be visually pinpointed, grab samples were obtained at each 100-ft marker on the Kewaunee circular dike.

Data from the four grab sampling times are tabulated in Tables 6-9 and graphed in Figures 35-38. Dye was detected along the entire length of the dike indicating seepage; however, there were also reaches with higher than average outflow indicating potential problem areas. Grab samples were not obtained at the zero marker nor along the breakwater dike due to the high

amount of dilution inside the CDF at these locations. Some reaches in the southwest corner were not included in the flow quantification calculations (indicated by * in Tables 6-9) due to the relatively low inside dye concentrations in these areas during the sampling times.

A composite of the outflow results of the four sampling times are presented in Figure 39. The composite graph verifies that the areas of higher seepage occurred in approximately the same locations during all four sampling times. These results are similar to the continuous sampling results. As with the continuous sampling, the wind direction and strength may have affected the magnitude and shifted the higher outflow locations.

Outflow percentages from the analyses of the results of the four sampling times were averaged (Table 10) and the result is plotted in Figure 40. The average percentages are plotted along the CDF in Figure 41 and provide a good representation of the outflow conditions.

Figure 34 indicates that highest seepage rate occurred at the edge of the repair in the 1800- to 1900-ft reach. Similarly, greater than average seepage rates occurred in the 1400- to 1500-ft reach at the edge of another repair near the filter cell. The only distinctive characteristic of the reach at the 1100-ft marker, where slightly higher than average seepage was determined, is that it is at the point where the CDF extends farthest into the lake.

Table 6

Kewaunee CDF Flow Quantification Data and Results

1000 Hours, 14 May 85

Reach Number	Location, feet	Dye Concentration, ppb		Percent Flow Estimate
		Inside	Outside	
1	50 - 150	8.75	1.25	*
2	150 - 250	58.00	1.70	*
3	250 - 350	71.00	0.85	1.75
4	350 - 450	71.50	0.60	0.50
5	450 - 550	71.50	1.00	2.49
6	550 - 650	72.00	1.60	5.48
7	650 - 750	73.00	1.25	3.67
8	750 - 850	72.50	1.00	2.45
9	850 - 950	72.00	1.05	2.72
10	950 - 1050	71.00	1.60	5.56
11	1050 - 1150	68.00	2.90	12.94
12	1150 - 1250	68.00	1.05	2.88
13	1250 - 1350	69.00	0.95	2.32
14	1350 - 1450	69.00	1.50	5.20
15	1450 - 1550	70.00	1.65	5.91
16	1550 - 1650	69.50	0.50	0.
17	1650 - 1750	69.00	2.50	10.56
18	1750 - 1850	72.00	5.25	24.98
19	1850 - 1950	75.00	2.00	7.21
20	1950 - 2050	74.00	1.10	2.89
21	2050 - 2150	73.00	0.60	0.48

Table 7

Kewaunee CDF Flow Quantification Data and Results

0900 Hours, 15 May 85

Reach Number	Location, feet	Dye Concentration, ppb		Percent Flow Estimate
		Inside	Outside	
1	50 - 150	7.60	0.95	*
2	150 - 250	64.00	1.25	*
3	250 - 350	60.00	1.25	1.44
4	350 - 450	55.00	0.90	0.84
5	450 - 550	55.00	1.15	1.36
6	550 - 650	51.00	1.35	1.93
7	650 - 750	49.00	1.45	2.26
8	750 - 850	54.00	1.15	1.39
9	850 - 950	58.00	1.70	2.41
10	950 - 1050	58.00	3.30	5.78
11	1050 - 1150	61.00	4.30	7.57
12	1150 - 1250	59.00	2.40	3.79
13	1250 - 1350	62.00	2.20	3.21
14	1350 - 1450	64.00	2.50	3.67
15	1450 - 1550	64.00	4.20	6.99
16	1550 - 1650	64.50	0.50	0.
17	1650 - 1750	65.00	5.75	10.01
18	1750 - 1850	63.00	9.75	19.62
19	1850 - 1950	63.00	6.50	12.00
20	1950 - 2050	64.00	5.00	8.62
21	2050 - 2150	63.00	4.20	7.11

Table 8

Kewaunee CDF Flow Quantification Data and Results

1400 Hours, 15 May 85

Reach Number	Location, feet	Dye Concentration, ppb		Percent Flow Estimate
		Inside	Outside	
1	50 - 150	1.00	0.50	*
2	150 - 250	1.50	0.50	*
3	250 - 350	7.75	0.70	*
4	350 - 450	17.50	0.50	*
5	450 - 550	27.50	0.75	*
6	550 - 650	38.00	0.80	0.61
7	650 - 750	38.00	0.55	0.10
8	750 - 850	40.00	0.50	0.
9	850 - 950	42.00	2.00	2.82
10	950 - 1050	42.00	4.35	7.70
11	1050 - 1150	42.00	3.40	5.66
12	1150 - 1250	41.50	1.40	1.69
13	1250 - 1350	43.50	0.85	0.62
14	1350 - 1450	46.50	0.70	0.33
15	1450 - 1550	49.00	5.60	8.85
16	1550 - 1650	49.50	0.50	0.
17	1650 - 1750	50.00	2.40	3.01
18	1750 - 1850	51.00	15.50	31.81
19	1850 - 1950	48.00	10.50	20.08
20	1950 - 2050	48.00	6.25	10.37
21	2050 - 2150	55.00	4.75	6.37

Table 9

Kewaunee CDF Flow Quantification Data and Results

0900 Hours, 16 May 85

Reach Number	Location, feet	Dye Concentration, ppb		Percent Flow Estimate
		Inside	Outside	
1	50 - 150	0.55	0.50	*
2	150 - 250	1.35	0.75	*
3	250 - 350	18.00	0.95	*
4	350 - 450	25.00	0.70	*
5	450 - 550	30.00	1.15	*
6	550 - 650	37.00	0.65	0.12
7	650 - 750	39.00	3.30	2.36
8	750 - 850	41.50	1.50	0.75
9	850 - 950	44.00	3.40	2.15
10	950 - 1050	46.00	2.90	1.67
11	1050 - 1150	45.00	14.50	13.79
12	1150 - 1250	46.00	2.70	1.53
13	1250 - 1350	45.00	1.95	1.01
14	1350 - 1450	44.00	1.20	0.49
15	1450 - 1550	45.00	6.75	4.91
16	1550 - 1650	46.00	0.50	0.
17	1650 - 1750	47.00	13.50	11.65
18	1750 - 1850	45.00	18.75	20.88
19	1850 - 1950	48.00	25.50	33.37
20	1950 - 2050	47.00	5.20	3.38
21	2050 - 2150	48.00	3.40	1.95

Table 10

Average Outflow Percentages For Kewaunee CDF

Location feet	Percent Flow Estimate
100	*
200	*
300	1.60
400	.68
500	1.92
600	2.04
700	2.10
800	1.15
900	2.53
1000	5.18
1100	9.99
1200	2.47
1300	1.79
1400	2.42
1500	6.67
1600	0
1700	8.81
1800	24.32
1900	18.17
2000	6.32
2100	3.98

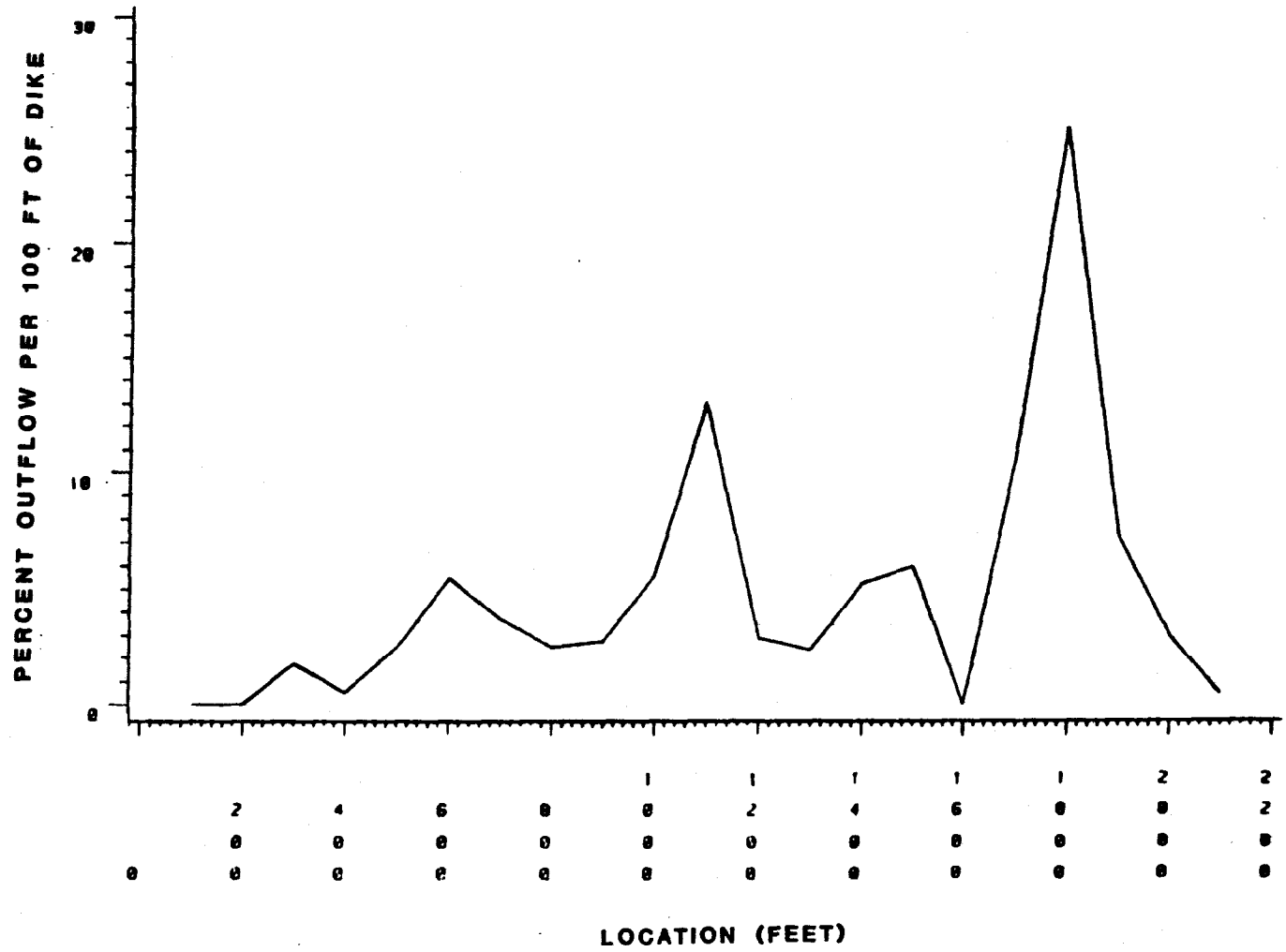

Figure 35. Percent of Total Outflow Along Kewaunee Dike at 1000 Hours, 14 May 85.

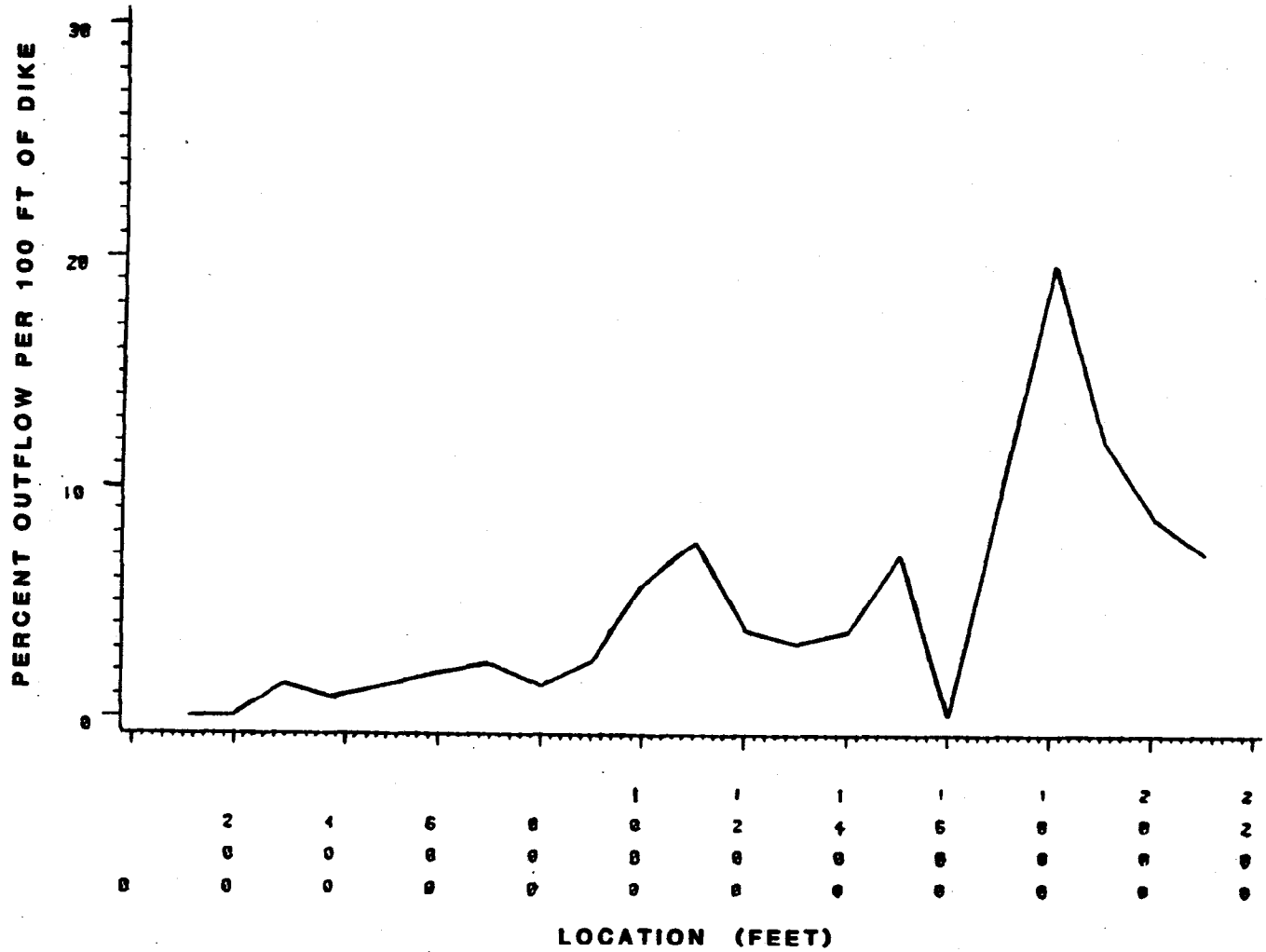

Figure 36. Percent of Total Outflow Along Kewaunee Dike at 0900 Hours, 15 May 85.

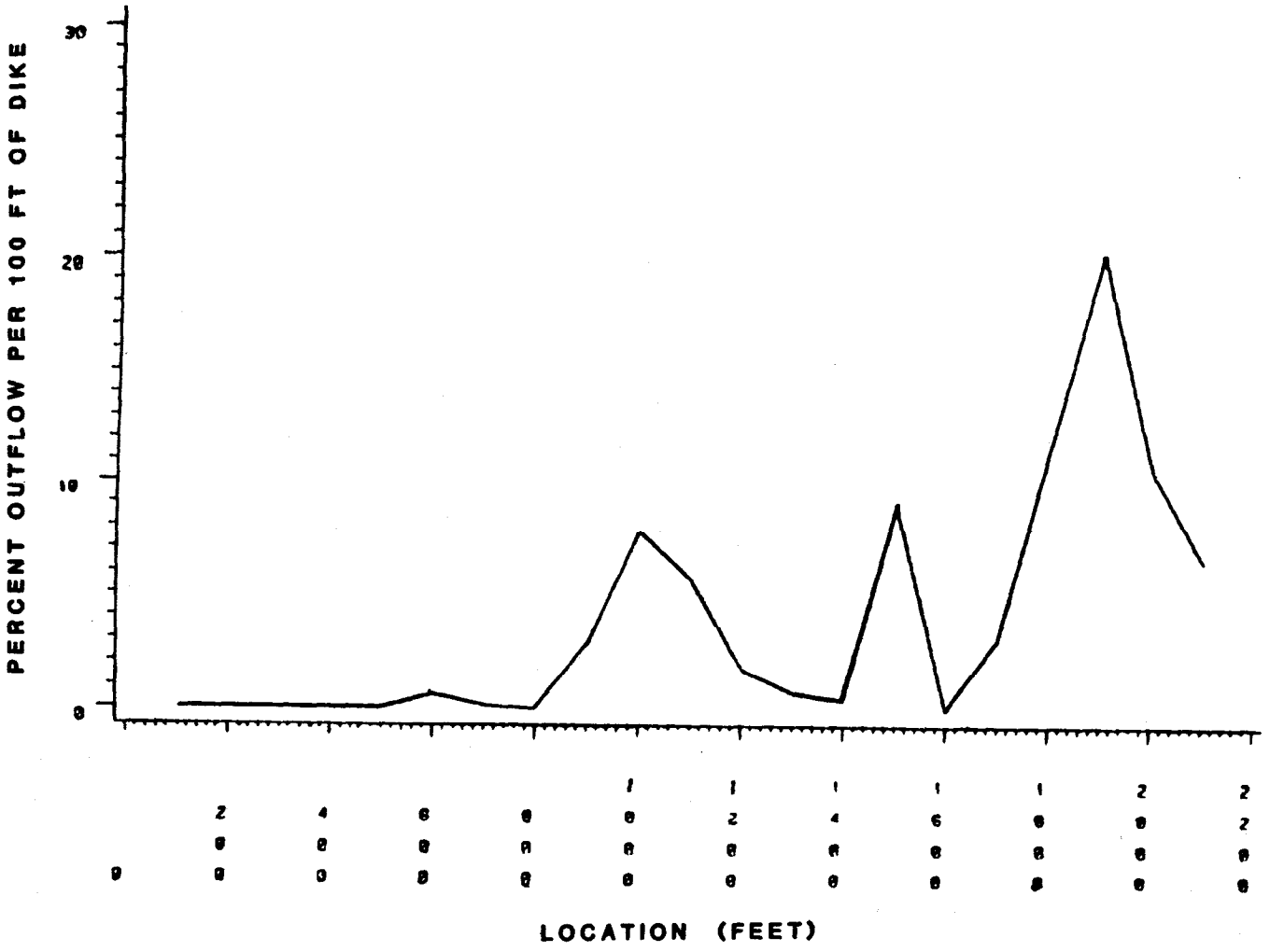

Figure 37. Percent of Total Outflow Along Kewaunee Dike at 1400 Hours, 15 May 85.

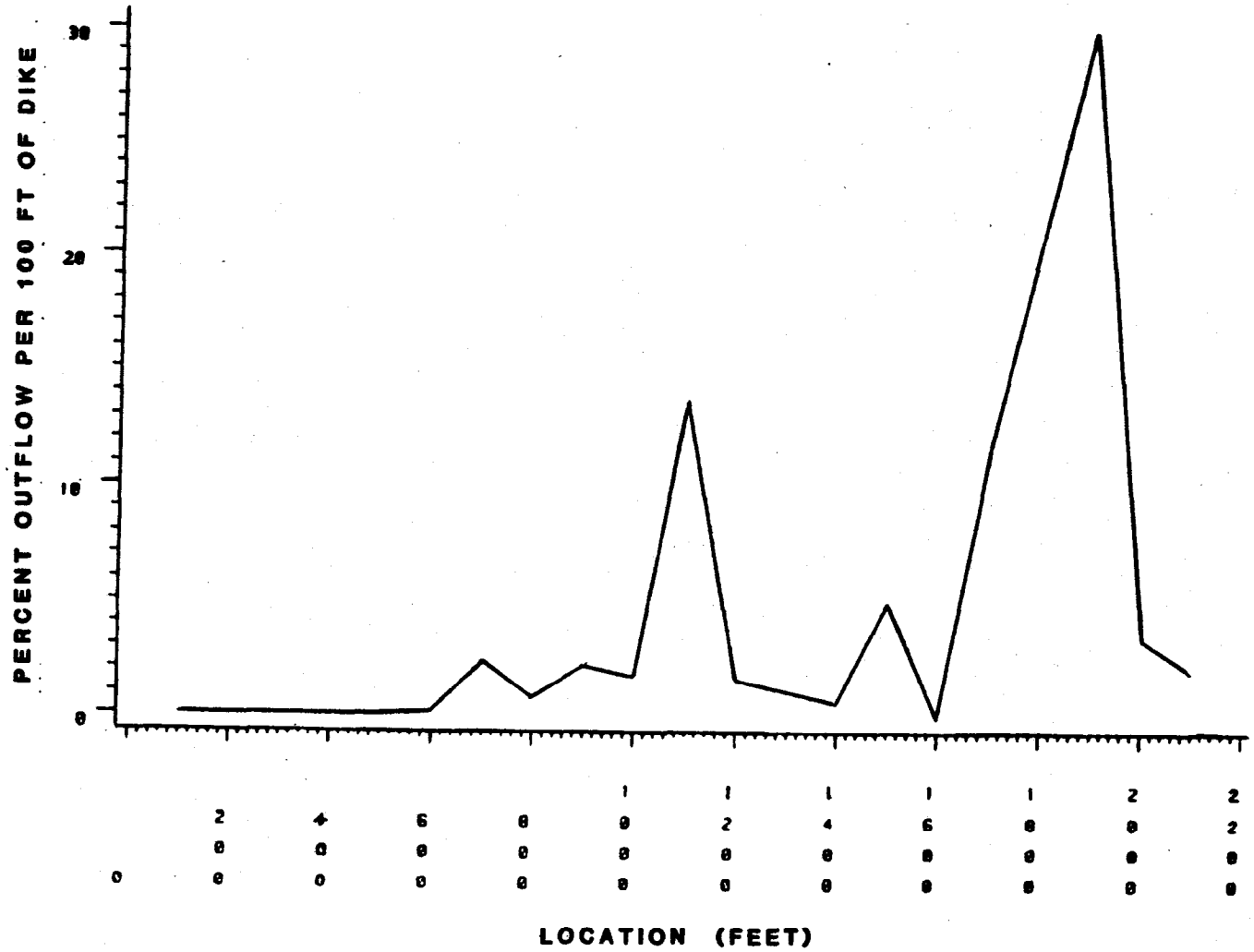

Figure 38. Percent of Total Outflow Along Kewaunee Dike at 0900 Hours, 16 May 85.

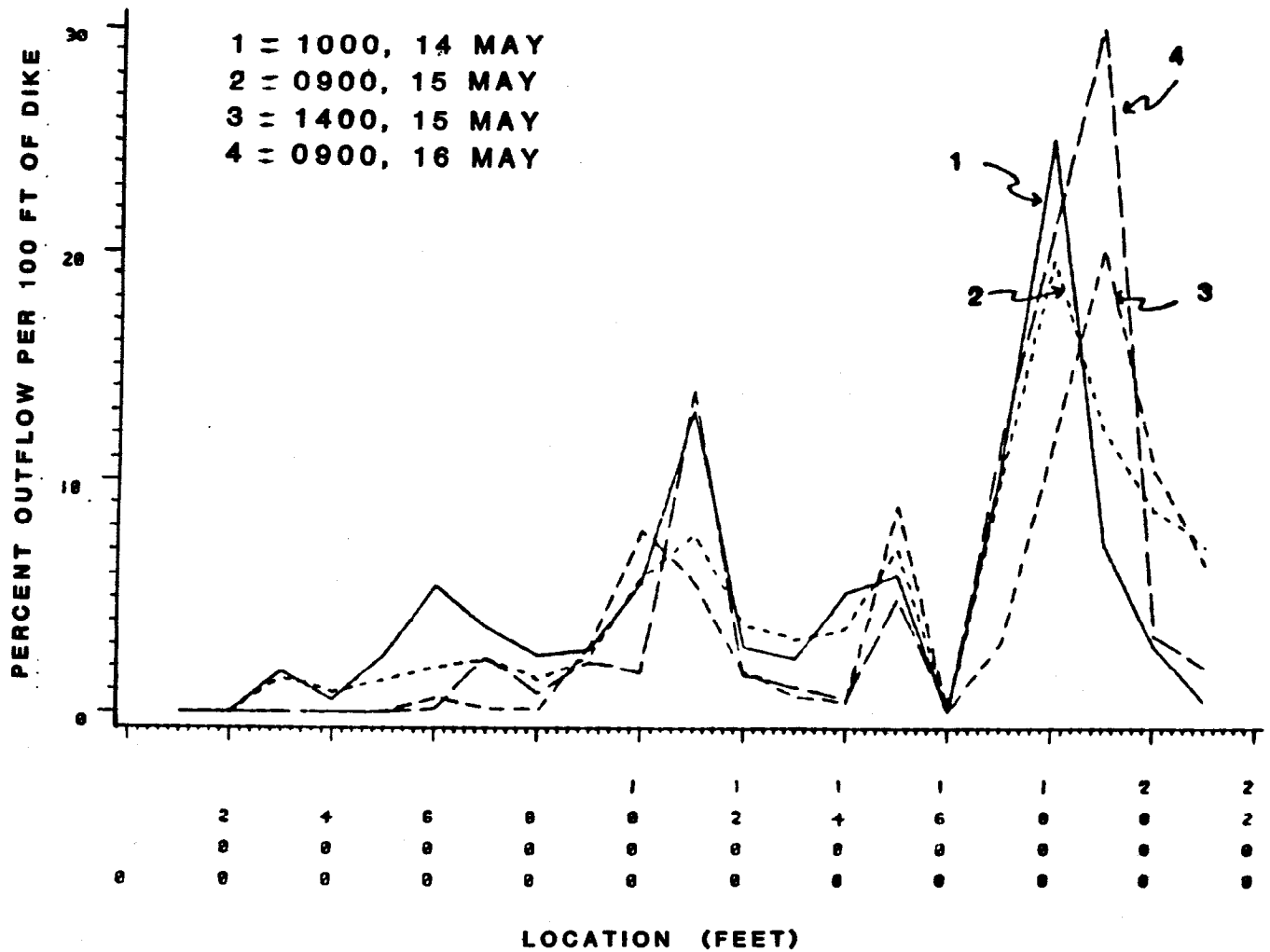

Figure 39. Composite of Total Outflows Along Kewaunee Dike.

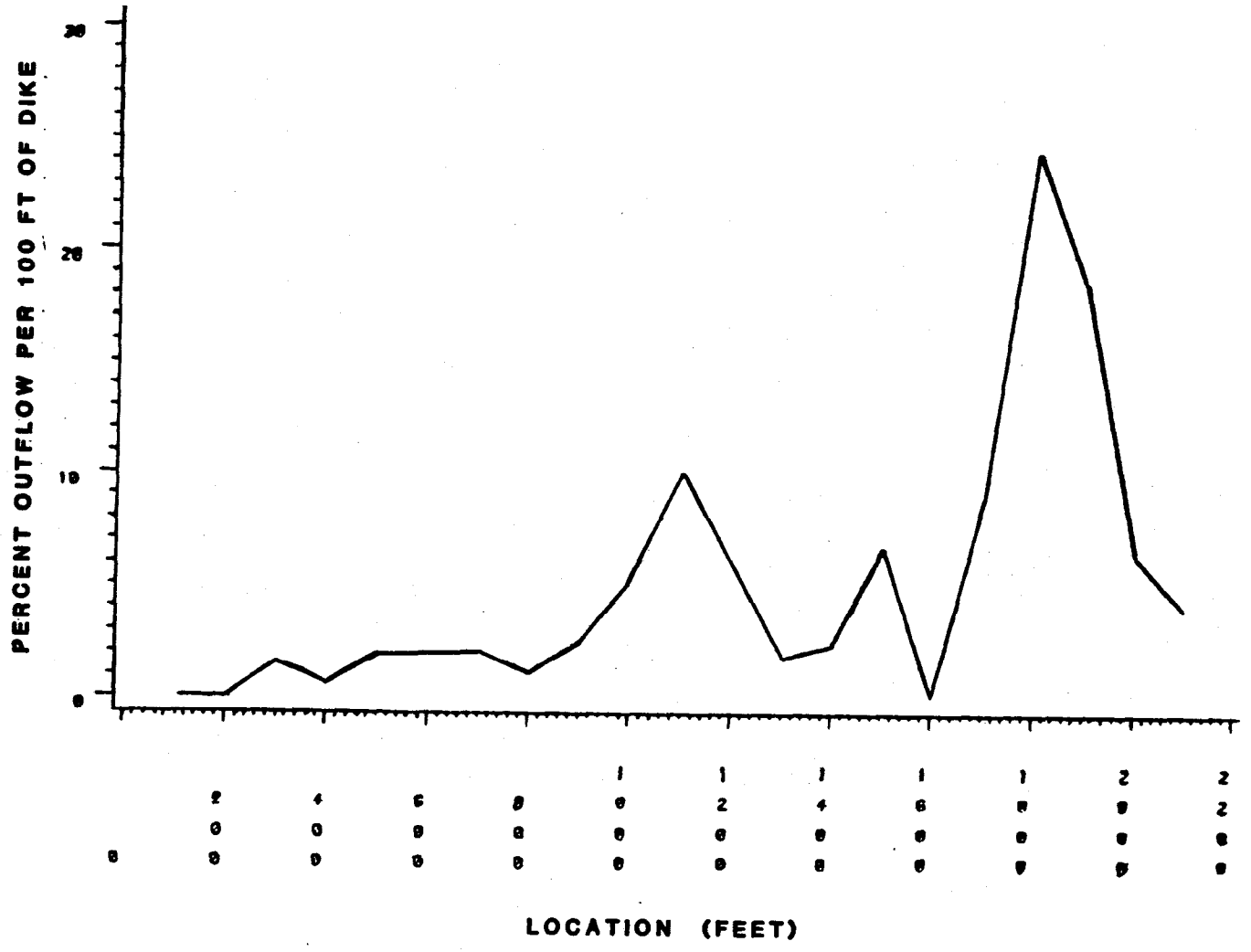

Figure 40. Average Percentages of Total Outflow Along Kewaunee Dike.

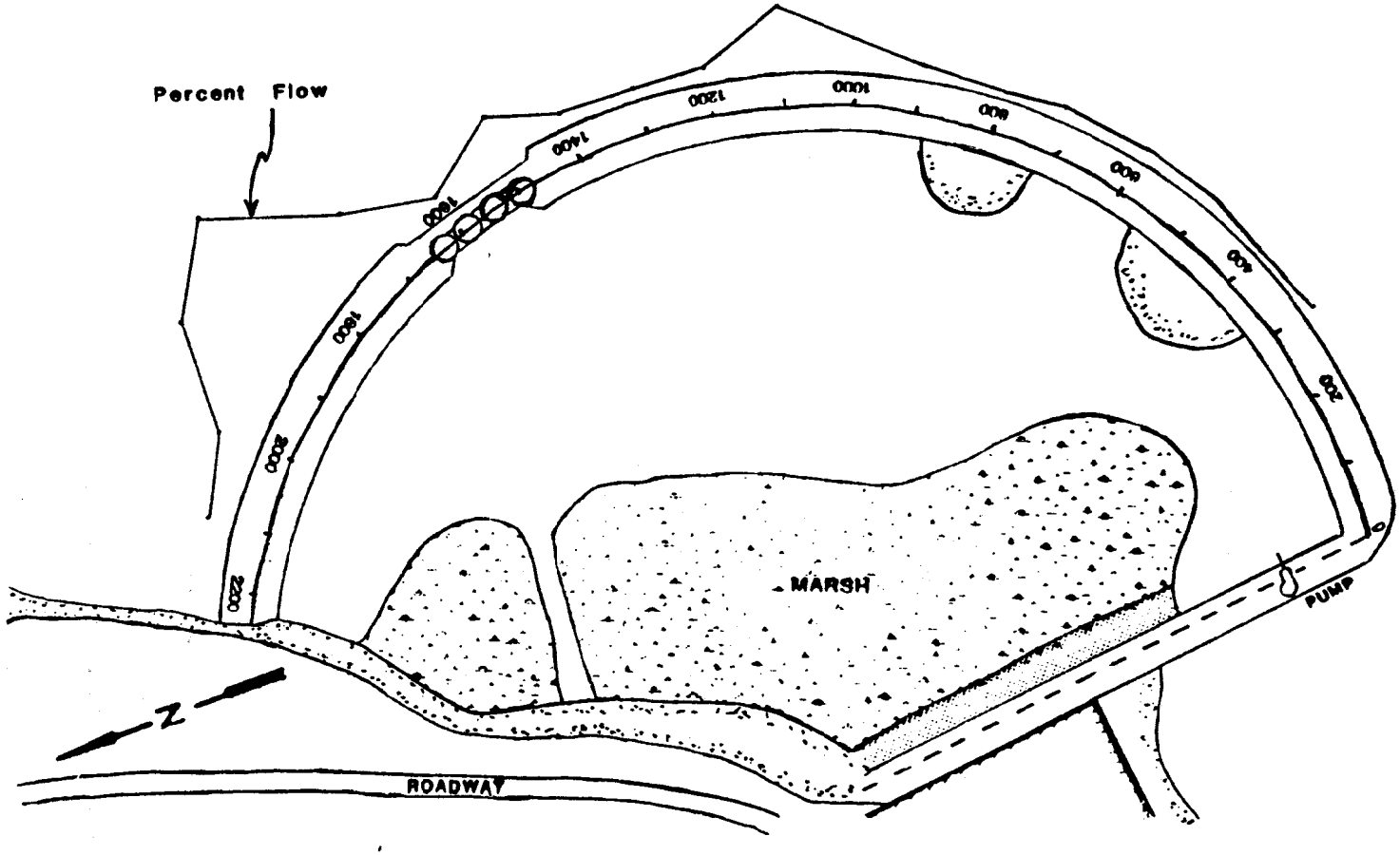

Figure 41. Kewaunee Harbor CDF with Average Outflow Rates.

PART VI: CONCLUSIONS

Dye tracer studies were performed at the Kenosha, Manitowoc, Milwaukee and Kewaunee Harbors CDF's to identify the nature and locations of excessive flow through the dikes, to estimate the relative flow rates at these locations, and to estimate the fraction of the outflow being discharged through the outflow reaches and filter cells. Based on the results of the dye tracer studies the following conclusions are warranted:

Kenosha and Manitowoc

a. Significant outflow at discrete points along the dikes was discovered at both sites. The locations and estimates of the magnitude of the outflow are presented in Tables 1 & 2.

b. Water passing through the dikes accounted for more than 90 percent of the outflow at both sites.

c. Mean detention times were not determined for the two sites since the number of outflow locations negated the value of those results.

Milwaukee

a. Flow passed through both the east and north dikes along their entire lengths rather than through single points.

b. Points of higher seepage rates were identified in the East 1000- to 1100-ft reach and at the northeast and northwest corners.

c. Flow through the dikes accounted for more than 90% of the total outflow.

d. Significant decreases in outflow occurred in areas where deltas of previously dredged material had been placed.

Kewaunee

a. Flow passed through the entire length of the circular dike rather than through single points.

b. Higher than average seepage through the dikes occurred near the 1100-ft marker and in the 1750-1950 ft reach.

c. Dilution due to pumping did not allow determination of the flow rate through the southwest corner repair. Higher than average seepage rates occurred in reaches adjacent to repairs made at both sides of the filter cells, but dye plumes could not be detected visually.

d. The dredged material deltas decreased the seepage at their locations (400- and 800-ft reaches) with respect to seepage at other locations but not to the same extent as deltas at the Milwaukee Harbor CDF.

General

a. The dikes composed of solid cores of fine gravels and sands retarded flow to about the same degree as the filter cells and therefore should retain solids.

b. The dikes composed of riprap and steel sheet piles cutoff walls had distinct locations that did not significantly retard flow since distinct dye plumes were visible. If the area for flow or gaps between piles and joints are large in these locations, the potential for release of solids is significant.

APPENDIX A: KENOSHA DATA TABLES

Table A-1

Dye Concentration at Filter Cells, Kenosha, 8-9 May 84

Sample Number	Elapsed Time hrs	Dye Conc. ppb	Sample Number	Elapsed Time hrs	Dye Conc. ppb
1	0*	0.25	23	10.5	40.0
2	0.5	0.25	24	11	39.5
3	1.0	0.25	25	11.5	39.0
4	1.5	57.0	26	12	39.0
5	1.75	142.5	27	12.5	40.0
6	2.0	130.5	28	13	39.0
7	2.5	30.0	29	13.5	40.0
8	2.75	16.5	30	14	40.0
9	3.0	11.5	31	14.5	38.0
10	3.16	9.5	32	15	36.0
11	3.25	8.0	33	15.5	36.5
12	3.5	5.5	34	16	37.0
13	4.0	6.0	35	16.5	37.5
14	4.5	6.5	36	17	37.5
15	6.5	46.5	37	17.5	37.5
16	7.0	38.0	38	18	37.0
17	7.5	39.0	39	18.5	36.0
18	8.0	37.0	40	19	35.5
19	8.5	38.0	41	19.5	37.0
20	9.0	40.5	42	21.5	33.5
21	9.5	40.5	43	22.5	33.5
22	10	40.5			

* Time 0 = 1200 hours, 8 May 84

Table A-2

Dye Concentration Along East Dike at Distance = 25 Feet, Depth = 0.5 Feet, Kenosha, 1315 Hours, 8 May 84

Sample	Location, feet	Concentration, ppb
1	0	25.0
2	50	10.0
3	100	0.2
4	150	3.0
5	200	0.4
6	250	8.0
7	300	0.2
8	350	60.0
9	400	>100
10	450	0.2
11	500	0.2
12	600	0.2
13	700	0.2
14	800	0.2
15	900	0.2
16	1000	0.2
17	1100	0.2

Background concentration = 0.2 ppb, Location 0 = North dike

Table A-3

Dye Concentration Along East Dike at Distance = 100 Feet, Depth = 0.5 Feet, Kenosha, 1415 Hours, 8 May 84

Sample	Location, feet	Concentration, ppb
1	0	40.0
2	100	3.0
3	200	5.0
4	300	3.0
5	400	3.0
6	500	0.5
7	600	0.2
8	700	0.2
9	800	0.2
10	900	0.2
11	1000	0.2
12	1100	0.2

Background concentration = 0.2 ppb, Location 0 = North dike

Table A-4

Dye Concentration Along East Dike at Distance = 100 Feet, Depth = 0.5 Feet, Kenosha, 1610 Hours, 8 May 84

Sample	Location, feet	Concentration, ppb
1	0	9.0
2	100	8.0
3	200	3.8
4	300	2.5
5	400	1.5
6	500	1.2
7	600	1.5
8	700	1.2
9	800	1.5
10	900	1.5
11	1000	0.5
12	1100	3.0

Background concentration = 0.2 ppb, Location 0 = North dike

APPENDIX B: MANITOWOC DATA TABLES

Table B-1

Dye Concentration at Filter Cell, Manitowoc, 30-31 May 84

Sample Number	Elapsed Time (hrs)	Dye Conc. (ppb)
1	0*	0.2
2	1.0	0.2
3	2.0	0.3
4	3.0	0.25
5	4.0	0.35
6	5.0	0.6
7	6.0	0.88
8	7.0	0.5
9	8.0	0.75
10	9.0	0.88
11	10.0	1.15
12	11.0	1.38
13	12.0	1.55
14	13.0	1.7
15	14.0	2.3
16	15.0	2.85
17	16.0	3.75
18	17.0	4.15
19	18.0	5.5
20	19.0	9.0
21	20.0	14.5
22	21.0	18.5

* Time 0 = 1645 hours, 30 May 84

Table B-2

Dye Concentration Along West Dike at Distance = 15 Feet, Depth = 0.5 Feet, Manitowoc, 1015 Hours, 31 May 84

Sample	Location, feet	Concentration, feet
1	0	2.5
2	100	2.0
3	200	2.5
4	300	4.0
5	400	8.0
6	500	8.0
7	600	8.0
8	700	9.0
9	800	6.5
10	900	6.0
11	1000	5.2
12	1100	5.2
13	1200	6.0
14	1300	8.0
15	1400	14.0
16	1500	6.5

Location 0 = South dike, Background concentration = 0.2 ppb

Table B-3

Dye Concentration Along North and East Dikes at Distance = 25 Feet, Depth = 0.5 Feet, Manitowoc, 1100 Hours, 31 May 84

Sample	Location, feet	Concentration, ppb
1	0	5.0
2	92.5	4.0
3	185	9.0
4	277.5	8.0
5	370	6.6
6	462.5	5.6
7	555	4.2
8	647.5	3.0
9	740	2.0
10	832.5	1.5
11	925	1.0
12	1017.5	1.0
13	1110	1.2
14	1202.5	0.8
15	1295	0.6
16	1387.5	6.0
17	1480	10.0
18	1572.5	15.0
19	1665	15.0
20	1757.5	16.0
21	1850	14.0
22	1942.5	2.5
23	2035	8.5
24	2127.5	76.0*
25	2220	1.0
26	2312.5	0.2
27	2400	0.2

Location 0 = Northwest corner at sidewalk, Background concentration = 0.2 ppb.
* plotted at concentration = 20 ppb in Fig. 12

Table B-4

Dye Concentration Along North and East Dikes at Distance = 25 Feet, Depth = 3.5 Feet, Manitowoc, 1345 Hours, 31 May 84

Sample	Location, feet	Concentration, ppb
1	0	3.0
2	82.5	4.8
3	165	5.6
4	247.5	3.8
5	330	3.8
6	412.5	3.4
7	495	3.4
8	577.5	3.2
9	660	0.5
10	742.5	0.5
11	825	0.4
12	907.5	0.4
13	990	0.3
14	1072.5	0.2
15	1155	0.2
16	1237.5	0.2
17	1320	1.0
18	1402.5	3.0
19	1485	4.0
20	1567.5	5.0
21	1650	2.2
22	1732.5	0.6
23	1815	0.4
24	1897.5	0.4
25	1980	0.4
26	2062.5	0.6
27	2145	0.2
28	2227.5	0.2
29	2310	0.2
30	2400	0.2

Location 0 = Northwest corner at sidewalk, Background concentration = 0.2 ppb

APPENDIX C: MILWAUKEE DATA TABLES

Table C-1

Dye Concentration at the Filter Cells Inlet, Milwaukee, 17-19 Sep 84

Sample Number	Elapsed Time hrs	Dye Conc. ppb
1	0*	0.20
2	1.0	0.25
3	2.0	0.22
4	3.0	0.21
5	4.0	0.23
6	5.0	0.45
7	6.0	0.86
8	7.0	0.69
9	8.0	1.70
10	9.0	1.75
equipment malfunction		
11	17.0	5.20
12	18.0	5.85
13	19.0	6.05
14	20.0	11.40
15	21.0	14.95
16	22.0	17.50
17	23.0	20.00
18	24.0	22.00
19	25.0	23.00
20	26.0	24.25
21	27.0	24.00
22	28.0	25.00
23	29.0	25.00
24	30.0	25.50
25	31.0	26.10

(Continued)

* Time 0 = 1800 hours, 17 Sept 84

Table C-1 (Concluded)

Sample Number	Elapsed Time hrs	Dye Conc. ppb
26	32.0	25.50
27	33.0	25.50
28	34.0	25.80
29	35.0	25.10
30	36.0	24.50
31	37.0	24.50
32	38.0	24.20
33	39.0	24.10
34	40.0	24.20
35	41.0	24.00
36	42.0	25.00
37	43.0	24.50
38	44.0	24.50
39	45.0	23.00
40	46.0	21.50
41	47.0	21.00
42	48.0	20.50

Table C-2

Dye Concentration at the Filter Cells Outlet, Milwaukee, 17-19 Sep 84

Sample Number	Elapsed Time hrs	Dye Conc. ppb
1	0*	0.20
2	1.0	0.20
3	2.0	0.25
4	3.0	0.20
5	4.0	0.25
6	5.0	0.23
7	6.0	0.25
8	7.0	0.20
9	8.0	0.20
10	9.0	0.25
11	10.0	0.30
12	11.0	0.27
13	12.0	0.25
14	13.0	0.25
15	14.0	0.25
16	15.0	0.22
17	16.0	0.23
18	17.0	0.45
19	18.0	0.23
20	19.0	0.60
21	20.0	0.45
22	21.0	0.37
23	22.0	0.55
24	23.0	0.37
25	24.0	0.25

(Continued)

* Time 0 = 1800 hours, 17 Sept 84

Table C-2 (Concluded)

Sample Number	Elapsed Time hrs	Dye Conc. ppb
26	25.0	0.20
27	26.0	0.23
28	27.0	1.37
29	28.0	0.68
30	29.0	0.70
31	30.0	0.68
32	31.0	0.37
33	32.0	0.35
34	33.0	1.12
35	34.0	1.60
36	35.0	1.17
37	36.0	1.97
38	37.0	0.80
39	38.0	2.33
40	39.0	1.10
41	40.0	2.10
42	45.0	2.50
43	48.0	2.30

Table C-3

Dye Concentration Along North and East Dikes, Depth = 0.5 Feet, Milwaukee, 0900 Hours, 18 Sep 84

Sample	Location, feet	Concentration, ppb
1	100	2.15
2	200	1.7
3	400	0.83
4	600	1.55
5	800	5.9
6	1000	3.85
7	1100	4.1
8	1300	0.39
9	1500	12.5
10	1700	0.34
11	1900	0.34
12	2000	38.2
13	2100	24.7
14	2200	2.8

Background Concentration = 0.2 ppb. Location 0 = West Wall

Table C-4

Dye Concentration Along North Dike, Depth = 1.0 Feet,

Milwaukee, 1400 Hours, 18 Sep 84

Sample	Location, feet	Concentration, ppb
1	0	0.2
2	50	0.2
3	100	0.3
4	150	0.2
5	200	0.2
6	250	0.2
7	300	0.2
8	350	0.3
9	400	0.2
10	450	0.2
11	500	0.2
12	550	0.2
13	600	0.3
14	650	0.2
15	700	0.4
16	750	0.2
17	800	0.2
18	850	0.5
19	900	1.3
20	950	1.5
21	1000	1.5
22	1050	2.3
23	1100	3.0

Background Concentration = 0.2 ppb, Location 0 = West Wall

Table C-5

Dye Concentration Along East Dike, Depth = 1.0 Feet,

Milwaukee, 1410 Hours, 18 Sep 84

Sample	Location, feet	Concentration, ppb
1	0	0.6
2	50	1.0
3	100	2.0
4	150	3.0
5	200	2.0
6	250	2.0
7	300	2.0
8	350	3.0
9	400	1.8
10	450	0.6
11	500	0.4
12	550	0.4
13	600	0.3
14	650	0.2
15	700	0.2
16	750	0.2
17	800	0.2
18	850	0.4
19	900	0.4
20	950	2.0
21	1000	4.0
22	1050	4.0
23	1100	3.0

Background Concentration = 0.2 ppb, Location 0 = North Dike

Table C-6

Dye Concentration Along East Dike, Depth = 3.5 Feet,
Milwaukee, 1440 Hours, 18 Sep 84

Sample	Location, feet	Concentration, ppb
1	0	0.2
2	50	0.2
3	100	0.5
4	150	0.4
5	200	0.3
6	250	0.2
7	300	0.2
8	350	0.3
9	400	0.2
10	450	0.25
11	500	0.2
12	550	0.25
13	600	0.25
14	650	0.25
15	700	0.5
16	750	0.2
17	800	0.2
18	850	0.2
19	900	1.0
20	950	2.0
21	1000	2.0
22	1050	3.0
23	1100	2.0

Background Concentration = 0.2 ppb, Location 0 = North Dike

Table C-7

Dye Concentration Along East Dike, Depth = 0.5 Feet,

Milwaukee, 1500 Hours, 18 Sep 84

Sample	Location, feet	Concentration, ppb
1	0	0.2
2	50	0.7
3	100	2.0
4	150	3.0
5	200	1.0
6	250	1.0
7	300	2.0
8	350	1.8
9	400	1.0
10	450	0.6
11	500	0.4
12	550	0.2
13	600	0.2
14	650	0.2
15	700	0.2
16	750	0.2
17	800	0.2
18	850	0.2
19	900	0.4
20	950	2.0
21	1000	4.0
22	1050	3.5
23	1100	3.0

Background Concentration = 0.2 ppb, Location 0 = North Dike

Table C-8

Dye Concentration Along North Dike, Depth = 0.5 Feet,

Milwaukee, 1330 Hours, 19 Sep 84

Sample	Location, feet	Concentration, ppb
1	0	1.5
2	50	0.8
3	100	0.9
4	150	0.8
5	200	0.5
6	250	0.9
7	300	1.1
8	350	0.5
9	400	0.4
10	450	0.6
11	500	0.8
12	550	0.7
13	600	1.3
14	650	0.9
15	700	0.7
16	750	0.7
17	800	0.7
18	850	0.7
19	900	0.7
20	950	1.2
21	1000	1.5
22	1050	1.5
23	1100	1.2

Background Concentration = 0.2 ppb, Location 0 = West Wall

Table C-9

Dye Concentration Along East Dike, Depth = 0.5 Feet,

Milwaukee, 1345 Hours, 19 Sep 84

Sample	Location, feet	Concentration, ppb
1	0	0.2
2	50	0.25
3	100	0.3
4	150	0.6
5	200	0.4
6	250	0.35
7	300	0.6
8	350	0.3
9	400	0.2
10	450	0.2
11	500	0.2
12	550	0.2
13	600	0.2
14	650	0.2
15	700	0.2
16	750	0.2
17	800	0.25
18	850	0.3
19	900	0.3
20	950	0.4
21	1000	0.3
22	1050	0.2
23	1100	0.2

Background Concentration = 0.2 ppb, Location 0 = North Dike

APPENDIX D: KEWAUNEE DATA TABLES

Table D-1

Dye Concentration Along Dike, Depth = 1.0 Feet,

Kewaunee, 1100 Hours, 15 May 85

Sample	Location, feet	Concentration, ppb
0	0	0.5
1	50	0.6
2	100	0.5
3	150	0.6
4	200	0.6
5	250	0.6
6	300	0.7
7	350	0.7
8	400	0.7
9	450	0.7
10	500	0.8
11	550	0.9
12	600	0.8
13	650	2.0
14	700	1.0
15	750	1.0
16	800	0.9
17	850	1.2
18	900	1.5
19	950	1.3
20	1000	1.0
21	1050	1.0
22	1100	1.5
23	1150	1.7
24	1200	1.8
25	1250	2.0
26	1300	1.2
27	1350	1.2

(Continued)

Background Concentration = 0.5 ppb, Location 0 = Southwest corner

Table D-1 (Concluded)

Sample	Location, feet	Concentration, ppb
28	1400	1.0
29	1450	1.0
30	1500	3.0
31	1550	6.0
32	1600	1.5
33	1650	1.5
34	1700	1.5
35	1750	1.6
36	1800	2.0
37	1850	4.0
38	1900	7.0
39	1950	10.0
40	2000	6.0
41	2050	7.0
42	2100	5.0

Table D-2

Dye Concentration Along Dike, Depth = 1.0 Feet,

Kewaunee, 1430 Hours, 15 May 85

Sample	Location, feet	Concentration, ppb
0	0	0.5
1	50	0.5
2	100	0.5
3	150	0.5
4	200	0.5
5	250	0.5
6	300	0.5
7	350	0.5
8	400	0.5
9	450	0.5
10	500	0.5
11	550	0.7
12	600	1.0
13	650	0.9
14	700	0.8
15	750	0.5
16	800	0.5
17	850	0.5
18	900	0.5
19	950	1.0
20	1000	1.0
21	1050	0.9
22	1100	0.8
23	1150	1.4
24	1200	1.3
25	1250	1.0
26	1300	0.7
27	1350	0.5

(Continued)

Background Concentration = 0.5 ppb, Location 0 = Southwest corner

Table D-2 (Concluded)

Sample	Location, feet	Concentration, ppb
28	1400	0.5
29	1450	2.0
30	1500	3.0
31	1550	1.0
32	1600	1.0
33	1650	1.0
34	1700	2.5
35	1750	3.5
36	1800	15.0
37	1850	11.0
38	1900	7.0
39	1950	6.0
40	2000	2.8
41	2050	4.8
42	2100	4.0

Table D-3

Dye Concentration Along Dike, Depth = 1.0 Feet,

Kewaunee, 0830 Hours, 16 May 85

Sample	Location, feet	Concentration, ppb
0	0	0.5
1	50	0.5
2	100	0.5
3	150	0.5
4	200	0.7
5	250	0.7
6	300	0.9
7	350	0.7
8	400	0.6
9	450	0.5
10	500	1.4
11	550	1.3
12	600	1.0
13	650	2.5
14	700	1.2
15	750	1.2
16	800	0.5
17	850	2.0
18	900	2.8
19	950	2.0
20	1000	3.0
21	1050	3.8
22	1100	8.0
23	1150	3.6
24	1200	3.0
25	1250	2.6
26	1300	1.2
27	1350	0.8

(Continued)

Background Concentration = 0.5 ppb, Location 0 = Southwest corner

Table D-3 (Concluded)

Sample	Location, feet	Concentration, ppb
28	1400	1.5
29	1450	9.0
30	1500	12.0
31	1550	1.4
32	1600	1.0
33	1650	1.0
34	1700	7.0
35	1750	15.0
36	1800	13.0
37	1850	8.0
38	1900	8.0
39	1950	4.0
40	2000	5.0
41	2050	3.2
42	2100	2.6

APPENDIX E

Derivation of Flow Quantification Equations

A mass balance at any point of discharge may be represented by the following equation:

$$Q_L * C_{IN} = (Q_L + Q_{DIL}) * C_{OUT} \quad \text{(E1)}$$

where:

Q_L = discharge rate
C_{IN} = dye concentration inside containment area
Q_{DIL} = dilution flow rate
C_{OUT} = dye concentration outside containment area

Assuming that the dilution is constant per unit length of the dike, let $Q_{DIL} = K * W$. Rewriting Eq (E1) yields:

$$Q_L = \frac{C_{OUT}}{C_{IN}} * (Q_L + KW) \quad \text{(E2)}$$

where:

K = constant dilution rate per unit length of dike
W = width of discharge

Letting $C_R = \frac{C_{OUT}}{C_{IN}}$ = concentration ratio

and expanding and rearranging yields:

$$Q_L = Q_L C_R + KW\ C_R \quad \text{(E3)}$$

$$Q_L(1 - C_R) = KW(C_R) \quad \text{(E4)}$$

$$\frac{Q_L}{K} = \frac{C_R * W}{1-C_R} \quad \text{(E5)}$$

The constant dilution assumption is generally valid when the currents around the dikes were similar.

Letting $Q_L(i)$ equal the discharge rate flow through point i, then, $\sum_{i=1}^{n} Q_L(i)$ equals the total flow from the area. The percent of the flow discharging at any point may be expressed as a fraction of the total flow.

$$Q_p(i) = \frac{Q_L(i)}{\sum_{i=1}^{n} Q_L(i)} * 100\% \qquad \text{(E6)}$$

where: $Q_p(i)$ = percent of flow passing through the dike at point i.
n = total number of discharge points

Dividing the top and bottom of the right side of Eq (E6) by K yields:

$$Q_p(i) = \frac{\frac{Q_L(i)}{K}}{\sum_{i=1}^{n} \frac{Q_L(i)}{K}} * 100\% \qquad \text{(E7)}$$

Applying equations (E5) to all points and summing yields:

$$\sum_{i=1}^{n} \frac{Q_L(i)}{K} = \sum_{i=1}^{n} \frac{C_R(i)}{1-C_R(i)} * W(i) \qquad \text{(E8)}$$

where: $W(i)$ = width of discharge of point i
$C_R(i)$ = concentration ratio at point i

Combining Equations (E7) and (E8) yields:

$$Q_p(i) = \frac{\frac{Q_L(i)}{K}}{\sum_{i=1}^{n} \frac{C_R(i)}{1-C_R(i)} * W(i)} *100\% \qquad \text{(E9)}$$

or

$$Q_p(i) = \frac{\frac{C_R(i)}{1 - C_R(i)} * W(i)}{\sum_{i=1}^{n} \frac{C_R(i)}{1 - C_R(i)} * W(i)} *100\% \qquad \text{(E10)}$$

The procedure to calculate the percent of the flow being discharge at each point is:

1) Compute the concentration ratio for each point i, $C_R(i)$,
2) Compute $\frac{C_R(i) * W(i)}{1 - C_R(i)}$ for each point i,
3) Sum $\frac{C_R(i) * W(i)}{1 - C_R(i)}$ for all points, and
4) Calculate $Q_p(i)$ for each point using Equation (E10).