HEAVY METALS IN LIQUID WASTE DISPOSAL:
WATER-SEDIMENT INTERACTIONS

A Thesis

by

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Submitted in partial fulfillment of the requirements of the
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Approved as to style and content by:

Dr. Ernest L. Estes

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ABSTRACT

Heavy Metals in Liquid Waste Disposal:
Water-Sediment Interactions
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Mary Christine Stordal
Faculty Advisor: Dr. Ernest L. Estes

Water and sediment samples taken from an area near the discharge of the Galveston Sewage Treatment Plant were analyzed for copper, nickel, lead and zinc. Two twenty-four hour sampling periods were conducted at four hour intervals: the first on 16-17 September 1978 and the second on 3-4 November 1978. The sewage treatment plant was found to discharge all four metal ions into the surrounding area. Lead and nickel ions appeared to also be brought into the area by the tides.

An accumulation of silt-sized sediment and organic particulates was found in an area less than 100 m from the discharge. High concentrations of metal ions were also found in the same area. A high correlation (greater than 0.90) between the particulates and metal ions indicates that adsorption and incorporation into the sediments is probably occurring.

Storm activity between September and November may have carried the accumulated particulates and metal ions out into the bay. Cause for concern exists because metal ions in the sediments can enter the food chain and concentrate in some commercial species (blue crabs, brown shrimp, and oysters).

ACKNOWLEDGEMENTS

I would like to thank my faculty advisor, Dr. E.L. Estes, for his aid through the entire study. I would also like to thank Charmaine Walter, Robert Brousseau, Mark Linver, Terry Gough and Mads Emanuelsen for their help with the collection and/or analysis of the samples. A special thanks goes to Charles Coleman for his advice on laboratory procedures and to Dr. D. E. Harper for his critical review of the paper. My deepest appreciation goes to Mads Emanuelsen for his moral support throughout the entire project.

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INTRODUCTION

In trace amounts, heavy metals are necessary, and some such as zinc, cobalt and copper, are essential for the existance of marine organisms (Bryan 1971 and Lisk 1971). In coastal regions, river and wind transport supply the necessary metal ions for biological functions (Riley and Skirrow 1975), but additions from man-made sources can increase metal concentrations to dangerous levels (Bryan 1971 and Lisk 1971). Among the many sources of heavy metals, municipal wastewater has been shown as a primary source of excess metal additions to estuarine and marine environments (Helz and others 1975).

Upon discharge into an aquatic environment from a wastewater treatment plant, the metal ions present are not only diluted by the estuarine water (Helz and others 1975), but undergo processes such as absorption by biota, precipitation, and adsorption onto clay and organic particulates (Bryan 1971). Adsorption is probably the primary process responsible for the concentration of various metal ions into bottom sediments (Scrudato and Estes 1975). Adsorption is the formation of weak van der Waals bonds between positively charged metal ions and negatively charged clay and organic particulates (Grim 1968). Helz and others (1975) observed a rapid decrease or fall-off of concentrations of metal ions in water near a sewage treatment plant and a corresponding increase in the associated sediments. Polychaete worms which are near the base of many marine food chains have been shown to remove large amounts of zinc from the sediments (Renfro 1973).

Format used in this paper was taken from Environmental Geology.

The Galveston sewage treatment plant is located at the southern end of Galveston Bay (Fig. 1). The sampling area is near one entrance of the Galveston Ship Channel and is a semi-enclosed area open to Galveston Bay on the northwest side (Fig. 2). Water depths in the area range from 20 cm at station 8 (Fig. 3) to 2 m at station 5; this fluctuates approximately 10 cm with the tides. The discharge point is located at the southern end of the area near station 1. Man-made walls and debris compose the east, southwest and south boundaries, while the area near station 8 is an exposed mud flat at low tide.

At the treatment plant, the sewage undergoes primary and secondary treatment as well as chlorination before the effluent is discharged into Galveston Bay (McLaughlin, personal communication). Approximately 3.4×10^7 liters per day (9 million gallons per day) are discharged near station 1. EPA regulations require effluent pH to be between 6 and 9; the sewage treatment plant has never deviated from this requirement (Shaw, personal communication). No special treatment is performed to remove heavy metal ions from the sewage effluent.

The four metal ions analyzed in this study, copper, nickel, lead and zinc, are toxic in excess amounts to biota (Bryan 1971 and Lisk 1971) and are commonly discharged from municipal sewage treatment plants (Helz and others 1975). Water and sediment samples were taken from an area near the main Galveston sewage treatment plant to delineate the fall-off of metal ion concentration in water as a result of adsorption and incorporation into sediments.

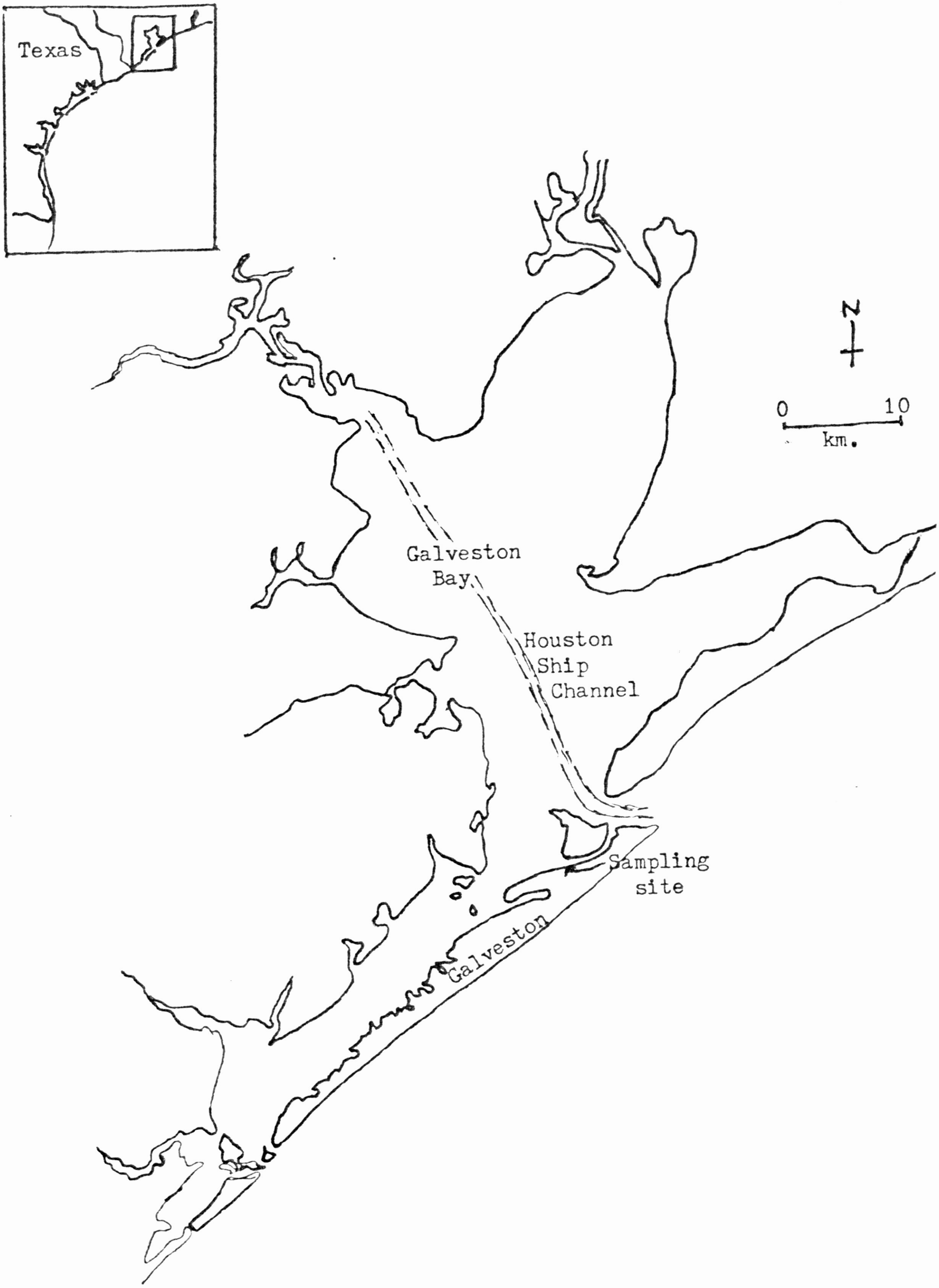

Figure 1. Galveston Bay, Texas and sampling site.

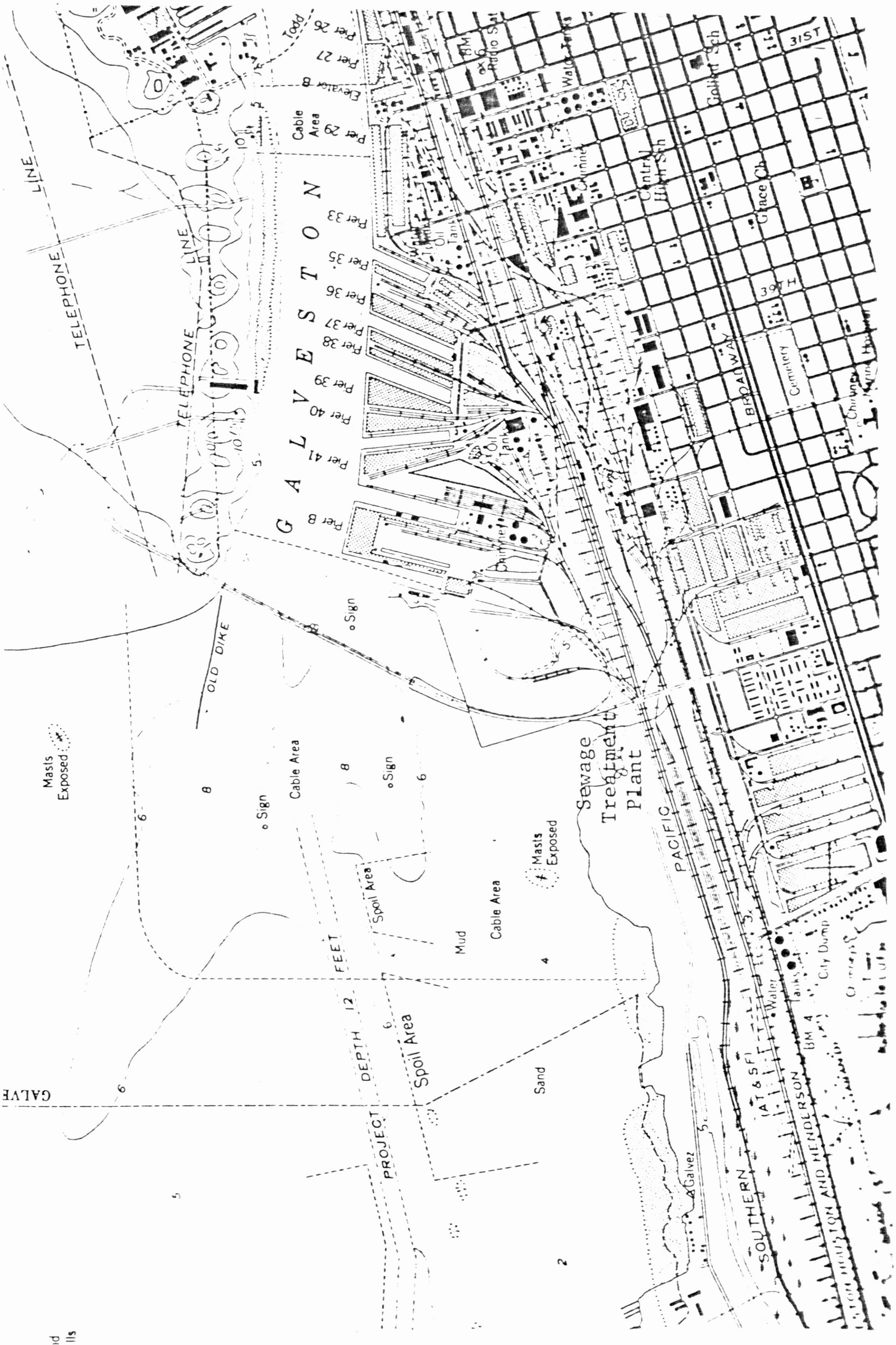

Figure 2. Galveston Sewage Treatment Plant and surrounding area.

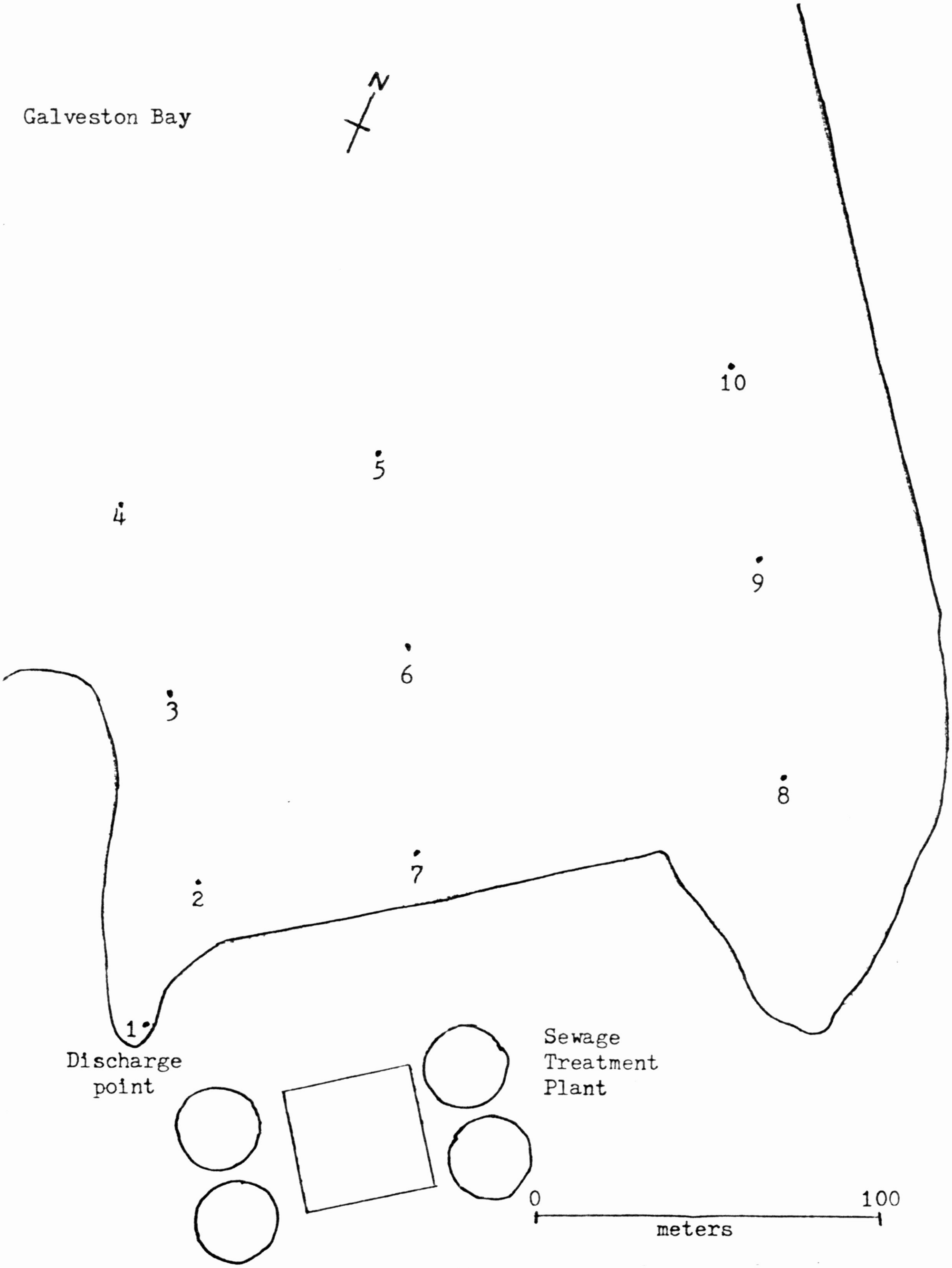

Figure 3. Study area near the discharge of Galveston Sewage Treatment Plant.

LITERATURE REVIEW

The detrimental effects of heavy metal ions on marine organisms have been well documented (Bryan 1971 and Lisk 1971). Results from many studies have inspired research into the sources and environmental sinks of the metal ions and the processes involved after release to the environment. Renfro (1973) found that approximately 98% of the metals supplied to a marine system concentrate in the sediments.

The primary source of natural metal supply to the coastline is river water with wind transported sediments and land run-off as minor contributors (Riley and Skirrow 1975). Sewage treatment plants (Helz and others 1975), industrial waste (Waldhauer and others 1978) and ship channels (Holmes and others 1974) supply a substantial amount of heavy metals to estuarine waters.

Abnormally high metal concentrations in the sediments are associated with metal concentrations in the water from man-made sources (Holmes and others 1974). Many bay, lake and estuarine sediments have been analyzed for concentrations of various metals (Duchart and others 1973, Bruland and others 1974, Keeney 1974, Helz and others 1975, Greig and McGrath 1977, and Greig and others 1977).

In the northwest Gulf Coast, Trefry and Presley (1976) have studied heavy metal concentrations in San Antonio Bay, the Mississippi River Delta and the continental shelf between these two areas. Also, along the Texas coastline, Corpus Christi Bay (Holmes and others 1974), Galveston Bay and the Houston Ship Channel sediments (Hann and Slowey 1972) have been found heavily polluted from industrial and municipal waste and ship activity.

Processes affecting the distribution of heavy metals have been reviewed by Leland and others (1973). Particle size and organic content are two major factors affecting metal concentrations in the sediments. O'Connor and Kester (1975) showed that high percentages of copper (greater than 90%) were adsorbed onto illite clay at a pH of 6 - 12 from both river water and sea water. Maximum sorption of lead onto various clays occurs at a pH of 7.5 (Scrudato and Estes 1975). Zinc has been found to be rapidly sorbed onto bay sediments (Holmes and others, 1974).

Specific chemical and physical properties, especially organic particulate content, pH and salinity, affect adsorption of metals and incorporation into the sediments. Changes in these properties can also result in desorption (O'Connor and Kester 1975) or redistribution of sediments containing high concentrations of metal ions (Holmes and others 1974). Thus, excess metal ions are a danger not only in the aquatic environment but also when incorporated in the sediments.

MATERIALS AND METHODS

Water and sediment samples were taken from 10 stations located near the discharge point of the Galveston sewage treatment plant (Fig. 3). Duplicate samples were taken at stations 2 and 5. Two 24-hour studies of this area were conducted; the first on 16-17 September 1978 and the second on 3-4 November 1978. Samples were taken at 4 hour intervals. Water samples were obtained with a glass jar from the side of the boat. An Ekman grab was used to obtain bottom sediment samples. Care was taken to remove sediment samples from the center of the grab to prevent contamination from the sides. Sediment samples were placed in a plastic whirl pac and returned to the laboratory after each collection. All samples were stored at 4°C and November samples were frozen until analysis.

A 400 ml aliquot of each water sample was placed in a polyethelene bottle with 40 ml of HCl. The acidified sample was evaporated in a glass beaker over low heat to one-tenth original volume. This was done to concentrate the metal ions. The sample was then gravity-filtered through #2 Whatman paper to remove particulate matter. The filtrate was caught in a single graduated cylinder (to minimize error), placed in a polyethelene bottle, and stored at 4°C until analysis. Blanks containing acidified double-distilled water were processed with each months samples.

The sediment samples were air-dried and a portion was weighed and placed in a 250 ml beaker. The samples were acid stripped using 1:1 nitric acid, followed by concentrated nitric and finally concentrated hydrochloric acid. The samples were refluxed for 30 to 45 minutes with each acid and swirled while being heated. Gravity filtration through #2 Whatman paper was used to separate the liquid from the sediments. The filtrate was brought up to a volume of 100 ml in a volumetric flask with double-distilled water and poured into a polyethelene bottle. Blanks were prepared with each set of sediments. All bottles, glassware and funnels were rinsed with double-distilled water and 10% HCl solution before use.

The samples were analyzed in triplicate for copper, lead, nickel and zinc with a Perkin-Elmer model 306 atomic absorbance spectrophotometer. The concentration obtained for the water samples was back calculated to the original volume and represented the total metal ion concentration. The sediment concentrations were adjusted to the dry weight of each sample and represented the acid leachable metal ions. Metal determinations on quadruplicate subsamples of both a sand rich and a silt rich sediment sample were made to determine the precision of the leaching method. Results indicated that at the 95% confidence interval there was no significant difference in the metal ion concentrations for any metal in each sample.

Grain size analysis was performed on sediment samples collected during one sampling period each month (September and November) and from two stations (1 and 10) for all time periods each month. The dry sieve and pipette sediment size analysis methods of Folk (1974) were used.

Total organic content of sediment samples collected during a 1400 hour sampling period in September and an 1800 hour sampling period in November and for all sampling periods each month for two stations

(1 and 10) was determined using a muffle furnace. Approximately 10 g of pre-weighed sample was placed in a crucible and heated for 2 to 4 hours at $900^{o}C$. Each sample was then reweighed and the percentage weight loss was calculated. Beyond 2 to 4 hours of heating (time was dependent on sediment type) it was determined that no further weight loss occurred and therefore all the carbon had been vaporized.

Some of the sediment data was analyzed statistically.

RESULTS

Water temperature and salinity were different at the discharge point than in the rest of the study area at all times in both months (Appendix I). From September to November the overall water temperature decreased approximately 6°C from around 28-31 °C to 22-25 °C, respectively. The water was 0.5 to 4 °C warmer at station 1 than at the other stations. The salinity was near 0 ppt at the discharge point and approximately 22-24 ppt at the outer stations during both months. In September, station 2 showed a tremendous fluctuation in salinity, ranging from 6 to 24 ppt. Salinity isopleths for one time period from each month show representative salinity gradients (Figs. 4 and 5).

The tidal pattern differed during the two sampling periods (Fig. 6). Semi-diurnal tides (two unequal highs and lows per day) occurred during each collection period and a very low tide occurred in November during the 1000 hr sampling period.

Of the four metals, lead was found in greatest concentrations in the water samples. All stations except station 1 contained concentrations greater than 1 ppm. Nickel was second in abundance and also was found in largest concentrations at the outer stations. In September, copper and zinc were present in approximately the same concentrations while in November zinc concentrations were below detection limits at most stations. Copper, lead and nickel concentrations had not changed between September and November (Appendix II).

Zinc isopleths for the period 1400-0600 hrs in November show the discharge and dispersion of the metal ions (Fig. 7a-e). At 1400 hr, very little zinc was present in the water, although no data is available

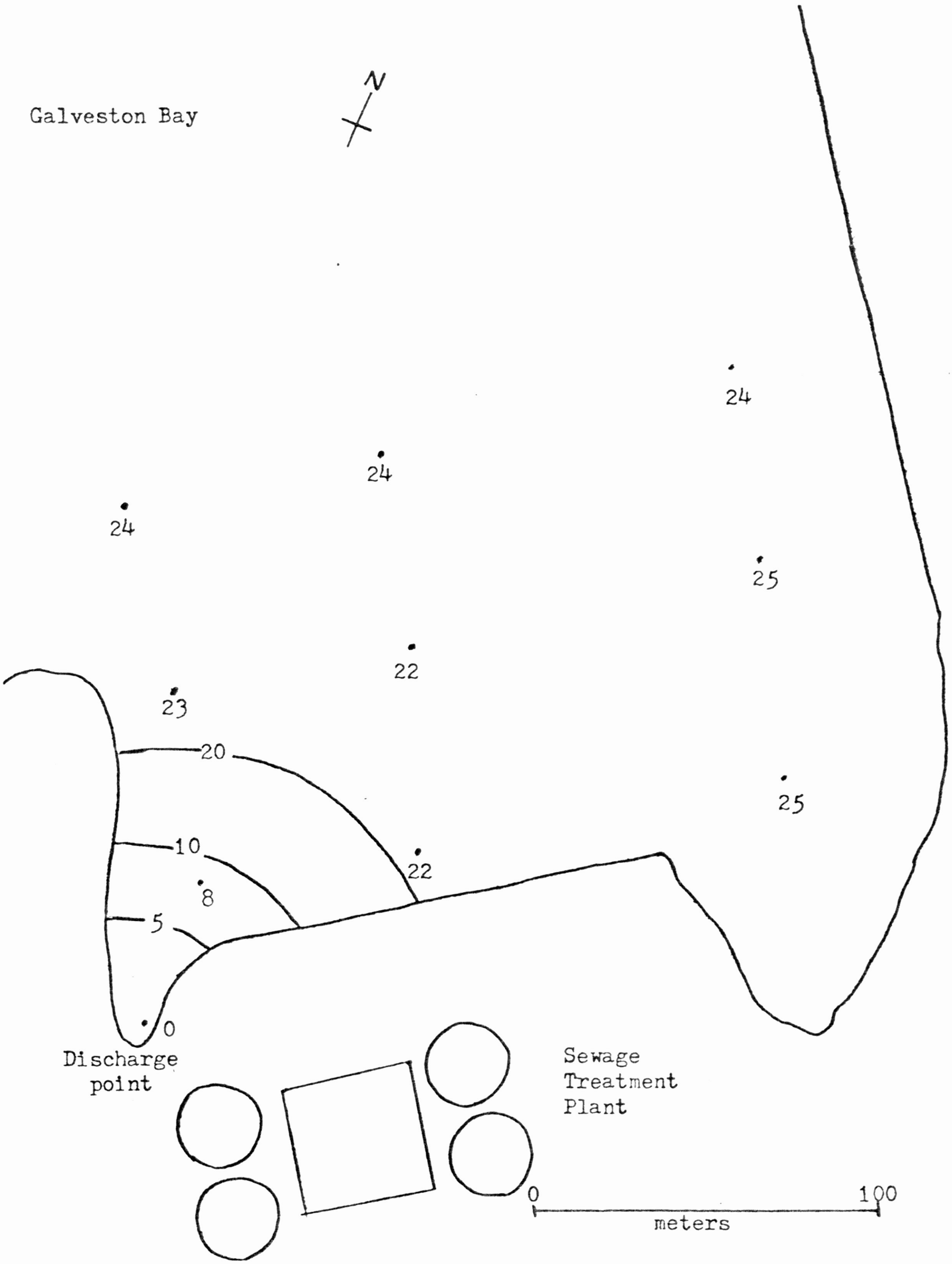

Figure 4. Salinity (ppt) isopleths, 1000 hr, 16 September 1978.

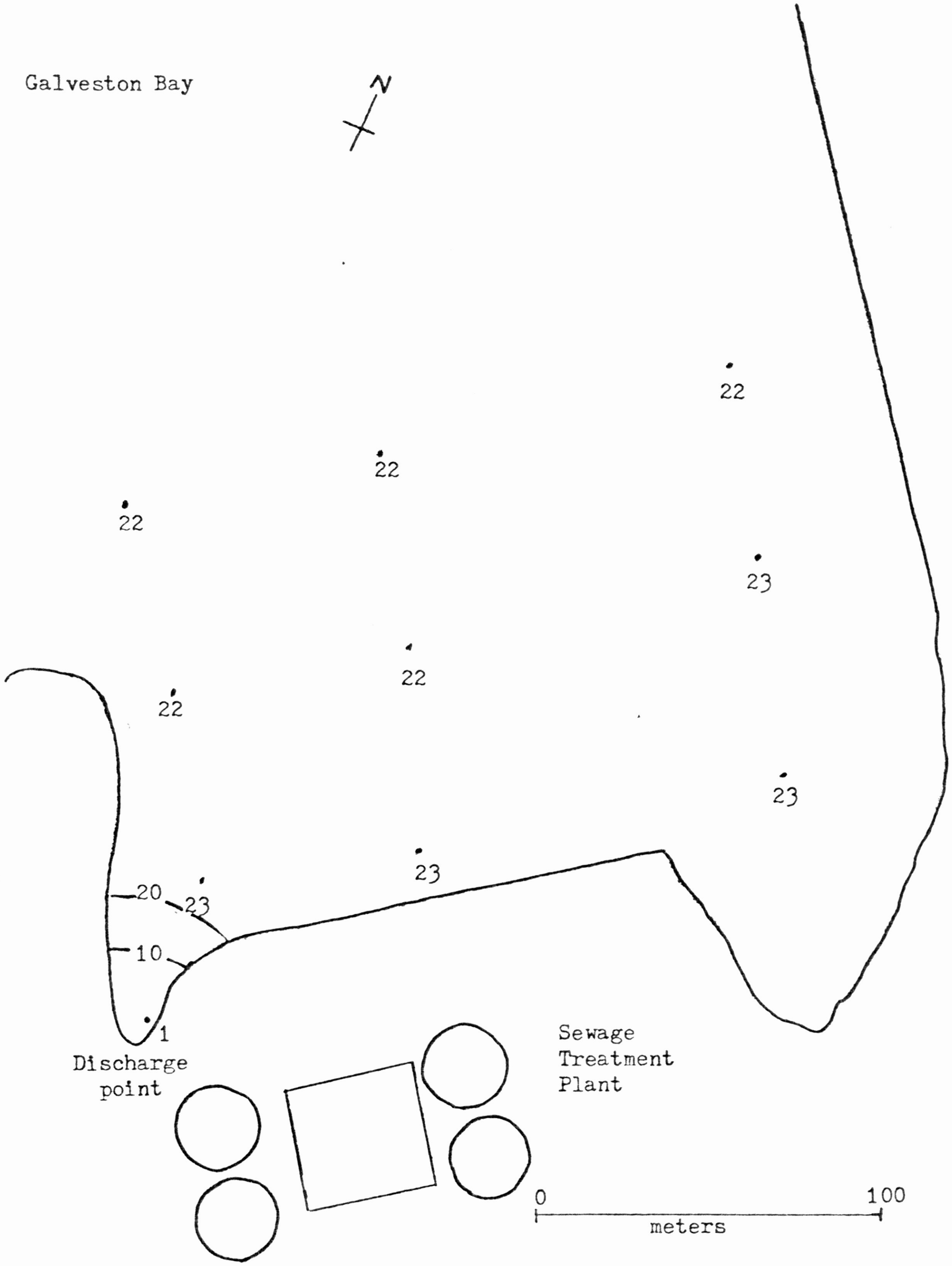

Figure 5. Salinity (ppt) isopleths, 2200 hr, 3 November 1978.

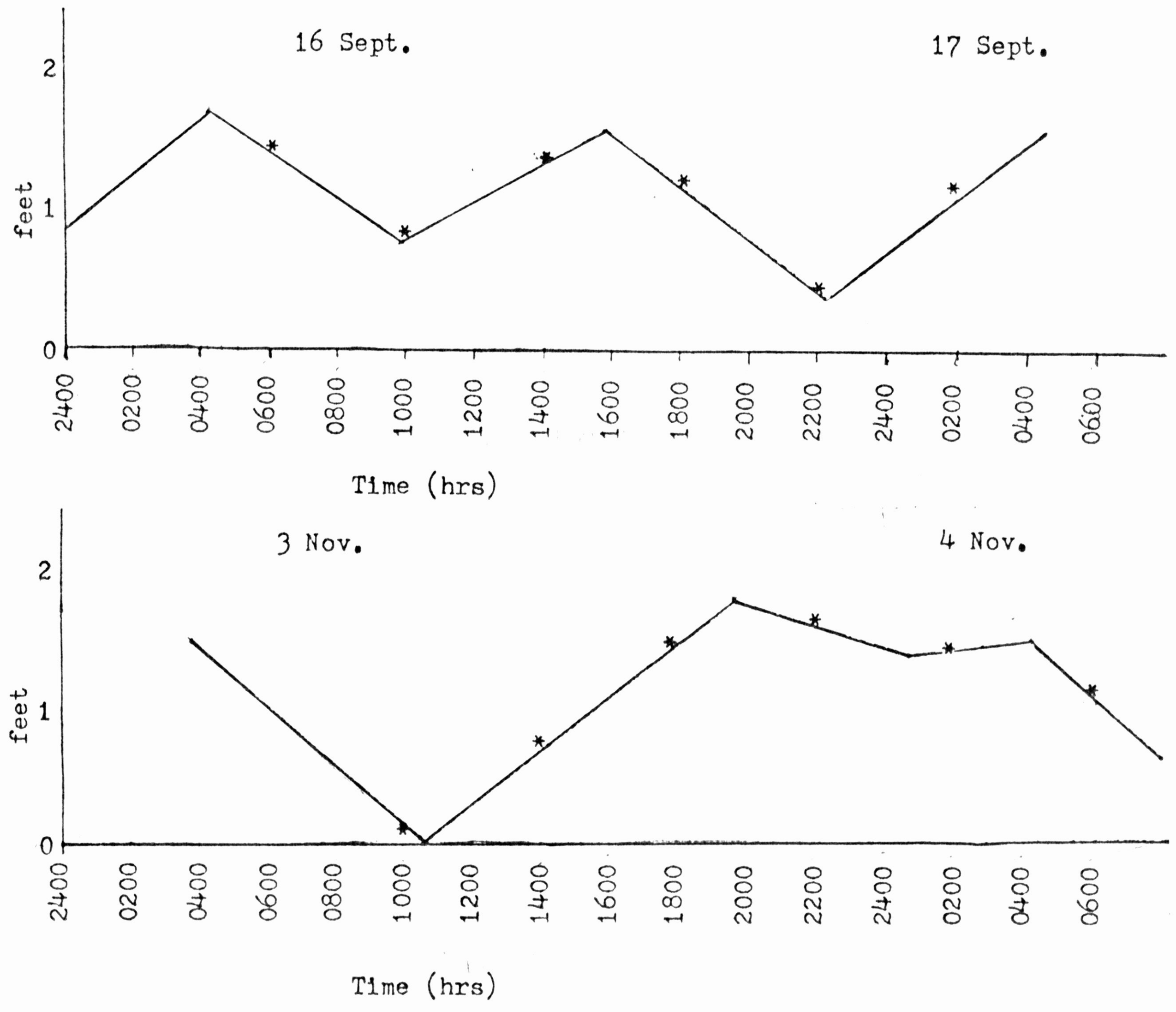

Figure 6. Graphs of tidal fluctuations of Galveston Bay during each sampling time, 16-17 September 1978 and 3-4 November 1978.

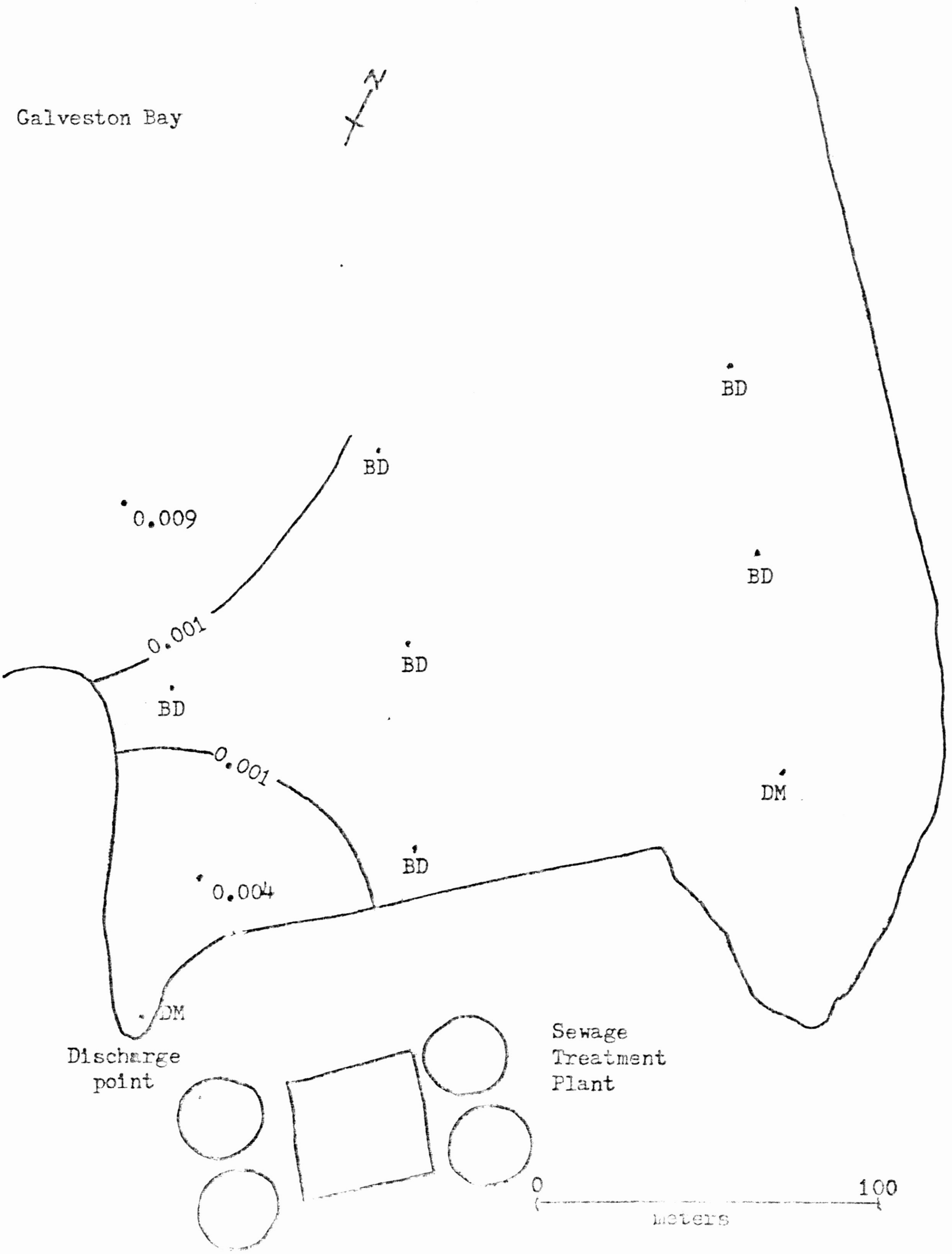

Figure 7a. Isopleths of zinc concentrations (ppm) in the water, 1400 hr, 3 November 1978.

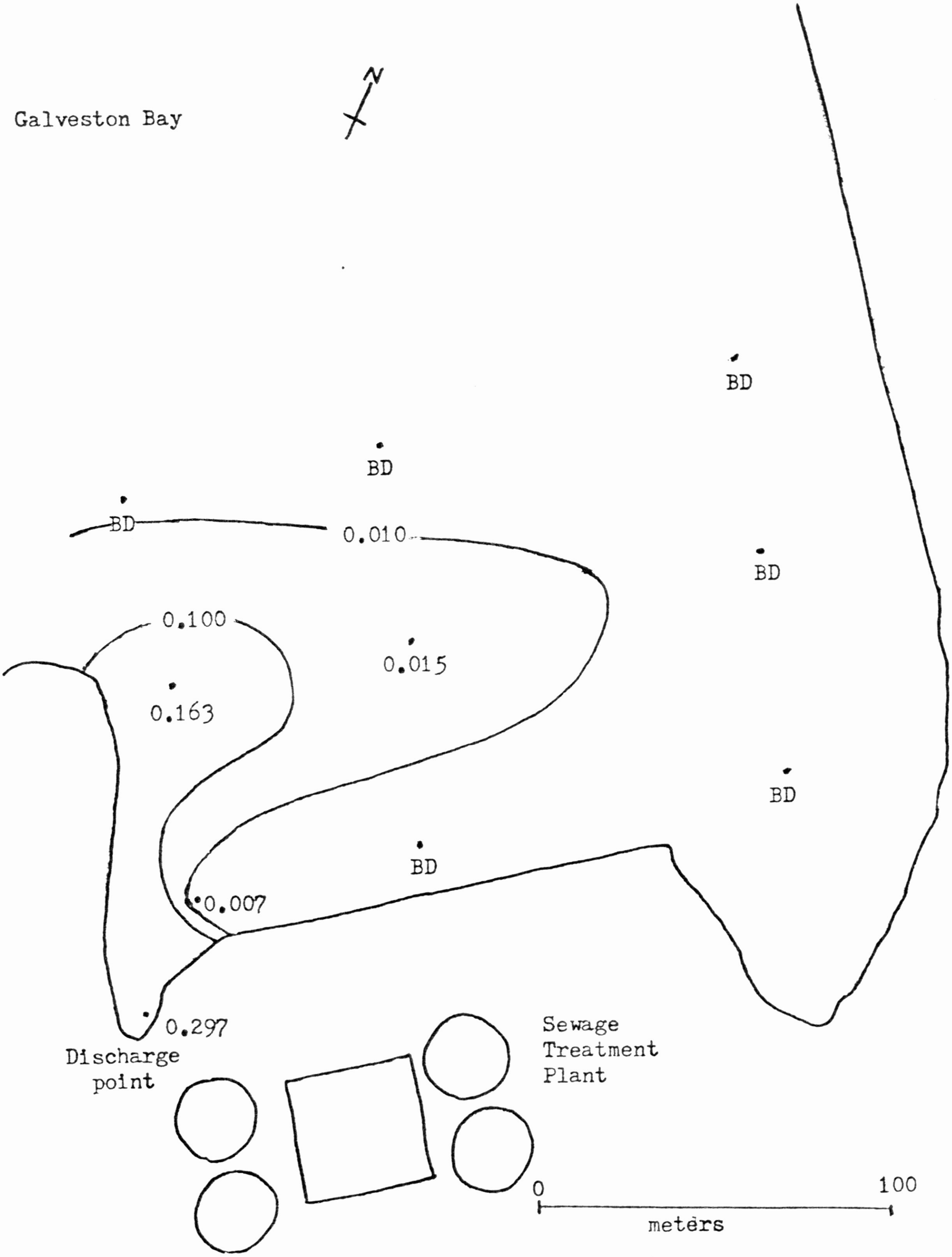

Figure 7b. Isopleths of zinc concentrations (ppm) in the water, 1800 hr, 3 November 1978.

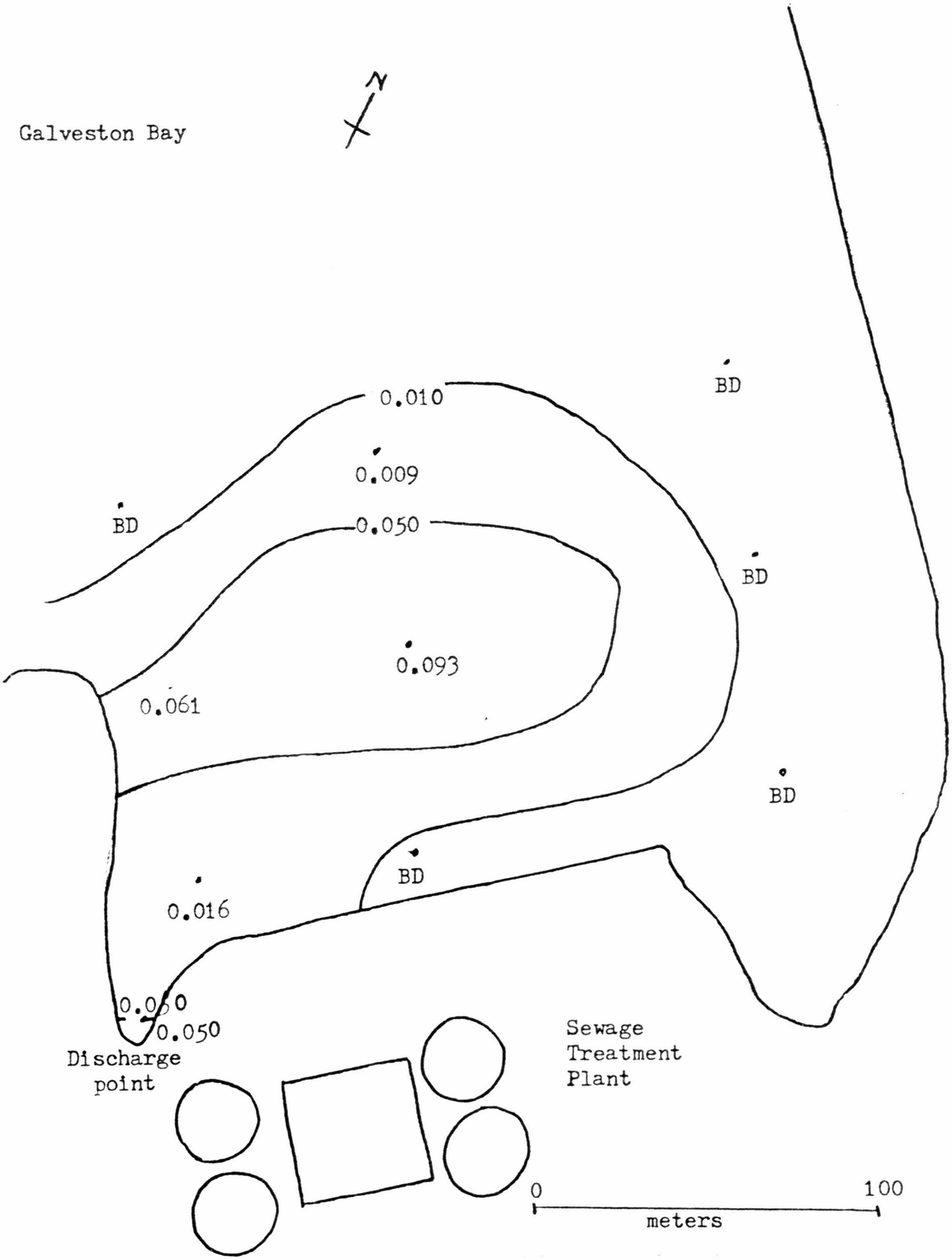

Figure 7c. Isopleths of zinc concentrations (ppm) in the water, 2200 hr, 3 November 1978.

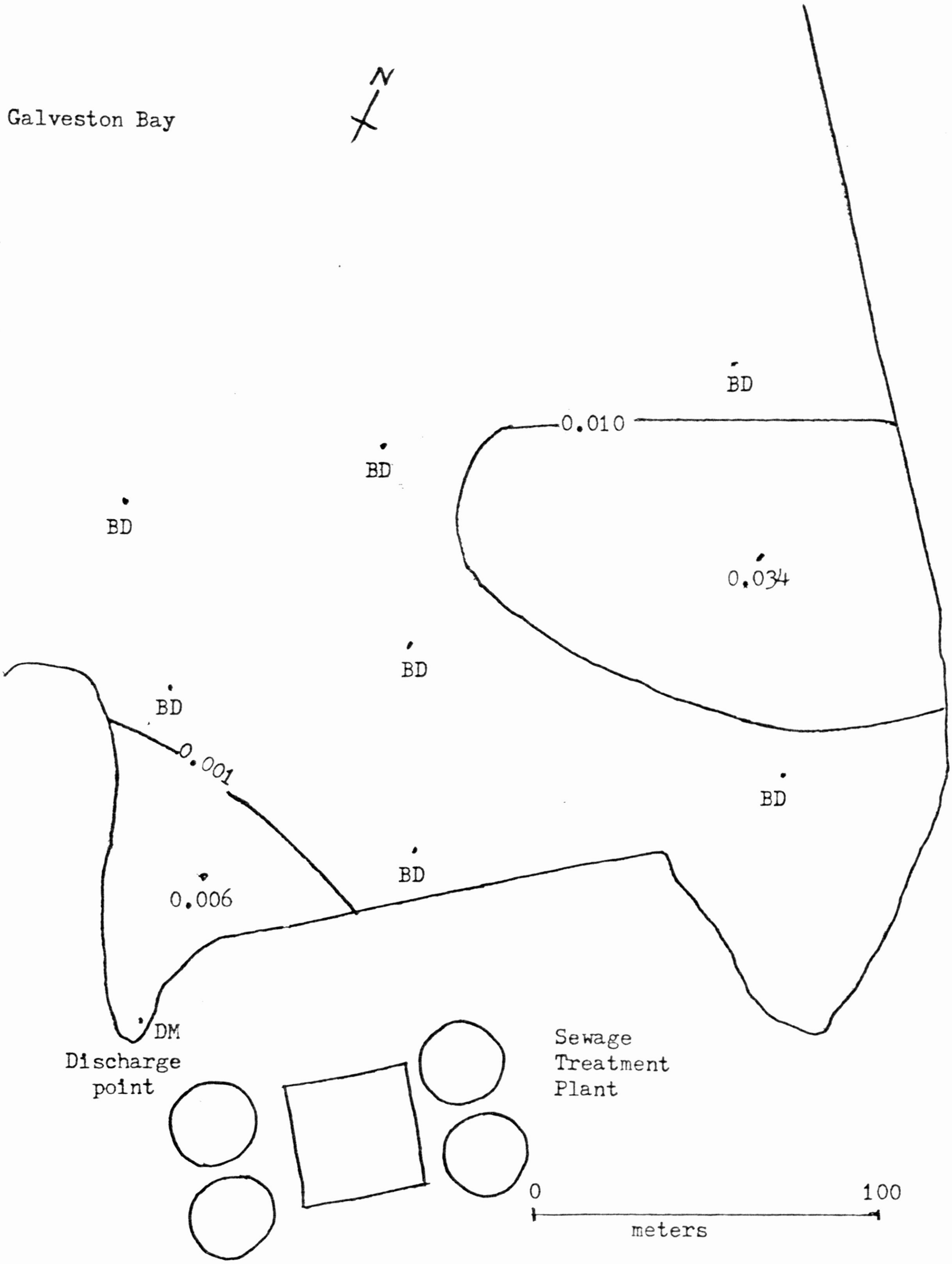

Figure 7d. Isopleths of zinc concentrations (ppm) in the water, 0200 hr, 4 November 1978.

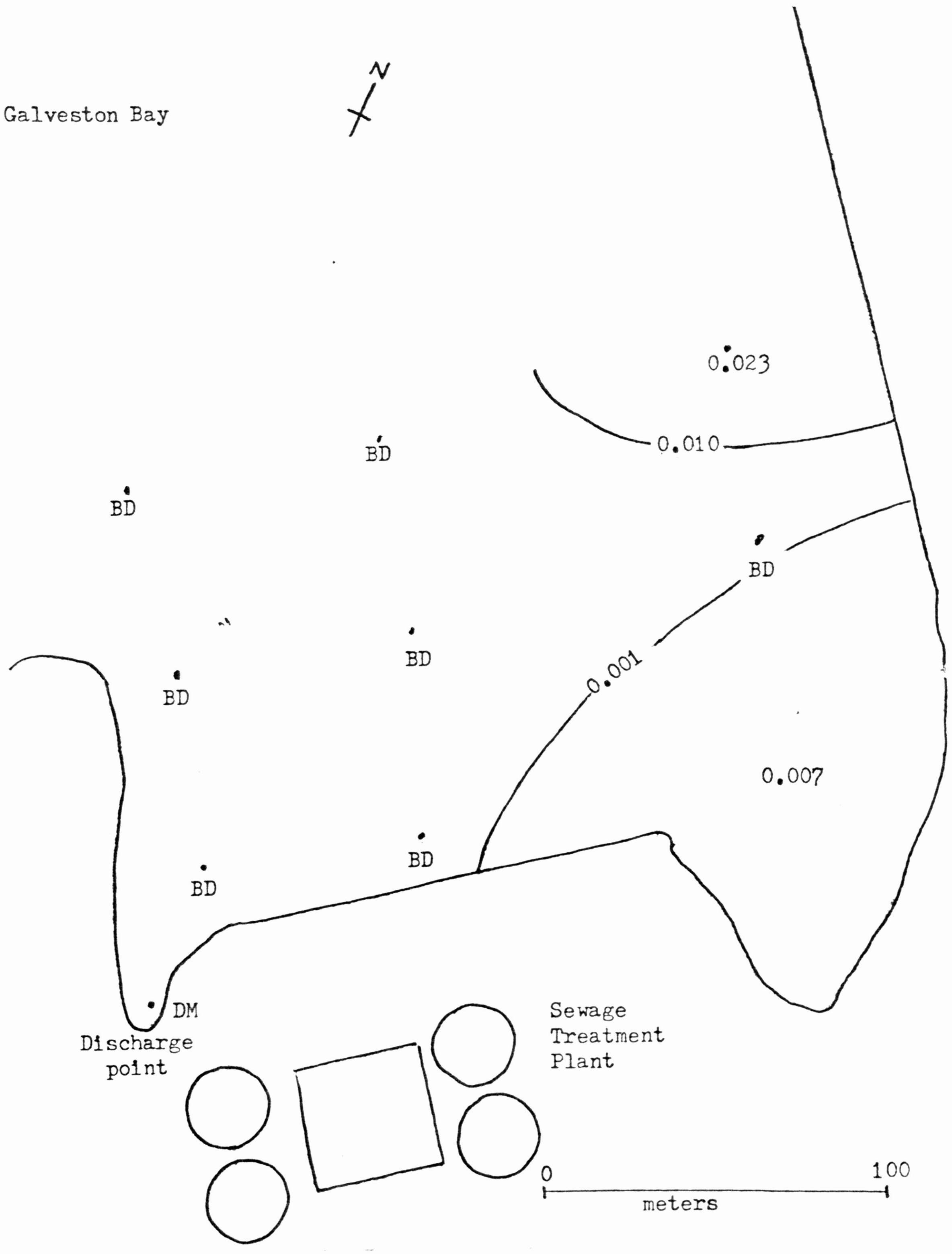

Figure 7e. Isopleths of zinc concentrations (ppm) in the water, 0600 hr, 4 November 1978.

from station 1. Four hours later (1800 hr), the sewage treatment plant was discharging approximately 0.297 ppm zinc, while at the next sampling period, the discharge had dropped to 0.050 ppm, and the zinc was spreading out into the water mass. Later, at 0200 hrs, the zinc concentration of 0.034 ppm was found at station 9, farther from the discharge point. Finally at 0600, the zinc remaining in measurable concentrations was carried to station 8 and station 10.

Lead was observed over the same time period in November to move in from the bay (Figs. 8a-e). At 1400 hr, the largest concentrations of lead were found at two of the outer stations. As the tide came in, the metal concentrations at stations closer in increased. When the tide was ebbing, the metal concentraions decreased. Again, the tide came in and brought an increase in lead concentrations. Finally at 0600 hrs, the tide went out and the metal concentrations decreased. Nickel also apparently moved with the tides while copper did not show any trends.

During both months, all four metal ions were discharged from the sewage treatment plant. For September samples, no trends in movement were observed. The lack of observable trends, however, may be due to the fact that a large number of the samples were contaminated during laboratory procedures, and this data had to be discarded.

In the sediments, zinc was found in the highest concentrations in contrast to the lowest concentrations in the water. Copper and lead values showed similar concentrations but were lower than zinc. Nickel was found in relatively low concentrations (Appendix III). Stations 2 and 7 contained nearly one order of magnitude greater concentrations of all four metals than the other stations in September. In November

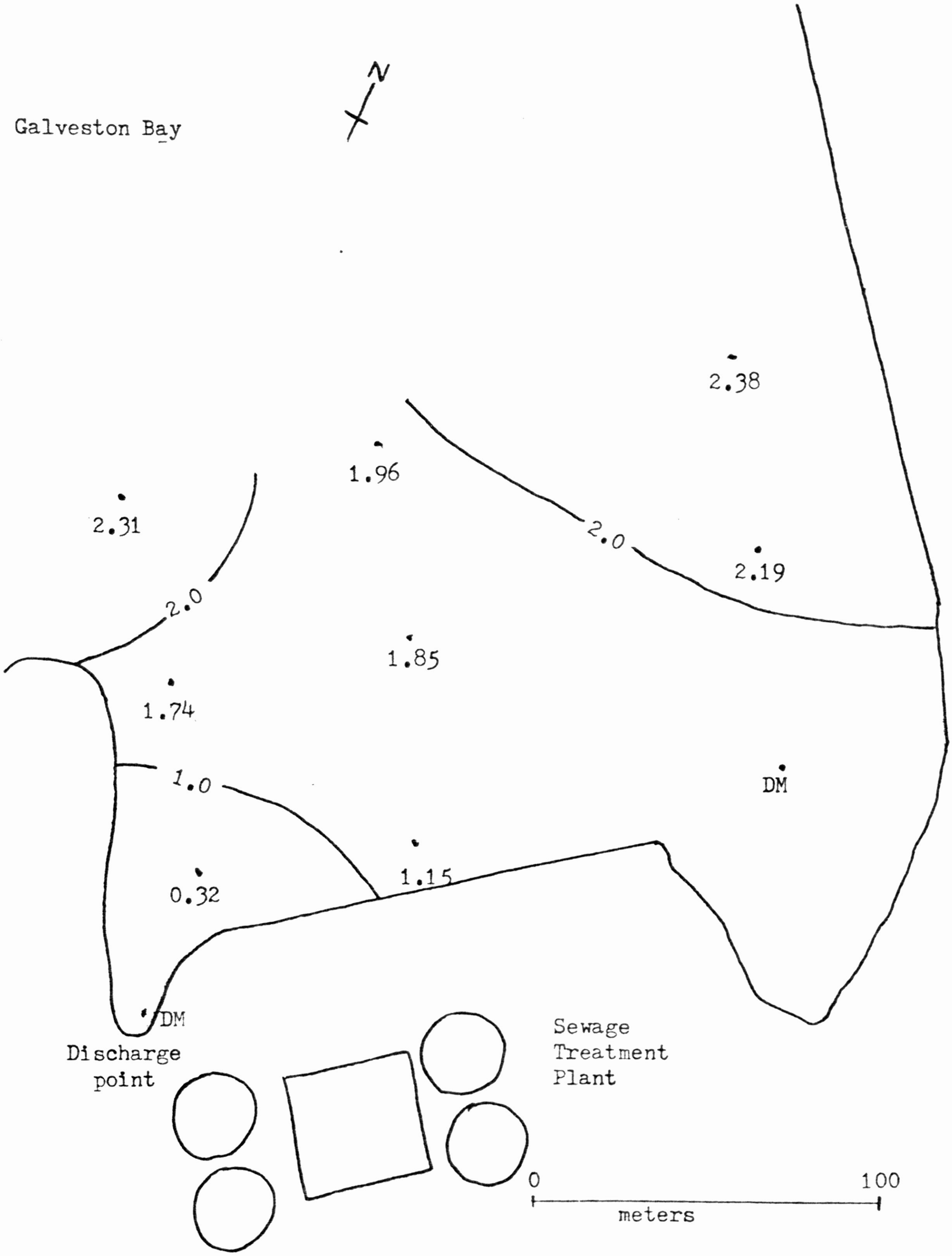

Figure 8a. Isopleths of lead concentrations (ppm) in the water, 1400 hr, 3 November 1978.

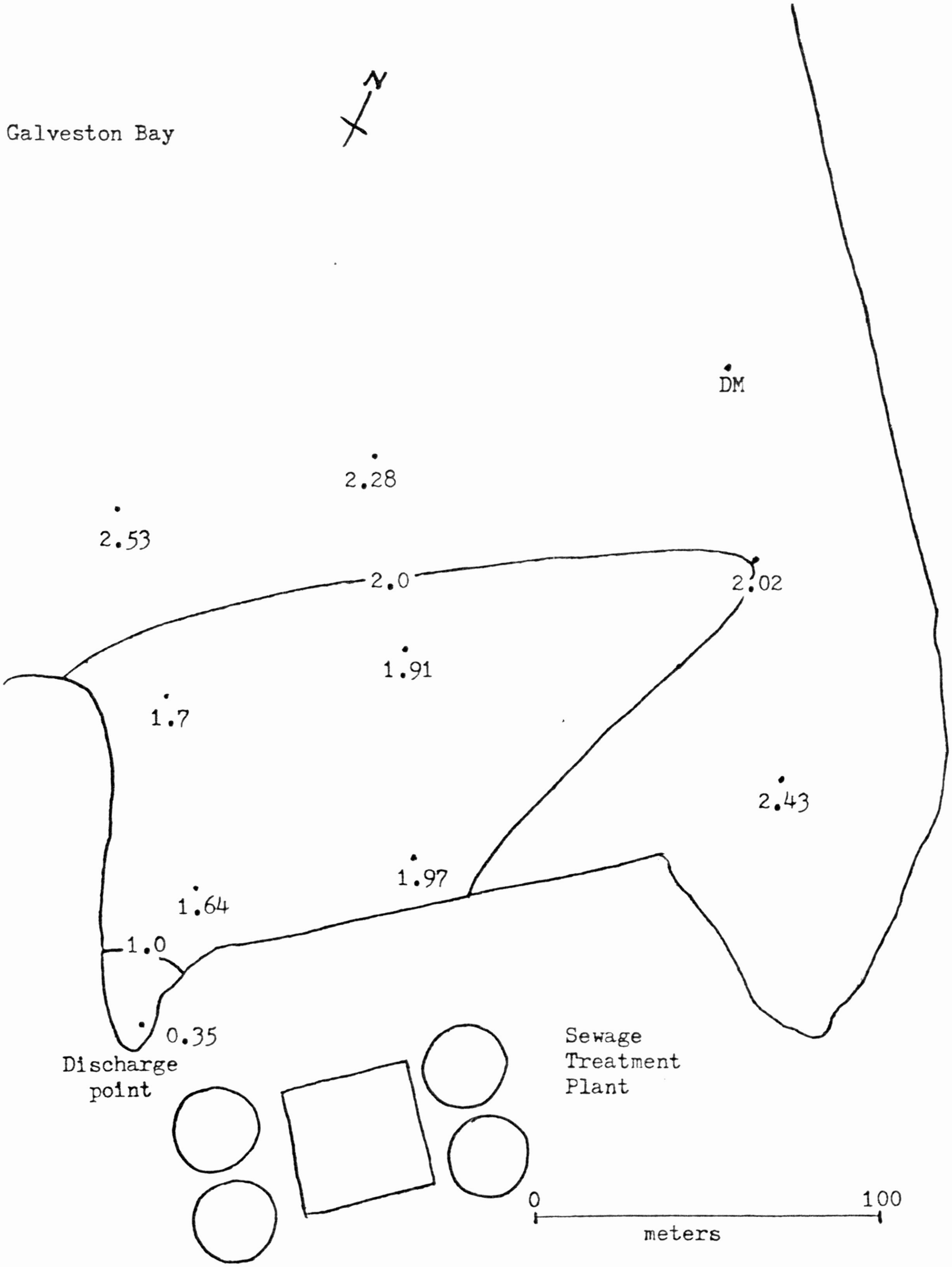

Figure 8b. Isopleths of lead concentrations (ppm) in the water, 1800 hr, 3 November 1978.

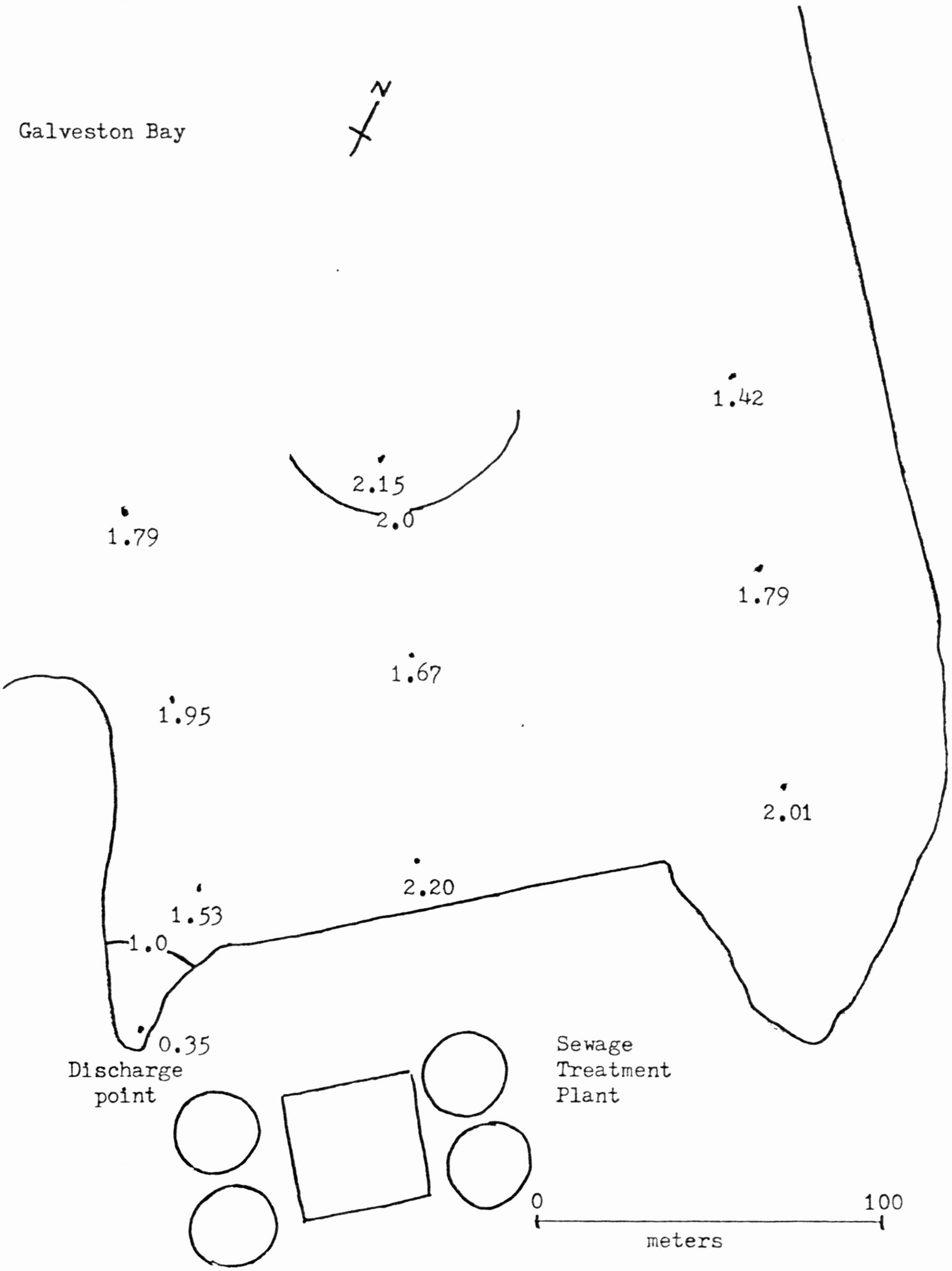

Figure 8c. Isopleths of lead concentrations (ppm) in the water, 2200 hr, 3 November 1978.

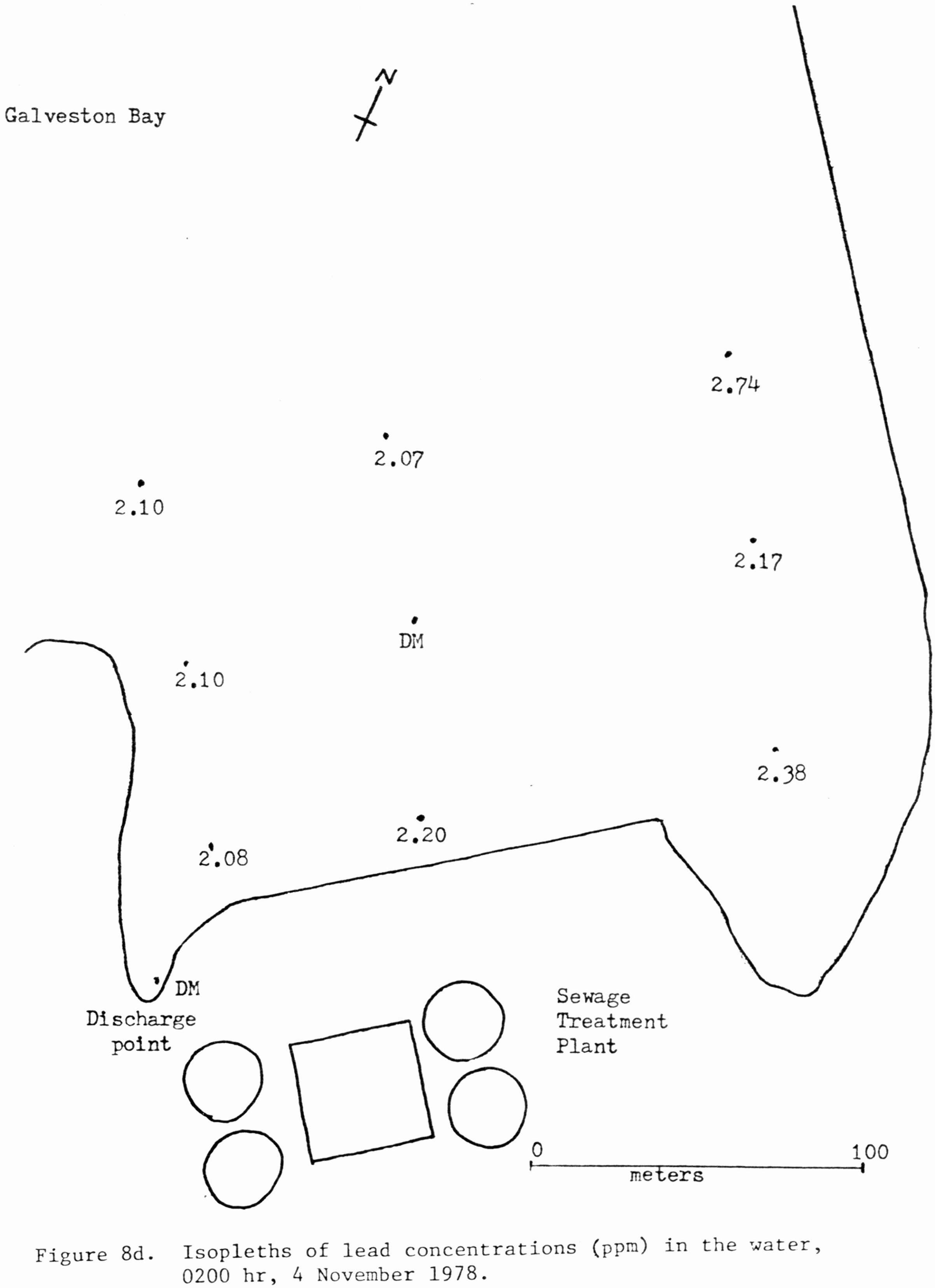

Figure 8d. Isopleths of lead concentrations (ppm) in the water, 0200 hr, 4 November 1978.

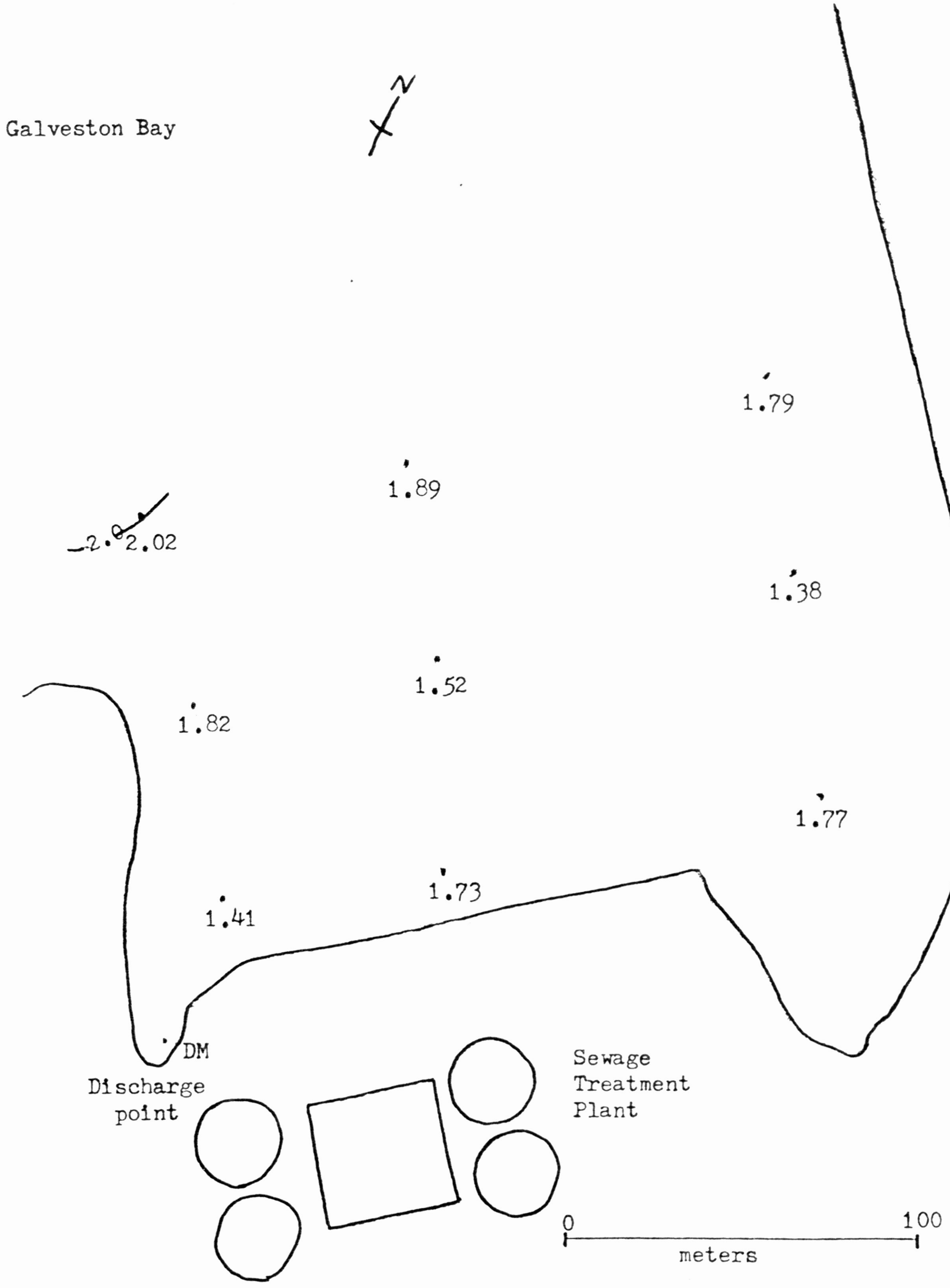

Figure 8e. Isopleths of lead concentrations (ppm) in the water, 0600 hr, 4 November 1978.

only station 2 had high metal concentrations. As an example, copper isopleths showed a high concentration of the metal at both stations in September (Fig. 9) and only one station in November (Fig. 10). Nickel, lead and zinc values displayed a similar pattern. Over the six time periods, only stations 1 and 2 showed a large fluctuation in metal content.

Grain size analysis for one set of samples during one time period each month (1400 hrs in September and 1800 hrs in November) showed that the mean size for most stations was in the fine sand range (2-3 Ø). In September, mean grain size at stations 2 and 7 was silt (Fig. 11), however, only station 2 sediments had a mean Ø in the silt range (4-9 Ø) in November (Fig. 12). The size analysis for two stations (1 and 10) collected at every time period showed little variation in mean Ø size (Appendix IV).

Total organic content determined on the same samples used for grain size analysis contained less than 5% organics at most stations (Appendix IV). Again, in September (Fig. 13) the total organic content was high (30-40%) at stations 2 and 7 while in November (Fig. 14) only station 2 contained greater than 30% organics. The organic content found in staions 1 and 10 samples from all time periods showed only small fluctuations.

It must be noted that at station 2 in November, where two samples were taken each time period, different mean particle size and organic content were observed in two samples from the same time period. Correspondingly, coarser or sandier samples contained less organics and lower metal concentrations. Only four of the twelve samples contained sig-

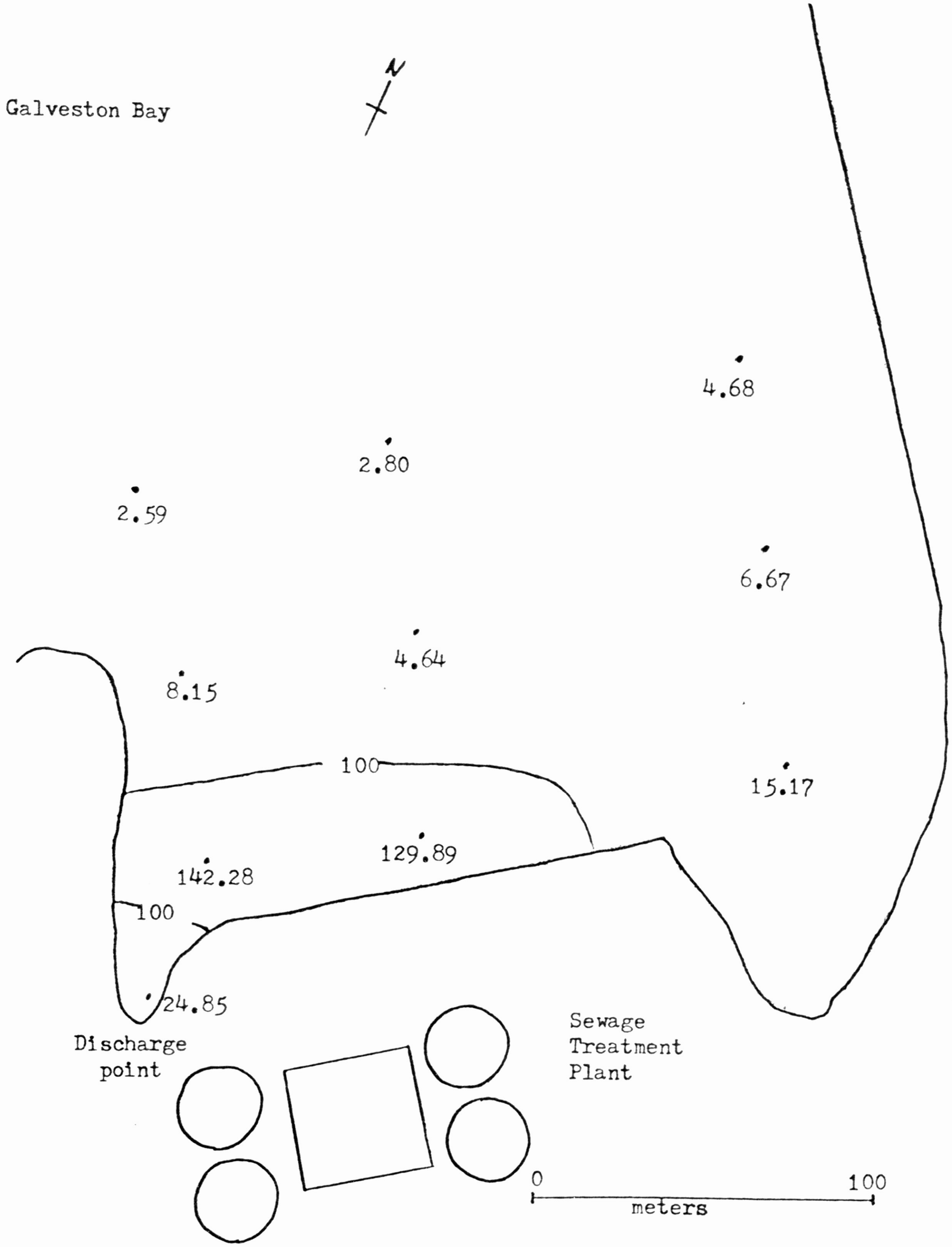

Figure 9. Isopleths of copper concentrations (ppm) in the sediments, 0600 hr, 16 September 1978.

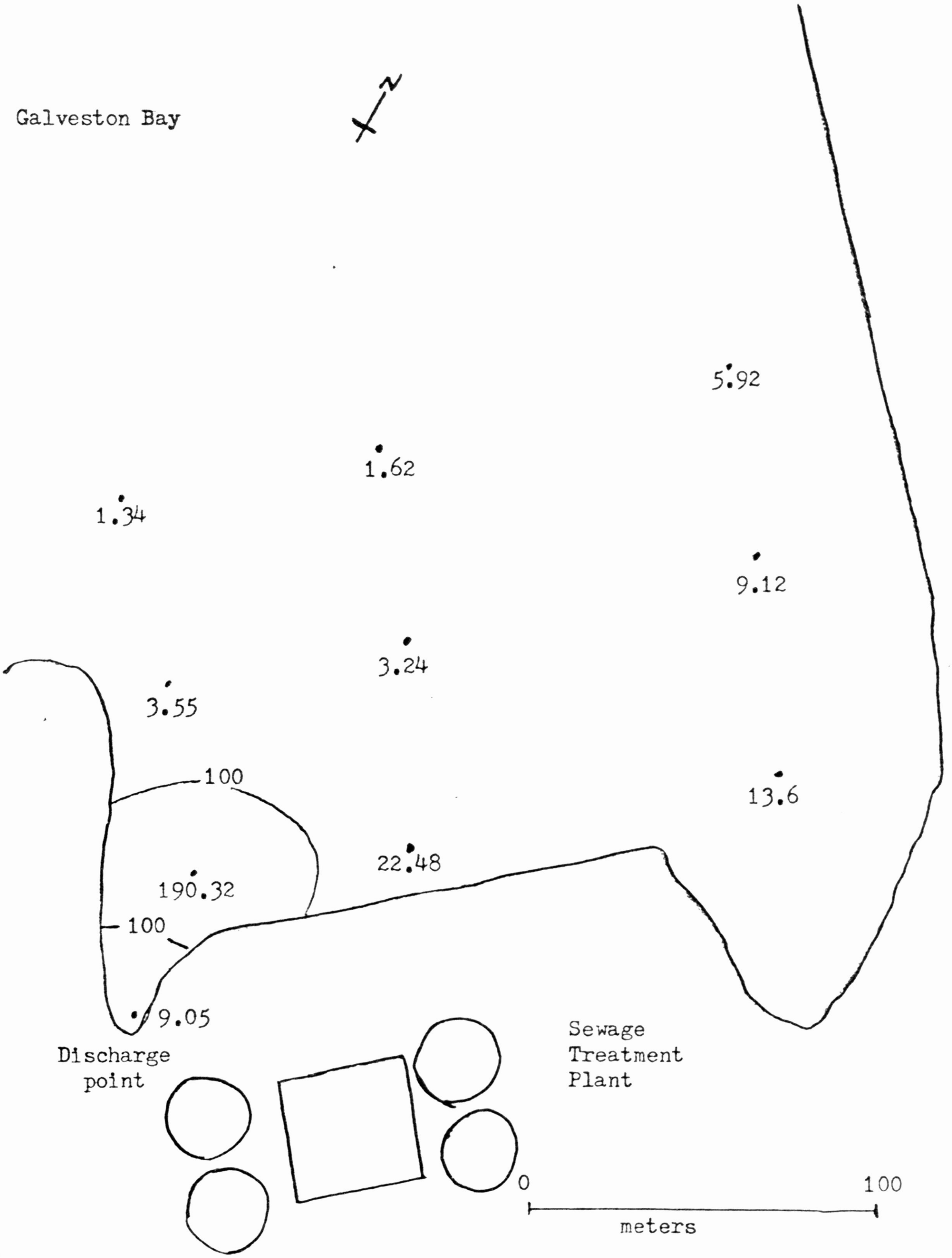

Figure 10. Isopleths of copper concentrations (ppm) in the sediments, 2200 hr, 3 November 1978.

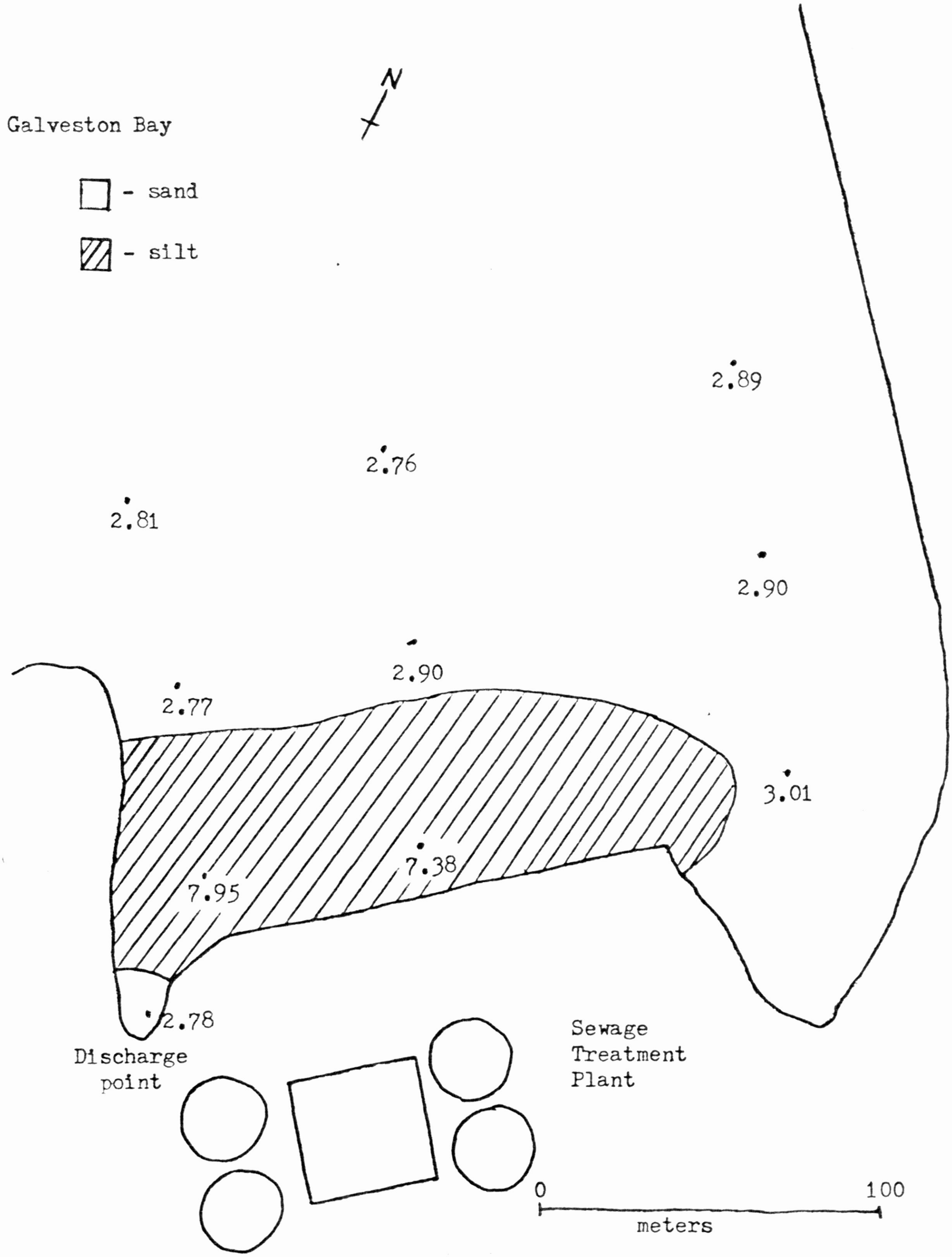

Figure 11. Mean Ø size of the sediments, 1400 hr, 16 September 1978.

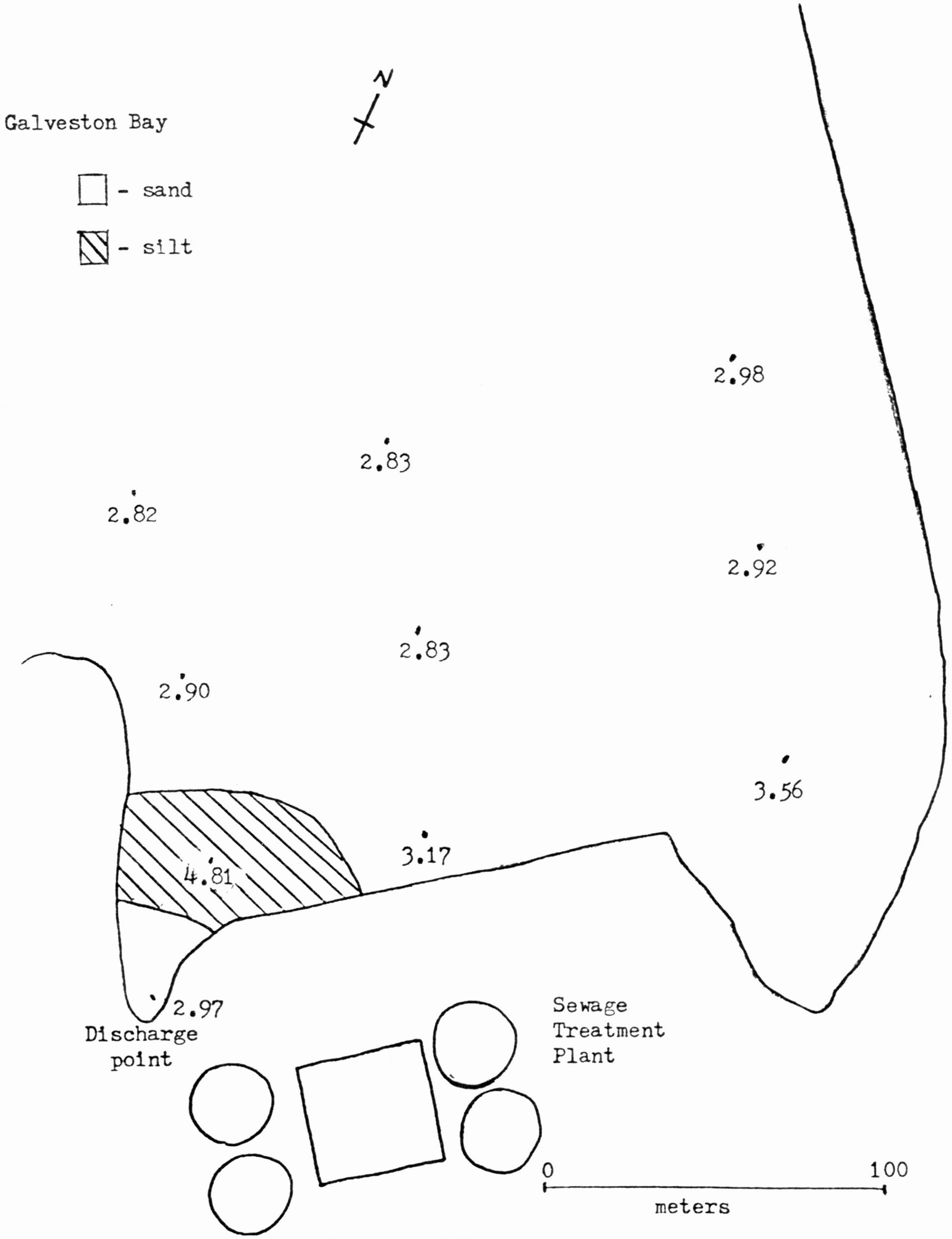

Figure 12. Mean Ø size of the sediments, 1800 hr, 3 November 1978.

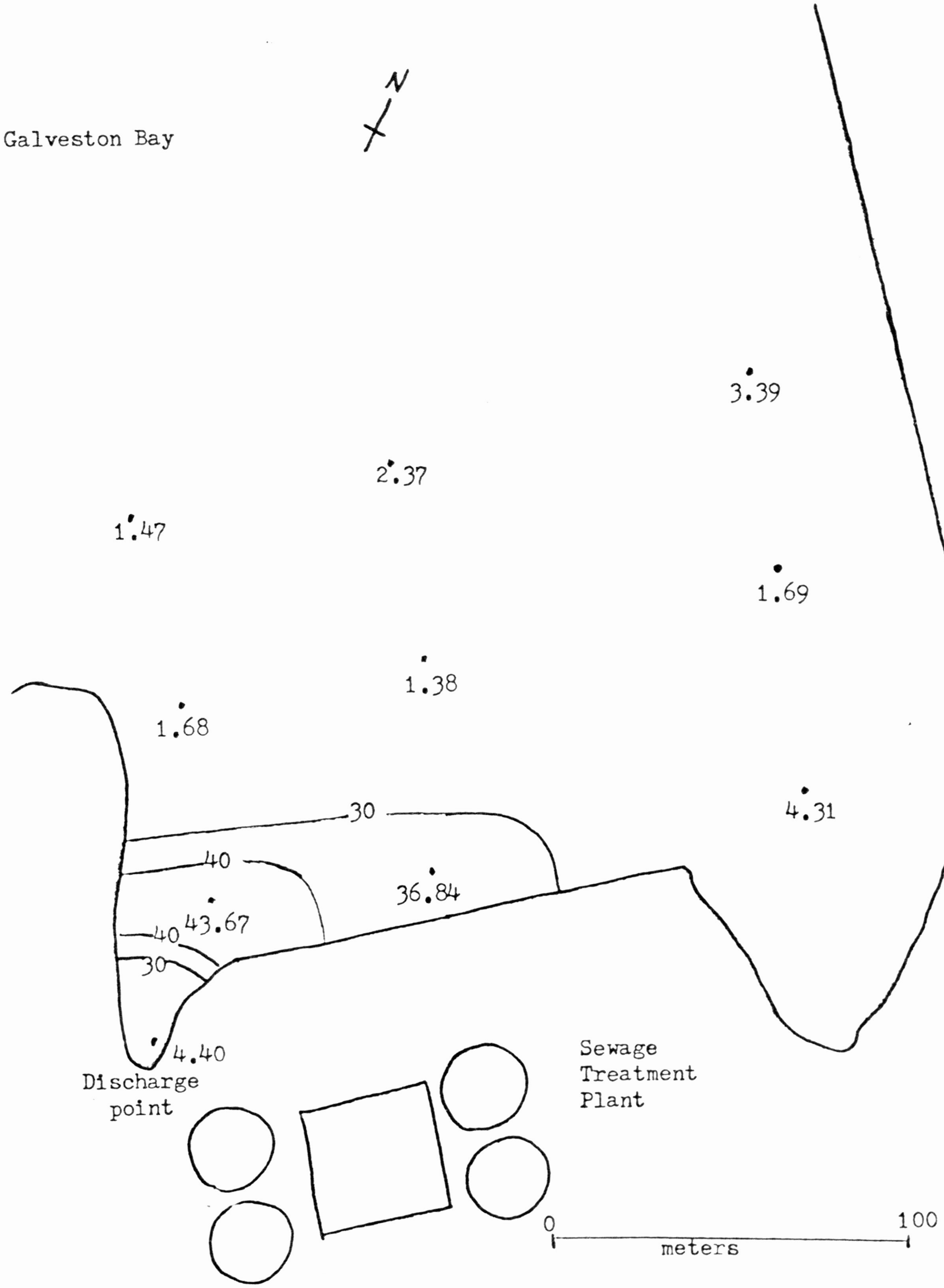

Figure 13. Percentage(%) organic content isopleths of the sediments, 1400 hr, 16 September, 1978.

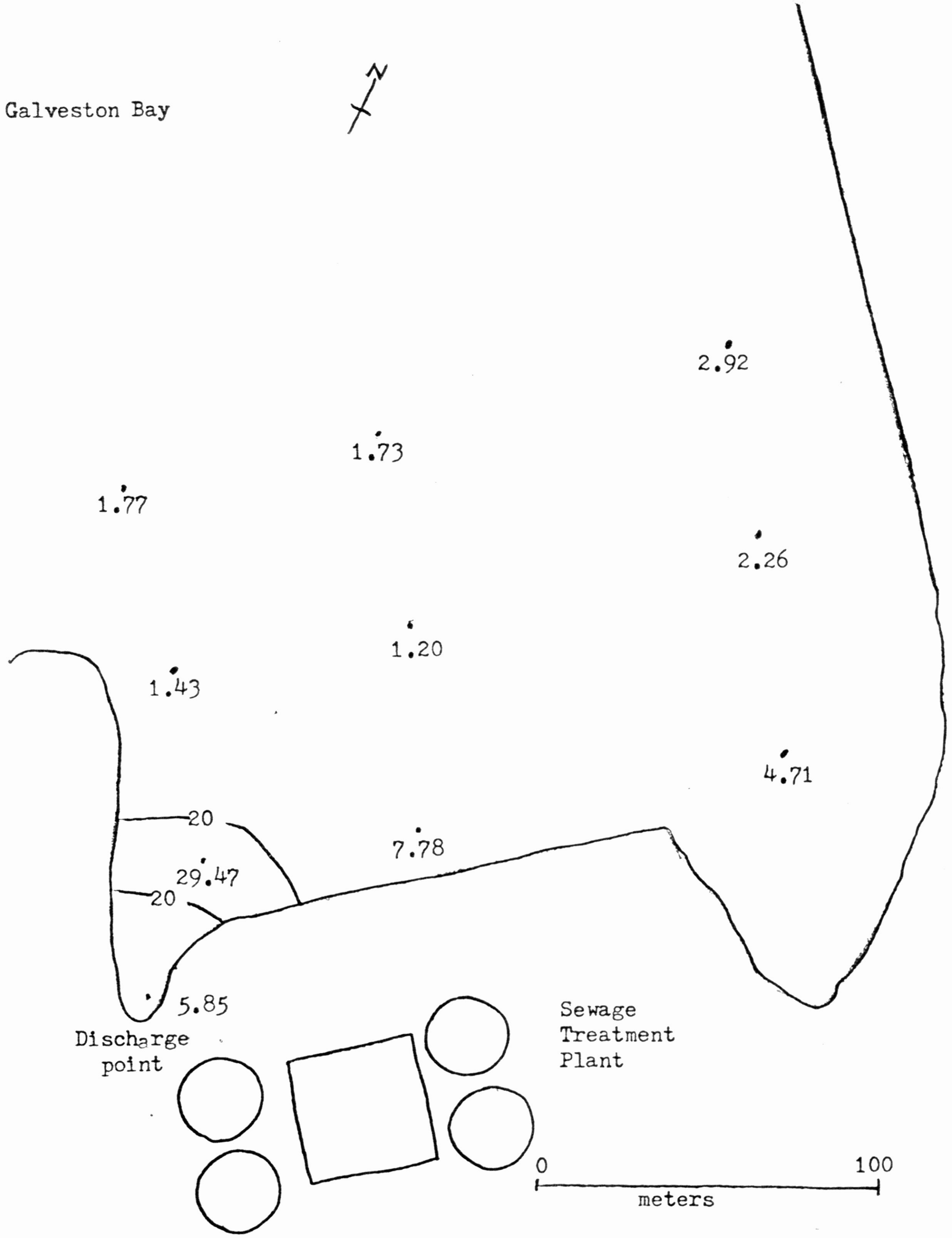

Figure 14. Percentage(%) organic content isopleths of the sediments, 1800 hr, 3 November 1978.

nificantly lower concentrations (e.g. for copper, 14.96 ppm compared to 210.16 ppm). For the isopleth maps, examples were taken from periods where the numbers did not vary greatly as in September. The two samples at both stations were averaged together when used to show isopleth lines.

Linear regression analysis was performed to relate metal ion concentration (ppm) in the sediments to mean grain size and percentage organic content. For example, metal ion concentration (ppm) vs. mean ϕ size was plotted for each metal from the 1400 hr sampling period in September (Figs. 15-18). A correlation of 0.99 for copper and nickel and a correlation of 0.98 for lead and zinc was observed. A similar correlation between concentration and percentage organic content for the same time period was observed (Figs. 19-22). In both cases, zinc concentrations were taken as ppm X 1/10 to simplify plotting. No correlation was found at stations 1 and 10 between metal concentration and mean ϕ size through the time periods. However a good correlation (0.90) between metal concentration and total organic content was found at the two stations across the time periods for all four metals in September. Good correlation (0.92-0.97) for November samples at 1800 hrs was found between metal concentration, mean ϕ size and total organic content. Also, metal concentrations at stations 1 and 10 did not correlate with mean ϕ size but did correlate with total organic content in November.

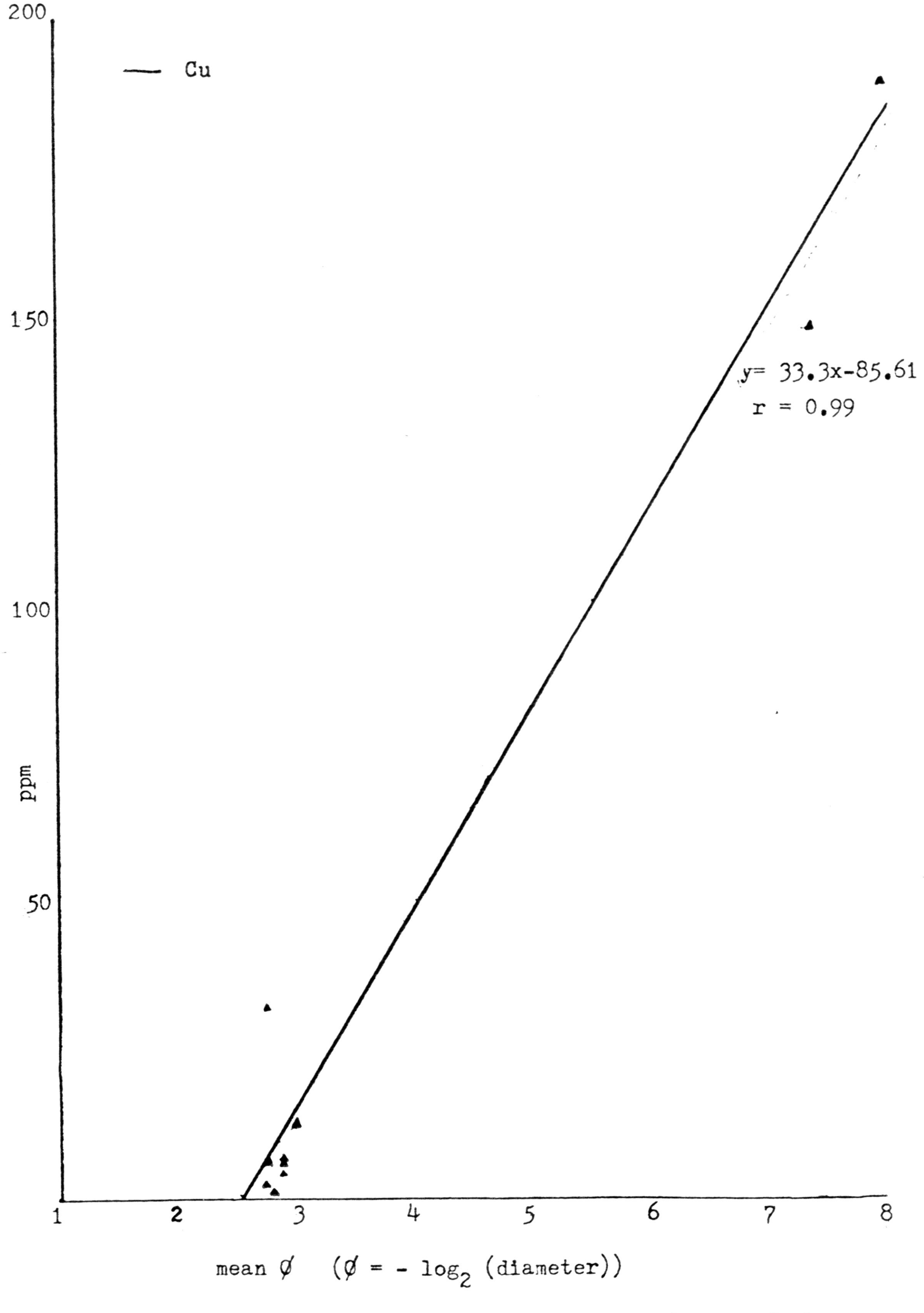

Figure 15. Regression analysis of copper vs. mean Ø size of the sediments, 1400 hr, September 1978.

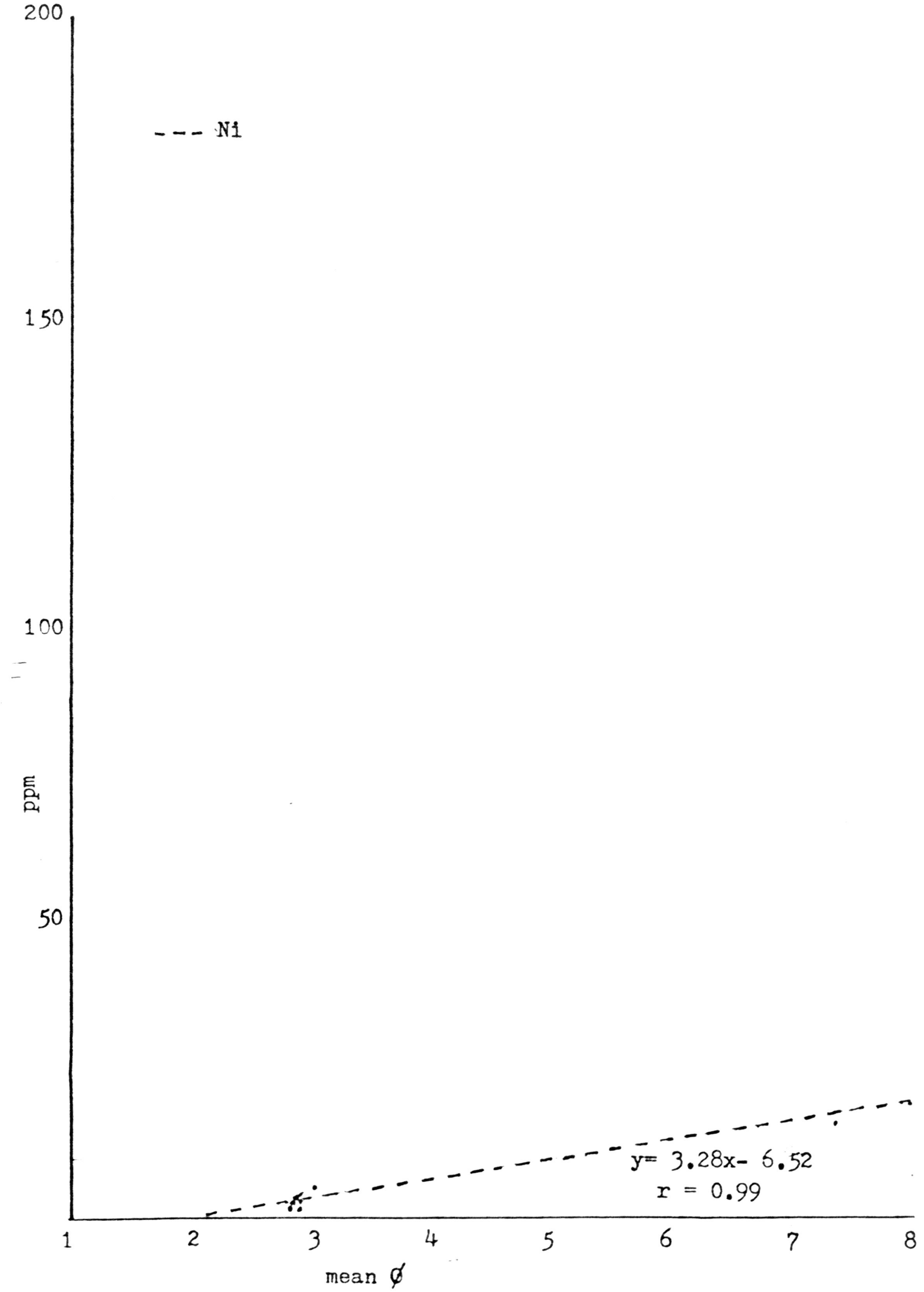

Figure 16. Regression analysis of nickel vs. mean Ø size in the sediments, 1400 hr, 16 September 1978.

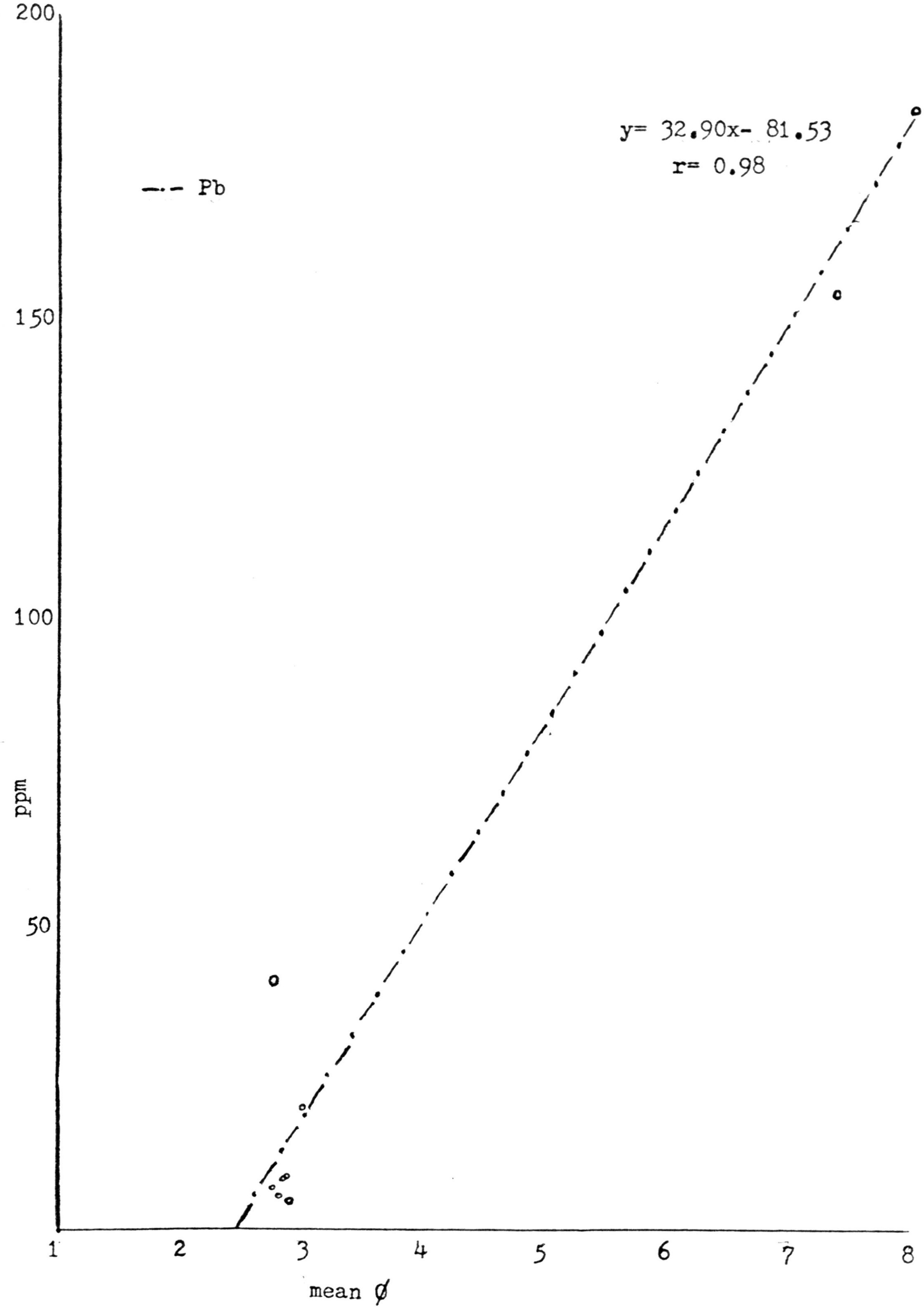

Figure 17. Regression analysis of lead vs. mean Ø size in the sediments, 1400 hr, 16 September 1978.

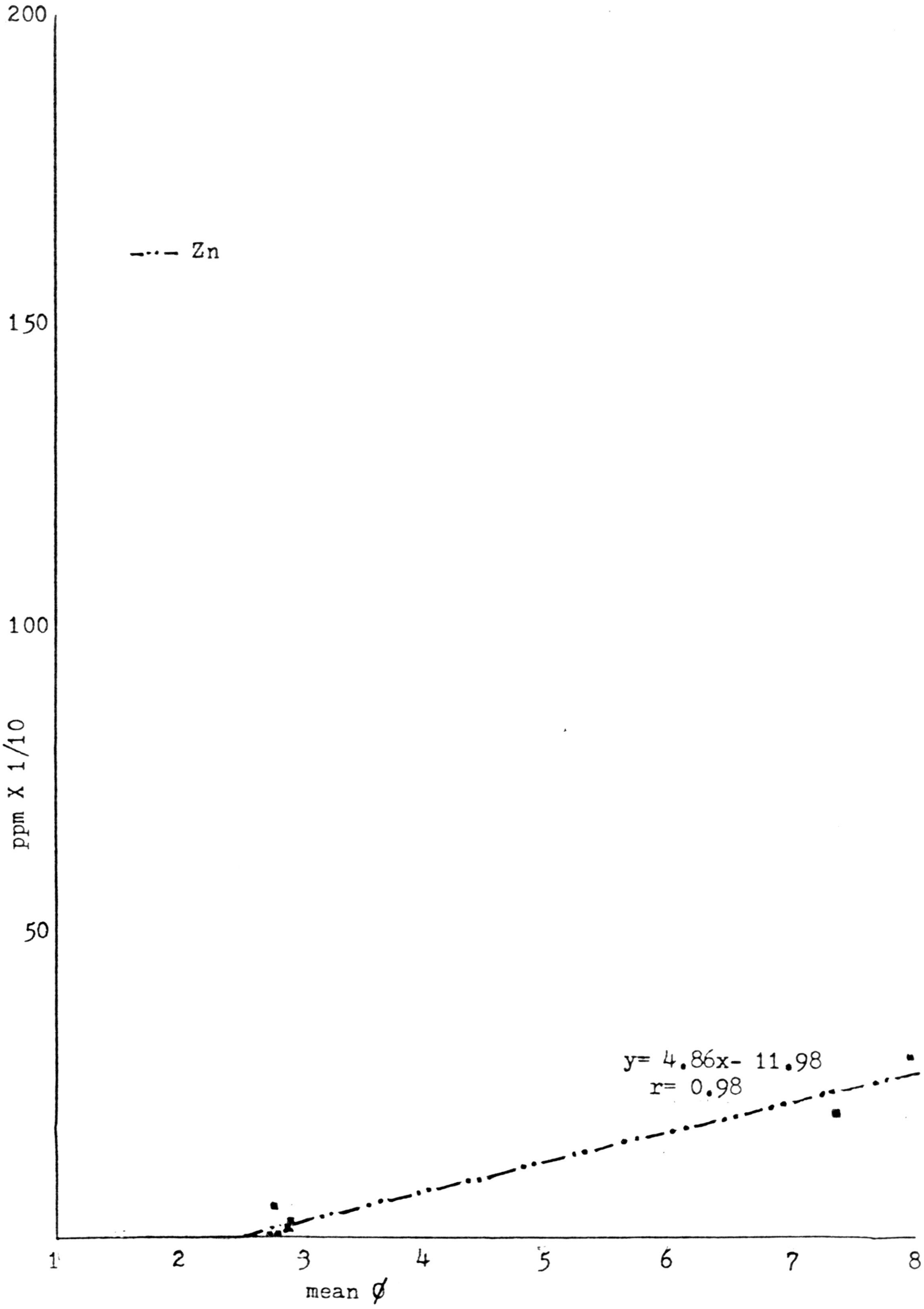

Figure 18. Regression analysis of zinc vs. mean ∅ size in the sediments, 1400 hr, 16 September 1978.

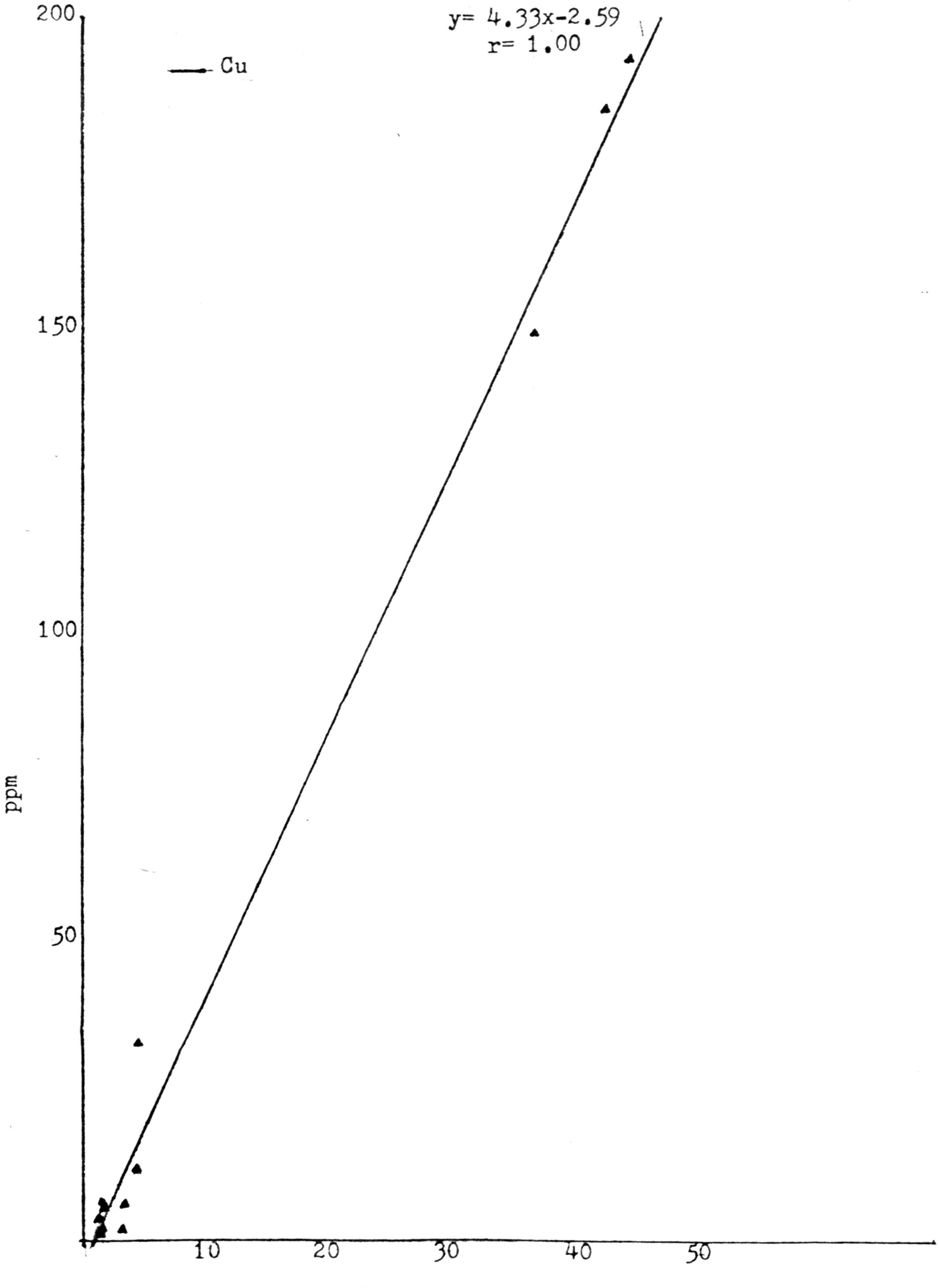

Figure 19. Regression analysis of copper vs. percentage organic content in the sediments, 1800 hr, 3 November 1978.

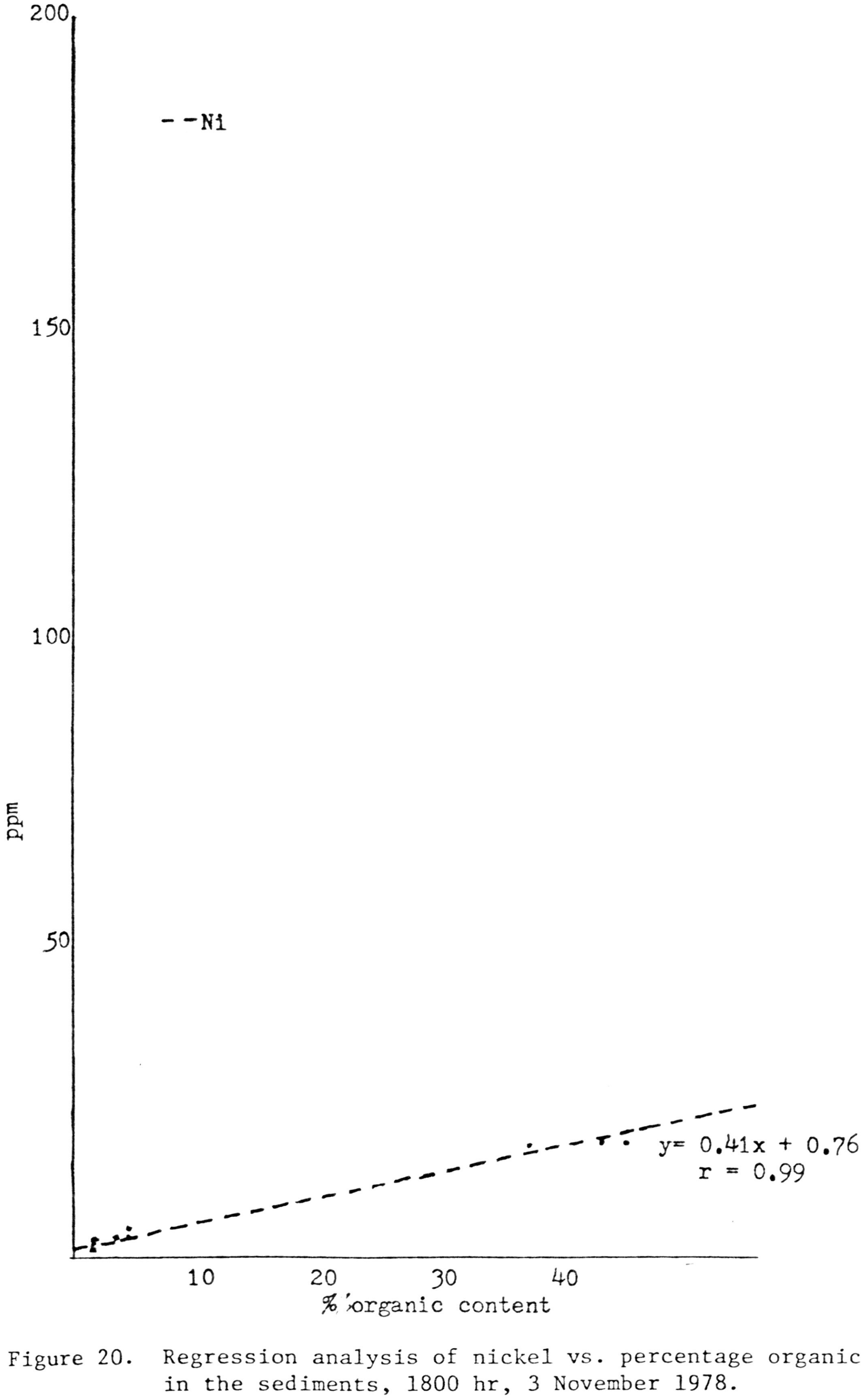

Figure 20. Regression analysis of nickel vs. percentage organic content in the sediments, 1800 hr, 3 November 1978.

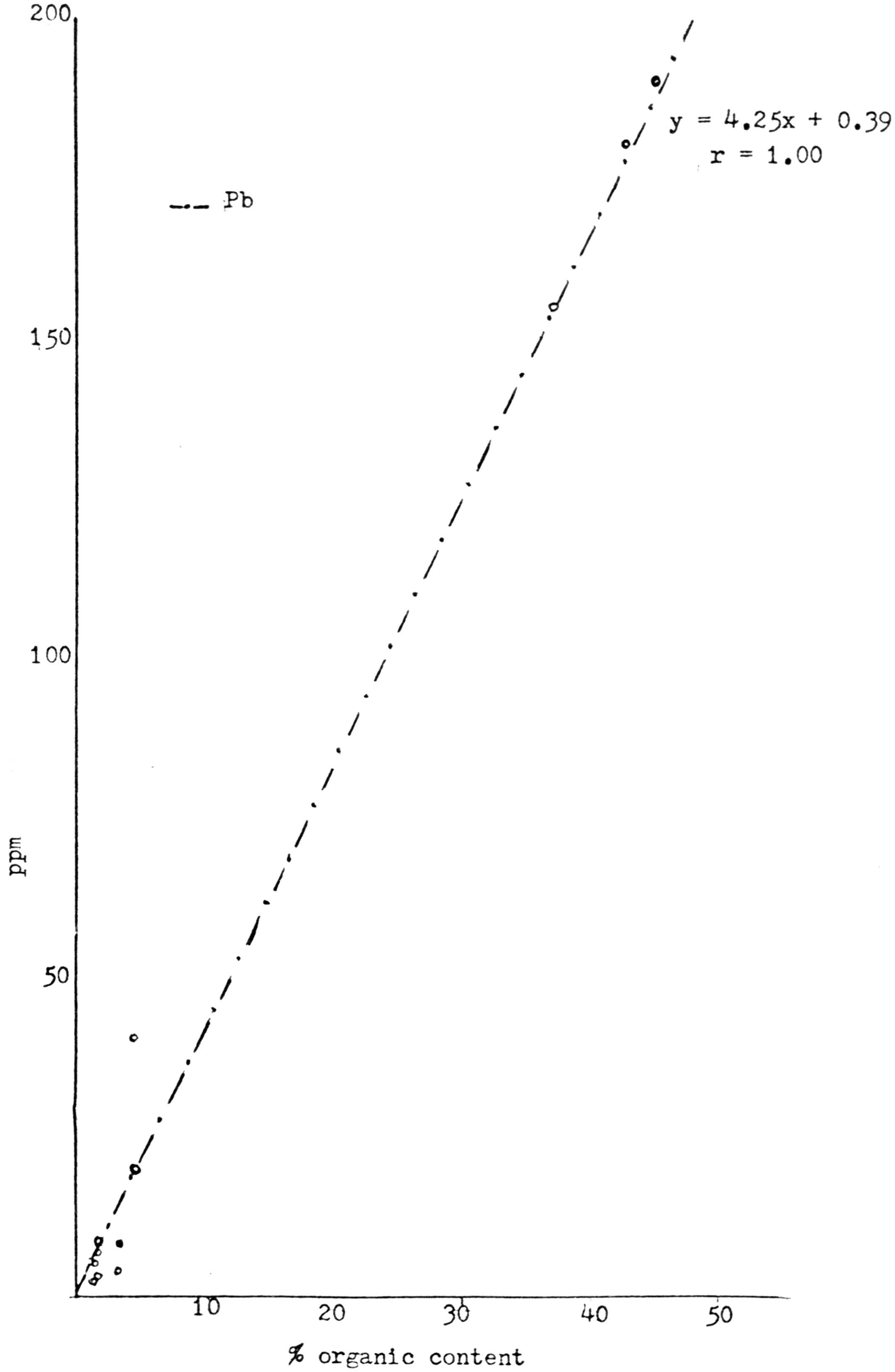

Figure 21. Regression analysis of lead vs. percentage organic content in the sediments, 1800 hr, 3 November 1978.

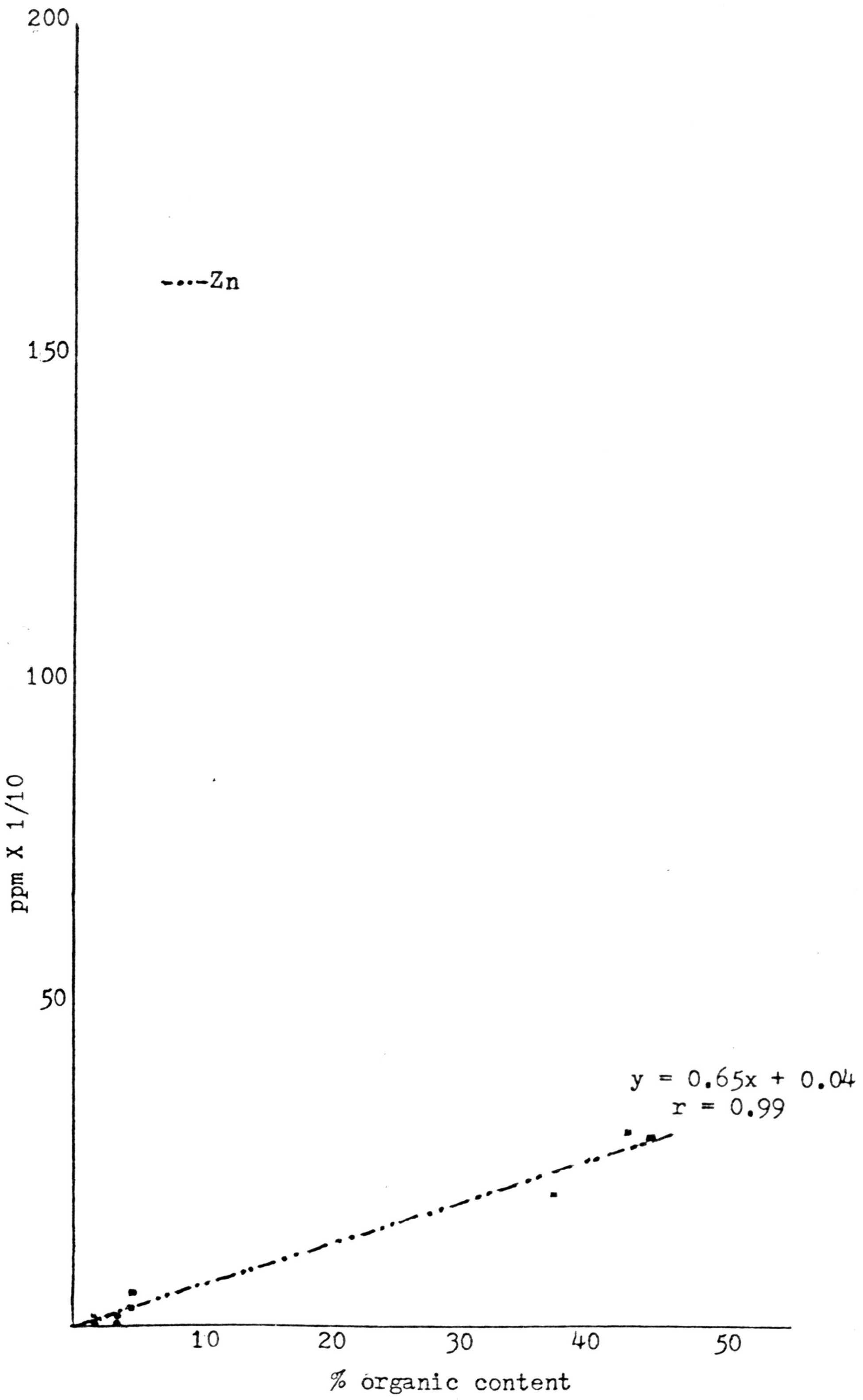

Figure 22. Regression analysis of zinc vs. percentage organic content in the sediments, 1800 hr, 3 November 1978.

DISCUSSION

For adsorption and concentration of heavy metals in the sediments to occur, certain chemical and physical criteria must be met. Most importantly, a site for the metal ion to attach must be provided. Clay and organic particles have been shown to make good sites (Leland and others 1973, O'Connor and Kester 1975, and Scrudato and Estes 1975). Once a site is provided, the ionic potential of the water containing the metal ion becomes important. Two factors affecting the ionic potential are salinity and pH. An increase in salinity inhibits adsorption slightly because of the increase in ions with which the metal can associate. However, the difference in the amount of metal ion adsorbed is only a small percentage (O'Connor and Kester 1975).

A pH of 6-12 is required for a significant percentage of metal ion to be adsorbed. At 7-7.5, the greatest percentage (approximately 95%) of copper (O'Connor and Kester 1975) and lead (Scrudato and Estes 1975) are adsorbed. Different clays display different adsorptive properties at different pH levels but pH 6 and 12 are the limits in most cases (Scrudato and Estes 1975). After adsorption, a low energy or depositional environment is necessary for the metal ion rich particles to settle and be incorporated into sediments.

The water temperature and salinity in the sewage treatment plant effluent were different than the surrounding waters. The effluent mixed with bay water in the vicinity of station 2 changing the temperature and salinity. The mixing area fluctuated with the tide. At low tide (Fig. 4), the salinity gradient extends beyond station 2 whereas during a high tide (Fig. 5) the mixing area is inshore of station 2.

Sewage treatment plants are required by EPA regulations to remove all particulates from the effluent before discharge (Water Pollution Control Federation 1976). It appears, however, that some particulates, both organic and inorganic, are discharged and accumulate near stations 2 and 7.

The four heavy metals analyzed in this study are also discharged from the plant (Appendix II). The metals accumulate in the same region as the sediment and organic particles. The high correlation of heavy metal concentrations with sediment size and organic content indicate that these are probably associated with each other. If adsorption were not occurring, the metal ions would be expected to remain with the water and be carried away with the tides. The zinc ion concentration (Figs. 7a-e) decreased in the area around stations 2, 3 and 6. Either dilution or adsorption is reducing the concentration, or a possible combination of both. Lead and nickel, which are carried in with the tides (Figs. 8a-e) also collect in an area near station 2.

In comparing concentrations of the four metal ions in water to that in the sediments around station 2, there is at least one order of magnitude increase in concentration in the sediments. Zinc appears to be readily incorporated, while nickel is not removed from the water to the same extent. Factors affecting the specific removal of the metal ions probably determine which will be concentrated in the sediments to the greatest extent.

The pH should have been taken with each water sample, however this was not done. It is possible to estimate the pH of the effluent as being between 6-9 (EPA required) and the bay waters as 8-8.3 (Shaw, personal communication). Therefore, assuming these limits, conditions in the water were correct for near maximum adsorption.

Fluctuations in metal concentration through the time periods appears to be a result of a patchy sediment distribution, particularly with regard to organic particles. The big difference noted at station 7 and the fluctuations at station 2 in November may also be a result of patchy sediment distribution. It is also possible that storm activity between the two sampling months removed the sediments from the area. In Corpus Christi Bay, which is similar in depth to Galveston Bay (Diener 1975), seasonal fluctuations in metal concentration and sediments were observed as a result of circulation changes caused by weather (Holmes and others 1974).

The fall-off of metal concentration in the water and corresponding increase in the sediments was not observed in this area. If the fall-off occurs, it appears to happen between stations 1 and 2. However, adsorption and concentration in the sediments does seem to occur around station 2.

Although the metal ions are more hazardous to marine organisms in the water mass (directly available) than when they are in the sediments, a change in pH or an increase in salinity (approaching 35 ppt) could cause desorption of some of the metal to the water. Thus the sediments may be only a temporary sink for the metal ions. The sewage treatment plant is not only a source of the metal ions but supplies particulates that appear to act as scavengers for metal ions in the area. This permits the accumulation of metal ions from many sources into hazardous concentrations in the sediments. If one rated San Antonio Bay sediment samples as relatively unpolluted with heavy metals and Galveston Bay and Houston Ship Channel sediments as polluted (Table 1). the samples from this study (Table 2) appear to be as polluted as Galveston Bay.

Methods to prepare the samples for analysis were different for the two areas, but the differences between San Antonio Bay and the study area is too large to be attributed to methodology alone. Water sample trace ion data from this study were not strictly comparable with data from other areas because methods of collection and analysis were very different. The fact that the data determined from this study indicates a much higher degree of metal concentration in this area does indicate a definite cause for concern.

The removal of the silt-sized sediments between September and November is a specific cause for concern. Along with the sediments, metal ions are being carried to other parts of the bay. This could result in an abnormal accumulation of heavy metal ions in an area that was previously relatively uncontaminated. Galveston Bay is a source of commercial shrimp, crabs and oysters which dwell on the bottom sediments (Diener 1975). These organisms have been known to concentrate heavy metal ions in their tissues (Bryan 1971) and therefore the accumulated and concentrated metals could eventually find their way into the seafood market. In the future, sewage treatment plants should be more closely monitored because of the many obvious and not so obvious sources of pollution. It appears from this study that tertiary sewage treatment is essential for waters being discharged into the estuarine environment.

Table 1. Leachable heavy metal concentrations for sediments from San Antonio Bay, Galveston Bay, and the Houston Ship Channel. (From Trefry and Presley 1976)

	Pb (ppm)	Zn (ppm)	Cu (ppm)	Ni (ppm)
San Antonio Bay				
Mean (N=51)	9.5	32.7	4.0	9.9
Range	14.4	51.7	8.3	10.3
	to	to	to	to
	3.3	5.6	1.6	2.6
Galveston Bay				
Mean (N=44)	24	51	19	22.1
Range	50	141	96	58
	to	to	to	to
	5	9.8	4	0.6
Houston Ship Channel	113	240	46	34
Mean (N=24)	268	622	157	63
Range	to	to	to	to
	30	74	17	15

Table 2. Leachable heavy metal concentrations for sediments from an area near the discharge of the Galveston main sewage treatment plant from two months.

	Pb (ppm)	Zn (ppm)	Cu (ppm)	Ni (ppm)
September				
Mean (N=72)	46.5	67.6	43.7	6.8
Range	190.7	304.5	194	20.8
	to	to	to	to
	2.1	3.3	1.6	1.5
November				
Mean (N=72)	31.7	67.3	28.0	6.3
Range	211.0	463.4	225.4	30.8
	to	to	to	to
	3.0	5.7	1.2	1.4

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Appendix I

TABLE I - A. Water temperature (^{o}C) near the discharge of Galveston Sewage Treatment Plant, 16-17 September, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	30.5	31.0	31.5	30.5	30.5	30.5
2	28.0	30.5	30.5	29.0	29.0	29.0
3	28.0	28.5	30.5	29.0	28.0	28.0
4	27.5	29.0	30.5	29.0	28.0	27.5
5	27.5	28.5	30.0	29.0	28.0	28.0
6	27.5	28.5	29.5	29.0	28.0	27.5
7	28.0	28.5	30.0	29.0	28.0	28.5
8	27.0	28.0	31.0	29.0	29.0	27.5
9	27.5	28.0	31.5	30.0	29.0	27.0
10	27.5	28.5	31.0	29.5	28.0	27.5

TABLE I - B. Water temperature (^oC) near the discharge of Galveston Sewage Treatment Plant, 3-4 November, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	26.0	DM*	28.0	26.0	24.0	27.0
2	21.0	29.0	27.0	25.0	22.0	22.0
3	22.0	28.0	24.0	22.5	22.0	22.0
4	22.0	24.5	24.0	22.0	22.0	22.0
5	22.0	26.0	23.0	22.5	22.0	22.0
6	22.0	24.5	24.0	23.0	22.0	22.0
7	22.0	DM	25.0	23.0	22.0	22.0
8	22.0	26.5	25.0	23.0	22.0	22.0
9	22.0	26.0	24.0	23.5	22.0	22.0
10	22.0	22.0	23.0	23.0	23.0	22.0

* DM - data missing

TABLE I - C. Salinity (‰) near the discharge of Galveston Sewage Treatment Plant, 16-17 September, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	0	0	2	1	3	2
2	10	8	22	14	6	24
3	24	23	20	16	25	22
4	24	24	24	21	25	23
5	24	24	23	22	23	24
6	22	22	20	22	23	21
7	24	22	24	24	23	26
8	24	25	24	23	23	25
9	25	25	24	24	25	26
10	18	24	23	23	25	24

TABLE I - D. Salinity (‰) near the discharge of Galveston Sewage Treatment Plant, 3-4 November, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	4	DM*	0.5	1	1	3
2	19	DM	14.5	19	23	21.5
3	21	DM	21	22.5	22	21.5
4	21.5	DM	21	23	22	22
5	22	DM	23	22.5	22	21.5
6	20	DM	22	22	22	22
7	21	DM	21	22.5	23	21.5
8	22	DM	21.5	23	23	22
9	22	DM	21.5	23.5	23	21.5
10	22	DM	22	23	22	21.5

* DM - data missing

Appendix II

TABLE II - A. Concentration (ppm) of Copper in the water near the discharge of Galveston Sewage Treatment Plant, 16-17 September, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	0.088	0.012	DM*	0.017	0.018	0.024
2	0.018	0.021	0.021	0.011	DM	0.014
2X	DM	0.012	DM	0.025	DM	0.025
3	0.016	0.024	0.033	DM	0.023	DM
4	DM	0.016	0.021	0.062	0.040	DM
5	DM	0.032	DM	DM	0.024	0.018
5X	DM	0.018	0.026	DM	0.017	DM
6	DM	DM	0.065	0.044	DM	0.029
7	0.022	0.033	0.024	0.023	0.025	DM
8	0.018	0.089	0.018	0.035	0.034	0.015
9	0.027	0.023	0.023	0.025	DM	DM
10	0.024	0.128	DM	0.029	0.022	DM

* DM - data missing

TABLE II - B. Concentration (ppm) of Nickel in the water near the discharge of Galveston Sewage Treatment Plant, 16-17 September, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	0.011	0.026	DM*	BD**	0.012	0.058
2	0.127	DM	0.261	0.223	DM	0.143
2X	0.295	0.130	DM	0.186	DM	0.151
3	0.214	0.247	0.205	0.227	0.139	DM
4	DM	0.208	DM	0.349	0.245	DM
5	DM	0.229	DM	DM	0.249	0.129
5X	DM	0.195	0.224	DM	0.199	DM
6	DM	0.204	DM	0.227	DM	0.222
7	0.207	0.204	0.260	0.306	0.144	DM
8	0.193	0.454	0.227	0.183	0.261	0.269
9	0.264	0.276	0.221	0.283	DM	DM
10	0.285	0.571	DM	0.245	0.237	DM

* DM - data missing

** BD - below detection

TABLE II - C. Concentration (ppm) of Lead in the water near the discharge of Galveston Sewage Treatment Plant, 16-17 September, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	0.44	0.53	DM*	0.35	0.53	0.23
2	1.98	2.39	2.17	2.43	DM	2.16
2X	2.68	1.60	DM	2.08	DM	2.01
3	2.48	2.72	2.26	DM	1.97	2.18
4	DM	2.40	2.30	1.88	2.76	DM
5	DM	2.26	DM	DM	2.58	2.11
5X	DM	DM	2.06	DM	2.29	DM
6	DM	2.33	2.22	2.68	DM	2.21
7	2.59	2.08	2.34	3.28	2.19	DM
8	2.39	2.42	2.53	2.42	2.48	2.70
9	3.06	2.76	2.59	2.85	DM	DM
10	2.72	2.59	DM	2.58	2.90	DM

* DM - data missing

TABLE II - D. Concentration (ppm) of Zinc in the water near the discharge of Galveston Sewage Treatment Plant, 16-17 September, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	0.035	0.098	DM*	0.032	0.141	0.048
2	0.073	0.107	0.030	0.050	DM	BD**
2X	0.079	0.051	DM	0.029	DM	BD
3	0.090	0.037	0.075	DM	DM	0.062
4	DM	0.041	0.062	BD	0.154	DM
5	DM	0.069	DM	DM	0.077	0.019
5X	DM	0.040	0.007	DM	0.014	DM
6	DM	0.002	0.026	0.086	DM	0.040
7	0.006	0.022	0.043	0.034	0.163	DM
8	0.103	0.066	0.034	0.085	0.076	0.039
9	0.009	0.012	0.032	0.028	DM	DM
10	0.070	0.022	DM	0.004	0.019	DM

* DM - data missing

** BD - below detection

TABLE II - E. Concentration (ppm) of Copper in the water near the discharge of Galveston Sewage Treatment Plant, 3-4 November, 1978.

STATION	TIME 0600	1000	1400	1800	2200	0200
1	DM*	DM	DM	0.017	0.008	DM
2	0.006	DM	0.129	0.018	0.014	0.029
2X	0.011	DM	0.012	DM	0.013	DM
3	0.013	0.011	0.025	0.019	DM	DM
4	0.017	0.021	0.027	0.019	0.022	0.017
5	0.015	DM	0.020	0.023	0.022	0.023
5X	0.022	0.014	0.019	0.020	0.027	0.025
6	0.013	0.019	0.025	0.021	0.019	DM
7	0.010	DM	0.027	0.017	0.014	0.022
8	0.012	0.006	DM	0.025	0.021	0.031
9	0.020	0.020	0.023	0.024	0.025	0.033
10	0.018	0.022	0.023	DM	0.016	0.021

* DM - data missing

TABLE II - F. Concentration (ppm) of Nickel in the water near the discharge of Galveston Sewage Treatment Plant, 3-4 November, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	DM*	DM	DM	0.078	0.156	DM
2	0.080	0.017	DM	DM	0.139	0.228
2X	0.157	DM	0.022	0.158	0.122	0.262
3	DM	0.177	0.181	0.175	DM	0.227
4	0.212	0.236	0.257	0.253	0.180	0.243
5	0.202	0.165	0.194	DM	0.241	0.201
5X	DM	DM	0.208	0.189	DM	0.269
6	0.145	0.224	0.189	0.203	0.184	DM
7	0.163	DM	0.154	0.182	0.273	0.233
8	0.160	0.119	DM	0.251	0.210	0.243
9	0.144	0.157	0.200	0.203	0.186	0.233
10	0.184	0.186	0.263	DM	0.121	0.268

* DM - data missing

TABLE II - G. Concentration (ppm) of Lead in the water near the discharge of Galveston Sewage Treatment Plant, 3-4 November, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	DM*	DM	DM	0.35	0.35	DM
2	1.59	DM	0.30	DM	1.61	2.08
2X	1.22	0.26	0.33	1.64	1.45	2.08
3	1.82	1.95	1.74	1.70	1.95	2.10
4	2.02	1.92	2.31	2.53	1.79	2.10
5	DM	1.70	1.76	2.46	2.21	2.20
5X	1.89	DM	2.16	2.09	2.08	1.94
6	1.52	2.01	1.85	1.91	1.67	DM
7	1.73	DM	1.15	1.97	2.20	2.20
8	1.77	1.31	DM	2.43	2.01	2.38
9	1.38	1.80	2.19	2.02	1.79	2.17
10	1.79	1.98	2.38	DM	1.42	2.74

* DM - data missing

TABLE II - H. Concentration (ppm) of Zinc in the water near the discharge of Galveston Sewage Treatment Plant, 3-4 November, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	DM*	DM	DM	0.297	0.050	DM
2	BD**	DM	0.006	BD	BD	BD
2X	BD	BD	0.001	0.007	0.032	0.012
3	BD	BD	BD	0.163	0.061	BD
4	BD	BD	0.009	BD	BD	BD
5	BD	BD	BD	BD	0.003	BD
5X	BD	DM	DM	BD	0.014	BD
6	BD	BD	BD	0.015	0.093	BD
7	BD	DM	BD	BD	BD	BD
8	0.007	0.009	DM	BD	BD	BD
9	BD	0.004	BD	BD	BD	0.034
10	0.023	0.076	BD	BD	BD	BD

* DM - data missing

** BD - below detection

APPENDIX III

TABLE III-A. Concentration (ppm) of Copper in the sediments near the discharge of Galveston Sewage Treatment Plant, 16-17 September, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	24.85	12.58	33.03	10.06	9.76	5.96
2	151.42	151.10	185.39	148.94	183.43	136.77
2X	133.14	152.88	193.68	150.48	188.95	132.40
3	8.15	5.16	6.42	5.08	6.91	7.82
4	2.59	1.65	1.65	11.99	1.44	2.49
5	2.71	2.05	2.21	1.66	4.00	2.16
5X	2.89	2.61	2.39	1.62	5.67	2.62
6	4.64	6.08	4.61	5.68	3.69	3.91
7	129.89	126.28	148.94	161.21	145.71	132.56
8	15.17	13.60	13.75	1.41	33.90	12.11
9	6.67	12.25	7.32	9.32	7.17	8.97
10	4.68	4.03	6.88	11.91	3.36	7.23

TABLE III - B. Concentration (ppm) of Nickel in the sediments near the discharge of Galveston Sewage Treatment Plant, 16-17 September, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	3.19	2.22	3.68	1.52	1.69	1.50
2	19.66	19.98	19.66	17.64	19.55	20.02
2X	20.11	18.75	18.67	17.11	20.77	15.77
3	1.80	1.57	2.24	1.95	1.86	2.34
4	2.09	1.74	1.36	3.96	1.92	1.44
5	2.18	1.99	2.52	1.95	3.38	1.88
5X	2.91	2.61	2.55	1.99	3.38	1.85
6	1.73	1.65	1.64	1.88	1.75	1.59
7	17.29	19.87	18.08	25.00	21.05	21.08
8	4.64	3.82	4.86	1.86	6.92	3.79
9	2.50	2.96	2.67	3.23	2.44	3.24
10	2.95	2.58	3.69	2.94	2.64	3.91

TABLE III - C. Concentration (ppm) of Lead in the sediments near the discharge of Galveston Sewage Treatment Plant, 16-17 September, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	34.67	18.67	40.97	16.72	20.22	11.25
2	156.68	152.80	180.71	146.28	188.08	135.87
2X	140.80	155.77	190.71	152.86	186.74	129.79
3	9.52	5.19	7.18	5.34	7.02	8.27
4	3.22	2.61	2.60	16.87	2.14	2.64
5	3.35	3.38	3.78	3.09	5.46	2.75
5X	4.56	4.12	4.02	3.02	5.33	3.03
6	4.34	5.06	5.42	5.02	4.57	4.26
7	135.63	135.56	155.71	162.38	152.38	134.34
8	19.66	18.08	20.46	2.85	54.59	17.49
9	9.08	11.35	9.31	11.75	8.72	11.48
10	6.06	6.55	8.91	6.46	5.76	10.40

TABLE III - D. Concentration (ppm) of Zinc in the sediments near the discharge of Galveston Sewage Treatment Plant, 16-17 September, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	36.23	18.90	53.94	16.49	16.06	10.13
2	197.79	261.29	304.49	235.64	292.55	186.59
2X	184.67	194.61	296.05	228.66	281.99	174.74
3	14.42	15.96	12.62	11.04	11.63	15.59
4	6.18	4.05	3.83	23.88	4.70	3.28
5	5.89	5.13	5.56	4.48	9.70	4.39
5X	5.22	8.17	5.69	4.75	10.77	4.80
6	10.34	11.77	16.29	11.58	9.72	8.84
7	175.64	185.23	201.26	221.26	252.19	181.85
8	29.41	26.47	29.54	4.50	82.43	25.89
9	17.34	20.14	17.14	20.50	16.35	22.06
10	13.88	11.90	15.66	11.98	13.77	17.03

TABLE III - E. Concentration (ppm) of Copper in the sediments near the discharge of Galveston Sewage Treatment Plant, 3-4 November, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	9.22	DM*	6.19	42.31	9.05	44.80
2	14.96	23.94	175.70	14.30	195.98	103.99
2X	210.16	225.43	36.08	126.28	184.66	159.73
3	4.16	5.48	3.39	4.41	3.55	6.38
4	1.28	1.36	1.24	1.30	1.34	1.18
5	3.38	1.53	1.56	1.36	1.47	1.74
5X	5.88	DM	1.58	1.47	1.76	1.58
6	3.91	4.17	3.38	3.33	3.24	3.00
7	17.10	DM	7.55	13.15	22.48	15.36
8	26.02	15.68	16.43	18.46	13.60	14.65
9	9.43	8.78	8.36	7.97	9.12	7.10
10	5.58	4.00	4.28	7.28	5.92	4.74

* DM - data missing

TABLE III - F. Concentration (ppm) of Nickel in the sediments near the discharge of Galveston Sewage Treatment Plant, 3-4 November, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	1.79	DM*	2.91	5.79	2.08	5.68
2	4.68	5.84	24.00	2.12	29.65	20.45
2X	26.20	30.81	8.07	22.75	30.32	21.63
3	4.57	2.46	1.44	1.85	1.67	2.80
4	2.04	2.25	2.35	1.43	2.27	2.39
5	4.02	2.38	2.14	2.20	2.25	2.73
5X	6.12	DM	2.39	2.47	2.75	2.39
6	1.84	3.62	2.02	3.14	1.90	1.72
7	4.01	DM	1.66	10.47	3.61	6.40
8	8.22	5.33	4.93	6.27	6.05	6.36
9	4.09	3.10	3.64	3.68	3.11	3.49
10	4.18	3.58	5.02	5.26	4.86	4.78

* DM - data missing

TABLE III - G. Concentration (ppm) of Lead in the sediments near the discharge of Galveston Sewage Treatment Plant, 3-4 November, 1978.

STATION	TIME 0600	1000	1400	1800	2200	0200
1	15.01	DM*	22.99	57.93	15.40	62.13
2	19.15	30.42	165.66	14.71	187.94	119.58
2X	204.15	210.98	39.01	136.52	181.82	163.06
3	20.61	6.79	4.60	5.35	4.17	8.77
4	3.34	3.28	3.39	3.04	3.51	3.05
5	5.85	3.89	3.40	3.64	3.50	4.15
5X	9.59	DM	3.88	3.46	3.99	3.77
6	4.81	4.71	14.21	5.17	14.17	4.68
7	21.63	DM	10.24	15.33	29.60	31.68
8	32.58	19.54	21.00	25.98	21.34	21.19
9	12.44	11.73	11.26	10.85	12.01	10.41
10	9.19	7.12	8.37	11.42	10.05	9.11

* DM - data missing

TABLE III - H. Concentration (ppm) of Zinc in the sediments near the discharge of Galveston Sewage Treatment Plant, 3-4 November, 1978.

	TIME					
STATION	0600	1000	1400	1800	2200	0200
1	24.37	DM*	44.88	93.95	24.75	103.99
2	38.30	61.85	351.41	31.86	404.02	251.30
2X	461.16	463.39	82.71	290.10	389.20	339.43
3	12.44	15.12	13.02	12.90	12.97	25.95
4	6.39	6.28	5.72	6.17	5.77	6.28
5	12.82	7.61	7.50	7.08	7.66	8.32
5X	21.38	DM	7.81	7.64	8.74	8.00
6	16.31	14.91	13.63	14.23	14.05	13.22
7	47.31	DM	24.82	38.95	58.09	57.85
8	76.54	43.90	50.74	58.23	45.02	51.62
9	33.31	29.80	29.91	30.34	33.30	26.38
10	21.36	20.72	17.52	27.12	23.50	20.51

* DM - data missing

Appendix IV

TABLE IV - A. Mean Ø size of sediments near the discharge of Galveston Sewage Treatment Plant, 1400 hr, 16 September, 1978 and 1800 hr, 3 November, 1978.

STATION	Sept. 1400 hr	Nov. 1800 hr
1	2.78	2.97
2	8.56	3.32
2X	7.24	6.29
3	2.77	2.90
4	2.81	2.82
5	2.89	2.77
5X	2.74	2.85
6	2.90	2.83
7	7.38	3.17
8	3.01	3.56
9	2.90	2.92
10	2.89	2.98

TABLE IV - B. Mean Ø size of the sediments from stations 1 and 10 near the Galveston Sewage Treatment Plant, all time periods, 16 -17 September, 1978 and 3-4 November, 1978.

TIME	Sept. Stat. 1	Sept. Stat. 10	Nov. Stat. 1	Nov. Stat. 10
0600	2.88	2.88	2.85	3.03
1000	2.87	2.94	DM*	2.99
1400	2.78	2.89	2.90	2.89
1800	2.77	2.90	2.97	2.98
2200	2.89	2.89	2.67	2.95
0200	2.77	2.93	2.84	2.97

* DM - data missing

TABLE IV - C. Percentage (%) organic content of sediments near the discharge of Galveston Sewage Treatment Plant, 1400 hr, 16 September, 1978 and 1800 hr, 3 November, 1978.

STATION	Sept. 1400 hr	Nov. 1800 hr
1	4.40	4.32
2	42.66	3.10
2X	44.68	32.88
3	1.68	1.12
4	1.47	1.36
5	1.69	1.30
5X	3.05	1.61
6	1.38	1.27
7	36.84	2.50
8	4.31	1.36
9	1.69	1.82
10	3.39	3.40

TABLE IV - D. Percentage (%) organic content of sediments from stations 1 and 10 near the discharge of Galveston Sewage Treatment Plant, all times, 16-17 September, 1978 and 3-4 November, 1978.

Time	Sept. Stat. 1	Sept. Stat. 10	Nov. Stat. 1	Nov. Stat. 10
0600	4.91	2.28	1.24	2.55
1000	2.00	2.90	DM*	2.13
1400	4.40	3.39	2.73	2.84
1800	2.56	1.82	4.32	3.40
2200	1.11	2.29	1.28	3.11
0200	1.24	2.75	5.45	2.92

* DM - data missing