Tampa Bay National Estuary Program
Technical Publication #04-97

TRACE METAL STATUS OF TAMPA BAY SEDIMENTS 1993-1996

October 1997

TRACE METAL STATUS
OF
TAMPA BAY SEDIMENTS
1993-1996

ENVIRONMENTAL PROTECTION
COMMISSION
OF HILLSBOROUGH COUNTY
1900 9th AVENUE
TAMPA, FL 33605

OCTOBER 1997

TRACE METAL STATUS
OF
TAMPA BAY SEDIMENTS
1993-1996

STEPHEN A. GRABE
ENVIRONMENTAL PROTECTION COMMISSION
OF HILLSBOROUGH COUNTY
1900 9th AVENUE
TAMPA, FL 33605

OCTOBER 1997

ENVIRONMENTAL PROTECTION COMMISSION OF HILLSBOROUGH COUNTY

ROGER P. STEWART
EXECUTIVE DIRECTOR

CHRISTOPHER A. DUNN
DIRECTOR, WATER MANAGEMENT DIVISION

TOM CARDINALE
ASSISTANT DIRECTOR,
ENVIRONMENTAL MONITORING & ANALYSIS

ACKNOWLEDGEMENTS

Sediment samples were collected by staff of the Hillsborough County Environmental Protection Commission (Mr. Roger Stewart, Director), the Manatee County Environmental Management Department (Ms. Karen Collins, Director), and the Pinellas County Department of Environmental Management (Mr. Will Davis, Director). The Tampa Bay National Estuary Program (Richard Eckenrod, Director and Holly Greening, Program Scientist) provided the financial support for analysis of the 1996 Manatee and Pinellas County samples. In 1993, Skidaway Institute of Oceanography, courtesy of the USEPA at Gulf Breeze and John MacCauley, analyzed the sediment samples. Beginning in 1994, sediment contaminants were analyzed by Hillsborough County's Environmental Protection Commission's laboratory staff (Steve Perez and Frances Olszewski). Silt-clay analyses were performed by Dr. Z. Lin (EPCHC) in 1993-1994 and by Manatee County's Department of Environmental Management (Maria Martinez and Deborah Plunkett) in 1995-1996.

EXECUTIVE SUMMARY

Contaminated sediments are of environmental concern because they have been associated with reductions in the numbers of species as well as numbers of animals, or, alternatively, with the proliferation of "pollution tolerant" animals. The Tampa Bay National Estuary Program addressed both ecological and human health risks associated with contaminated sediments in a 1996 study. They found that, for Tampa Bay, ecological risks were associated with several metals but effects on human health were not indicated. The primary sources of metal contaminants to Tampa Bay include urban runoff, atmospheric deposition, and point-source discharges (*e.g.* ,industrial discharges and storm sewers).

Charting the Course, the management plan for Tampa Bay, includes among its objectives: (a) the identification of "hotspots" and sources of contaminants; (b) the improvement of both stormwater treatment and source-controls in order to ameliorate these "hotspots"; and (c) to continue to monitor the bay for changes in response to remediation.

Sediment monitoring for metals, pesticides, and hydrocarbons has been an element of the Tampa Bay National Estuary Program's synoptic monitoring program since 1993. The completion of the 1996 sediment metals analyses now permit an assessment of "baseline" conditions of metal contamination from which to measure future improvements in Tampa Bay.

The baseline conditions for trace metal contamination of Tampa Bay, suggest that **approximately 6% (24 mi^2) of Tampa Bay sediments are of "marginal" quality (low probability of being toxic to aquatic life) and barely 1% (4 mi^2) are "subnominal" (higher probability of being toxic to aquatic life).**

The most industrialized segment of Tampa Bay, Hillsborough Bay, shows the greatest degradation. **Approximately 33% (13 mi^2) of Hillsborough Bay sediments are of "marginal" quality** (due to cadmium) and **almost 8% (3 mi^2) of Hillsborough Bay sediments are "subnominal"** (due to chromium and nickel).

Approximately 14% (5 mi^2) of Boca Ciega Bay (1996 data only), 6% (5.7 mi^2) of Lower Tampa Bay, 5% (4 mi^2) of Old Tampa Bay, and 4% (4.8 mi^2) of Middle Tampa Bay have sediments of "marginal" quality. The Manatee River and Terra Ceia Bay sediments appear to be the least contaminated by metals, although almost 8% (1.5 mi^2) of the

Manatee River is marginal with regards to silver. These *Manatee County data also need to be viewed cautiously because these estimates are based upon only a single year of data.*

Approximately 5% (1.8 mi^2) of Boca Ciega Bay, and only 1% of Old, Middle, and Lower Tampa Bay have "subnominal" sediments.

Of concern is the observation, albeit based upon a very small subset of the data, that **the Hillsborough, Palm, and Alafia rivers, show evidence of greater impairment than Hillsborough Bay proper and warrant additional attention.**

TABLE OF CONTENTS

ACKNOWLEDGEMENTS i
EXECUTIVE SUMMARY ii
TABLE OF CONTENTS iv
LISTOFFIGURES v
LIST OF TABLES xi
SECTION I: INTRODUCTION 1
SECTION II: MATERIALS & METHODS 3
II.1.STUDY DESIGN 3
II.2. FIELD METHODS 3
II.3. LABORATORY METHODS 11
II.4. DATA ANALYSES 12
SECTION III: RESULTS 14
III.1. PERCENT SILT + CLAY & METAL CONCENTRATIONS 14
III.2 STATUS OF THE BAY SEGMENTS 14
III.2.1. Old Tampa Bay 14
III.2.2. Hillsborough Bay 21
III.2.2.1 Hillsborough River 21
III.2.2.2 Palm River 21
III.2.2.3 Alafia River 33
III.2.3. Middle Tampa Bay 33
111.2.3.1Little Manatee River 33
III.2.4. Lower Tampa Bay 33
III.2.5. Boca Ciega Bay 52
III.2.6. Terra Ceia Bay 52
III.2.7. Manatee River 52
III.2.8. Synthesis 52
SECTION IV: DISCUSSION 67
SECTION V: RECOMMENDATIONS 70
SECTION VI: LITERATURE CITED 71

LIST OF FIGURES

Figure 1. Location of sampling stations for sediments in the Old Tampa Bay segment of Tampa Bay, 1993-1996. 4

Figure 2. Location of sampling stations for sediments in the Hillsborough Bay segment of Tampa Bay, 1993-1996. Open circles designate 1996 sampling locations in the Hillsborough, Palm, and Alafia Rivers. 5

Figure 3. Location of sampling stations for sediments in the Middle Tampa Bay segment of Tampa Bay, 1993-1996. Open circles designate approximate sampling locations in the Little Manatee River, 1996. 6

Figure 4. Location of sampling stations for sediments in the Lower Tampa Bay segment of Tampa Bay, 1993-1996.. 7

Figure 5 . Location of sampling stations for sediments in the Boca Ciega Bay segment of Tampa Bay, 1995-1996. 8

Figure 6. Location of sampling stations for sediments in the Terra Ceia Bay segment of Tampa Bay, 1993-1996. 9

Figure 7. Location of sampling stations for sediments in the Manatee River segment of Tampa Bay, 1993-1996. 10

Figure 8. Mean (and standard error) % silt+clay by bay segment. Tampa Bay, 1993-1996. 15

Figure 9. Cumulative proportion of the % Silt+Clay in Old Tampa Bay segment sediments, 1993-1996. 16

Figure 10. Trace metal concentrations vs. aluminum. Old Tampa Bay segment, 1993-1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error. 17

LIST OF FIGURES (continued)

Figure 11. Cumulative proportions of trace metals in the Old Tampa Bay segment, 1993-1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely. 18

Figure 12. Percentage of bay segments with "marginal" (metal concentration >TEL< PEL) sediment quality. Tampa Bay, 1993-1996. 19

Figure 13. Percentage of bay segments with "subnominal" (metal concentration >PEL) sediment quality. Tampa Bay, 1993-1996. 20

Figure 14. Cumulative proportions of the average PEL quotient for trace metals in the Old Tampa Bay segment, 1993-1996. Vertical line demarcates the threshold above which toxic effects are likely. 22

Figure 15. Mean (and standard error) of the PEL quotient for metals, by bay segment. Tampa Bay, 1993-1996 23

Figure 16. Cumulative proportion of the % Silt+Clay in Hillsborough Bay sediments, 1993-1996. 24

Figure 17. Trace metal concentrations vs. aluminum. Hillsborough Bay segment, 1993-1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error. 25

Figure 18. Cumulative proportions of trace metals in the Hillsborough Bay segment, 1993-1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely. 27

Figure 19. Cumulative proportions of the average PEL quotient for trace metals in the Hillsborough Bay segment, 1993-1996. Vertical line demarcates the threshold above which toxic effects are likely. 28

LIST OF FIGURES (continued)

Figure 20. Cumulative proportion of the % Silt+Clay in Hillsborough River sediments, 1995-1996. . . . . **29**

Figure 21. Trace metal concentrations vs. aluminum. Hillsborough River, 1995-1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error. **30**

Figure 22. Cumulative proportions of trace metals in the Hillsborough River, 1995-1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely. **31**

Figure 23. Cumulative proportions of the average PEL quotient for trace metals in the Hillsborough River, 1995-1996. Vertical line demarcates the threshold above which toxic effects are likely. **32**

Figure 24. Cumulative proportion of the % Silt+Clay in Palm River sediments, 1995-1996. . . . . **34**

Figure 25. Trace metal concentrations vs. aluminum. Palm River, 1995-1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error. **35**

Figure 26. Cumulative proportions of trace metals in the Palm River, 1995-1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely. **36**

Figure 27. Cumulative proportions of the average PEL quotient for trace metals in the Palm River, 1995-1996. Vertical line demarcates the threshold above which toxic effects are likely. **37**

LIST OF FIGURES (continued)

Figure 28. Cumulative proportion of the % Silt+Clay in Alafia River sediments, 1995-1996. 38

Figure 29. Trace metal concentrations vs. aluminum. Alafia River, 1995-1996, Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error. 39

Figure 30. Cumulative proportions of trace metals in the Alafia River, 1995-1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely. 40

Figure 31. Cumulative proportions of the average PEL quotient for trace metals in the Alafia River, 1995-1996. Vertical line demarcates the threshold above which toxic effects are likely. 41

Figure 32. Cumulative proportion of the % Silt+Clay in Middle Tampa Bay sediments, 1993-1996. 42

Figure 33. Trace metal concentrations vs. aluminum. Middle Tampa Bay, 1993-1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error. 43

Figure 34. Cumulative proportions of trace metals in Middle Tampa Bay, 1993-1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely. 44

Figure 35. Cumulative proportions of the average PEL quotient for trace metals in the Middle Tampa Bay segment, 1993-1996. Vertical line demarcates the threshold above which toxic effects are likely. 45

LIST OF FIGURES (continued)

Figure 36. Cumulative proportion of the % Silt+Clay in Little Manatee River sediments, 1995-1996. 46

Figure 37. Trace metal concentrations vs. aluminum. Little Manatee River, 1995-1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error. 47

Figure 38. Cumulative proportions of trace metals in the Little Manatee River, 1995-1996. Vertical lines demarcate the "Threshold Effects Level" [TEL] , below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely. 48

Figure 39. Cumulative proportions of the average PEL quotient for trace metals in the Little Manatee River, 1995- 1996. Vertical line demarcates the threshold above which toxic effects are likely. 49

Figure 40. Cumulative proportion of the % Silt+Clay in Lower Tampa Bay sediments, 1995-1996. 50

Figure 41. Trace metal concentrations vs. aluminum. Lower Tampa Bay, 1993-1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error. 51

Figure 42. Cumulative proportions of trace metals in Lower Tampa Bay, 1993-1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], ,above which adverse ecological effects are likely. 53

Figure 43. Cumulative proportions of the average PEL quotient for trace metals in the Lower Tampa Bay segment, 1993-1996. Vertical line demarcates the threshold above which toxic effects are likely. 54

LIST OF FIGURES (continued)

Figure 44. Cumulative proportion of the % Silt+Clay in Boca Ciega Bay sediments, 1995-1996. 55

Figure 45. Trace metal concentrations vs. aluminum. Boca Ciega Bay segment, 1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error. 56

Figure 46. Cumulative proportions of trace metals in the Boca Ciega Bay segment, 1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely. 57

Figure 47. Cumulative proportions of the average PEL quotient for trace metals in the Boca Ciega Bay segment, 1996. Vertical line demarcates the threshold above which toxic effects are likely. 58

Figure 48. Cumulative proportion of the % Silt+Clay in Terra Ceia Bay sediments, 1993-1996. 59

Figure 49. Trace metal concentrations vs. aluminum. Terra Ceia Bay segment, 1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error. 60

Figure 50. Cumulative Proportions of Trace Metals in the Terra Ceia Bay segment, 1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely. 61

Figure 51. Cumulative proportions of the average PEL quotient for trace metals in the Terra Ceia Bay segment, 1996. Vertical line demarcates the threshold above which toxic effects are likely. 62

LIST OF FIGURES (continued)

Figure 52. Cumulative proportion of the % Silt+Clay in Manatee River sediments, 1993-1996. 63

Figure 53. Trace metal concentrations vs. aluminum. Manatee River segment, 1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error. 64

Figure 54. Cumulative proportions of trace metals in the Manatee River segment, 1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely. 65

Figure 55. Cumulative proportions of the average PEL quotient for trace metals in the Manatee River segment, 1996. Vertical line demarcates the threshold above which toxic effects are likely. 66

LIST OF TABLES

Table 1. Summary of TEL, ERL, PEL, and ERM concentrations (ppm) of trace metals. 13

Table 2. Summary of linear regression analyses: Association of metal concentrations ($\log_{e}$ n+1 ppm) with the percentage of silt+clay (arcsine $\%SC^{.5}$): All bay segments. Tampa Bay, 1993-1996. 14

Table 3. Summary of mean trace metal concentrations (ppm): By bay segment. Tampa Bay, 1993-1996. 26

SECTION I
INTRODUCTION

Tampa Bay has been the object of intensive investigations of sediment contamination by the University of South Florida (Doyle *et al.* 1985; Doyle *et al.* 1989; Brooks & Doyle 1991 & 1992), the National Oceanographic & Atmospheric Administration (Long *et al.* 1991; Long *et al.* 1994; Daskalaskis & O'Connor 1994; Long *et al.* 1995a; Carr *et al.* 1996), and the Florida Department of Environmental Protection (Seal *et al.* 1994). Coastal Environmental, Inc. (1996) also summarized the results of several of these investigations.

These studies have shown that the lower Hillsborough River, parts of Hillsborough Bay (*e.g.*,Ybor Channel), Allen Creek, Cross Bayou Canal, Bayboro Harbor, St. Petersburg Yacht Basin, lower Boca Ciega Bay, Bear Creek, parts of Middle Tampa Bay, and two locations in the Manatee River have sediments which are contaminated and/or toxic (Long *et al.* 1991; Long *et al.* 1994; Daskalskis & O'Connor 1994; Seal *et al.* 1994; Carr *et al.* 1996). "Hotspots" were typically located proximate to point sources, storm drains, marinas, and canals (Long *et al.* 1991). The least contaminated sites included Safety Harbor, central and eastern Old Tampa Bay, Big Bayou, Little Bayou, and Bayou Grande (Long *et al.* 1994).

Where Tampa Bay sediments were found to be toxic, they were characterized by high concentrations of mixtures of chemicals. Among the metals found to be most often associated with toxic sediments were cadmium, copper, lead, mercury, and zinc (Carr *et al.* 1996). The Tampa Bay National Estuary Program (McConnell *et al.* 1996) has determined, via application of several risk assessment criteria, that chromium, copper, mercury, nickel, and silver are to be designated as priority "contaminants of concern".

Carr *et al.* (1996) concluded that *"the frequency of the sediment guideline exceedences and the associated toxicity indicates that the...benthic community may be subject to adverse contaminant-induced impacts at a number of locations throughout Tampa Bay."* Note however, that <u>the NOAA studies selected sample locations to represent areas of known contamination (from prior studies) or areas likely to be contaminated</u> (Long *et al.* 1994). A consequence of this sample design was that 70% to 80% of NOAA's study area was determined to be impacted (Carr *et al.* 1996). Estimates of sediment toxicity ranged, depending upon the bioassay test, from 0.08% to >80% of the 550 km^2 sampled by NOAA

(Long *et al.* 1996). When concordance among two bioassays was set as the criterion for toxicity, only 0.1% of Tampa Bay was considered to have toxic sediments (Long *et al.* 1996).

This study is designed produce areal estimates of "subnominal" benthic habitat in Tampa Bay by adopting a randomized, probability-based sampling protocol (see below). Rather than focusing on areas of the bay likely to be contaminated, as the NOAA studies did, this study design is unbiased (Coastal Environmental, Inc. 1994). The focus of this report is contamination of Tampa Bay by eight trace metals (arsenic, cadmium, chromium, copper, lead, nickel, silver, and zinc). Sampling took place over a four year "baseline" period (1993-1996) and included the four primary segments of Tampa Bay (Old, Hillsborough, Middle and Lower Tampa Bay); the Boca Ciega Bay, Terra Ceia Bay, and Manatee River segments were only surveyed in 1996.

SECTION II
MATERIALS & METHODS

11.1. STUDY DESIGN

Coastal Environmental, Inc. (1994) designed the benthic/sediment contaminant monitoring program for Tampa Bay after the USEPA's Environmental Monitoring and Assessment Program ("EMAP") design (USEPA 1990). The design is stratified (by bay segment), random, and probability-based; this design is capable of producing approximate unbiased estimates of the various environmental variables measured, as well as unbiased estimators of the standard error of the mean (Coastal Environmental, Inc. 1994).

The mechanics of the study design are outlined in Coastal Environmental, Inc. (1994) and Grabe *et al*. (1996). Strata definitions ***(i.e.,*** bay segments: Old Tampa Bay [OTB], Hillsborough Bay [HB], Middle Tampa Bay [MTB], Lower Tampa Bay [LTB], Boca Ciega Bay [BCB], Terra Ceia Bay [TCB], and Manatee River [MR]) are after Lewis & Whitman (1985). Sample locations for sediment contaminants were randomly selected in 1993. The 1994 sample locations were the same as 1993. Sample locations were rerandomized for both 1995 and 1996.

Boca Ciega Bay, Terra Ceia Bay, and the Manatee River were only added to the sediment contaminant aspect of the program in 1996. Data were also generally lacking for four rivers (Hillsborough [HR], Palm [PR], Alafia [AR], and the Little Manatee [LMR]) during this period. To alleviate this deficiency, a rectangular grid (2.5 km^2) was superimposed over these rivers for the 1996 sampling. Random x,y coordinates were drawn until sampling points were located within the rivers. This approach yielded three sampling locations in the Palm River and five in each of the other rivers. Samples were collected during September-October of each year. Sample locations are shown in Figures 1-7.

II.2.FIELD METHODS

Sediment samples were collected with a stainless steel Young-modified Van Veen grab sampler (0.04m^2). Prior to sampling at each station in 1993 and 1994, the sampler was rinsed with ambient bay water (Courtney *et al.* 1993). In 1995 and 1996 the sampler was

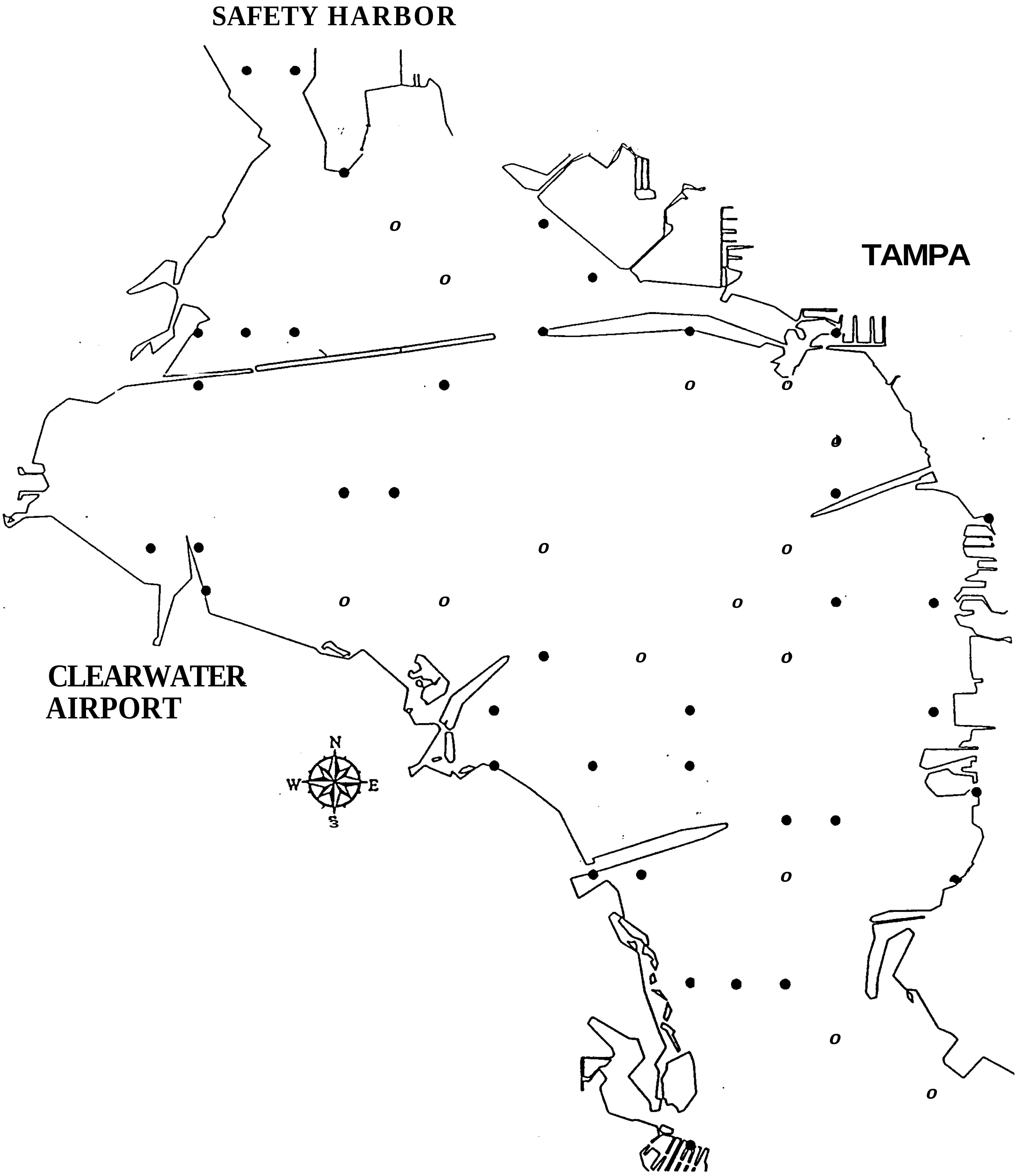


Figure 1. Location of sampling stations for sediments in the Old Tampa Bay segment of Tampa Bay, 1993-1996.

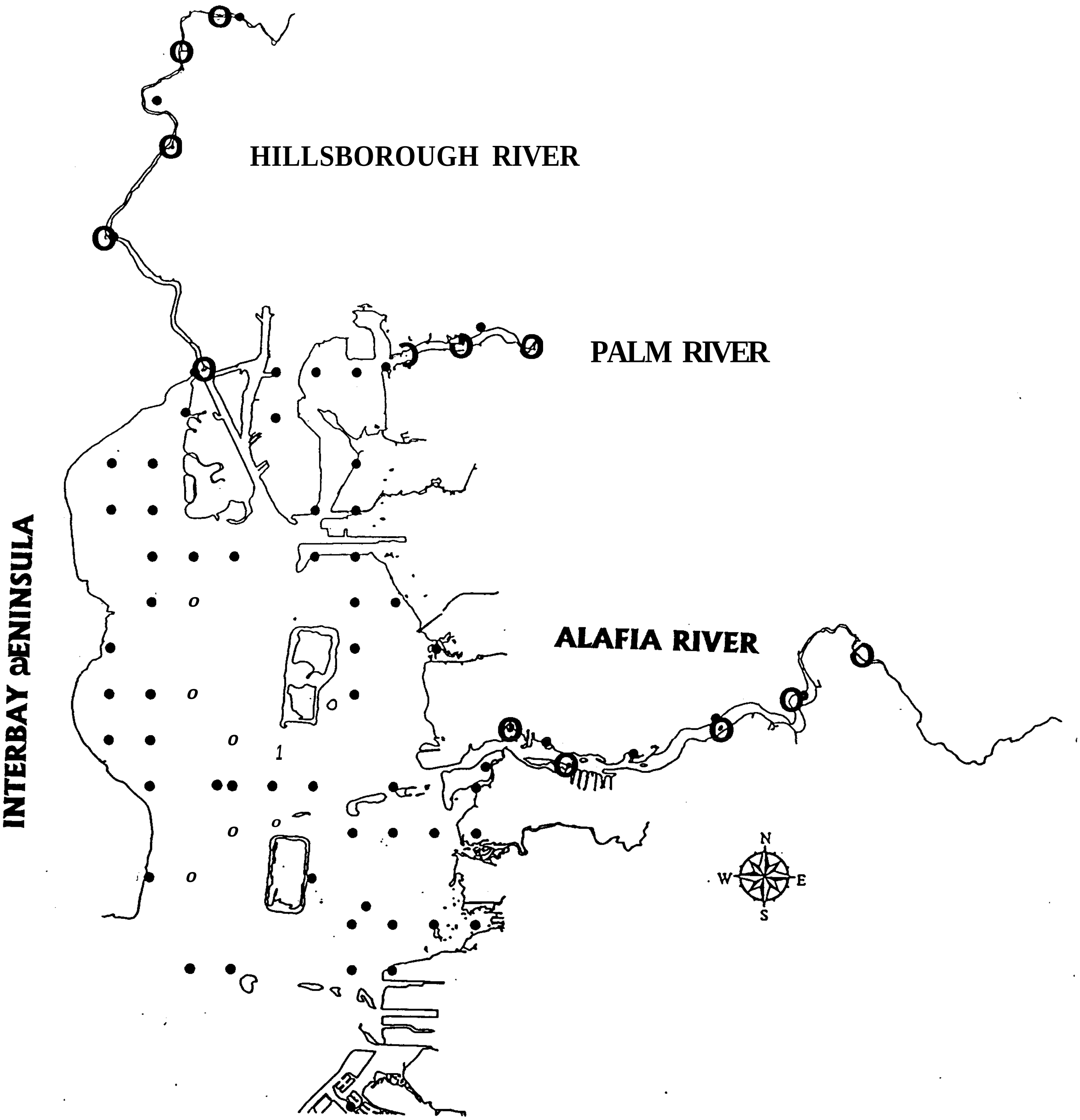


Figure 2. Location of sampling stations for sediments in the Hillsborough Bay segment of Tampa Bay, 1993-1996. Open circles designate 1996 sampling locations in the Hillsborough, Palm, and Alafia Rivers.

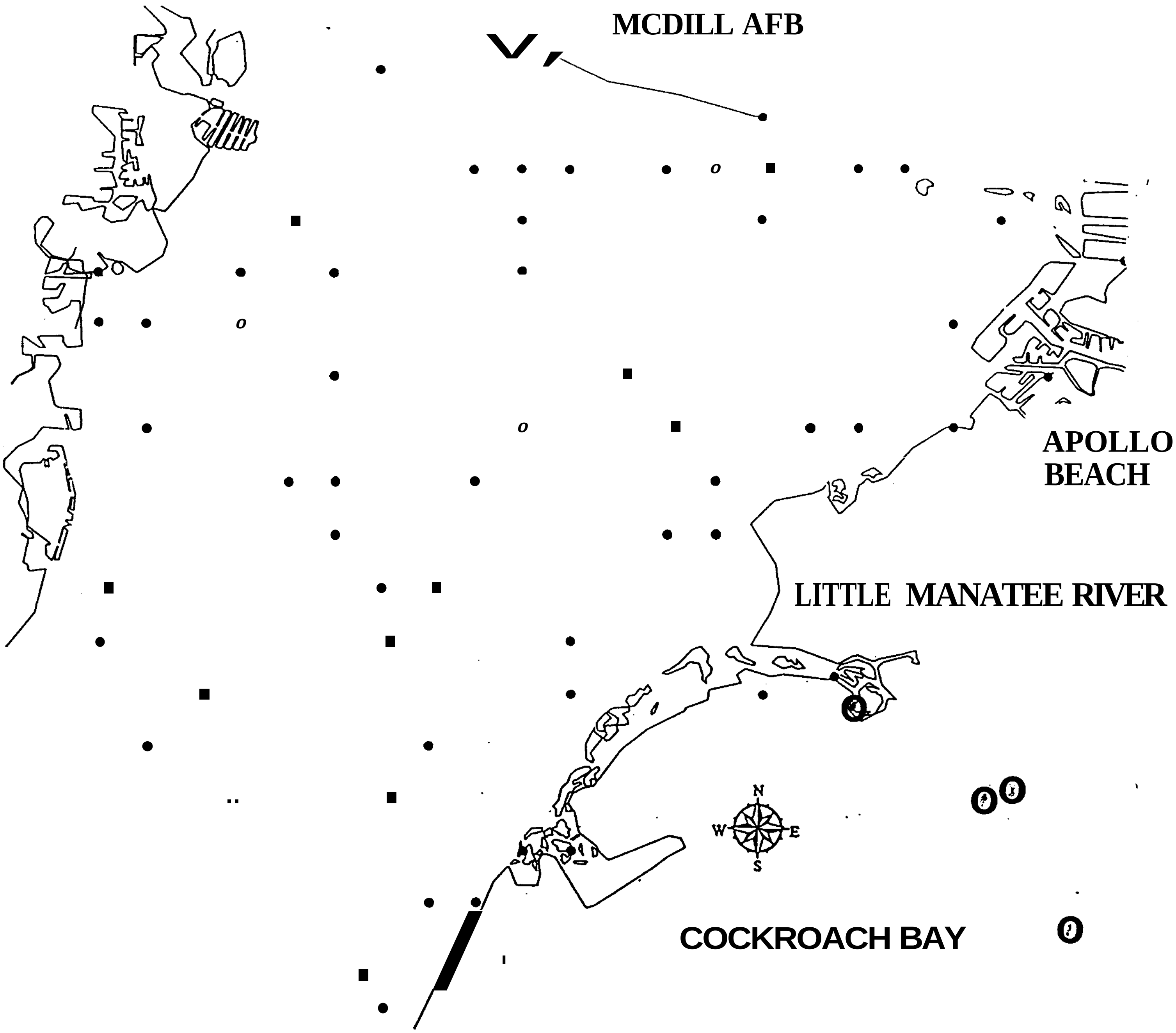


Figure 3. Location of sampling stations for sediments in the Middle Tampa Bay segment of Tampa Bay, 1993-1996. Open circles designate approximate sampling locations in the Little Manatee River, 1996.

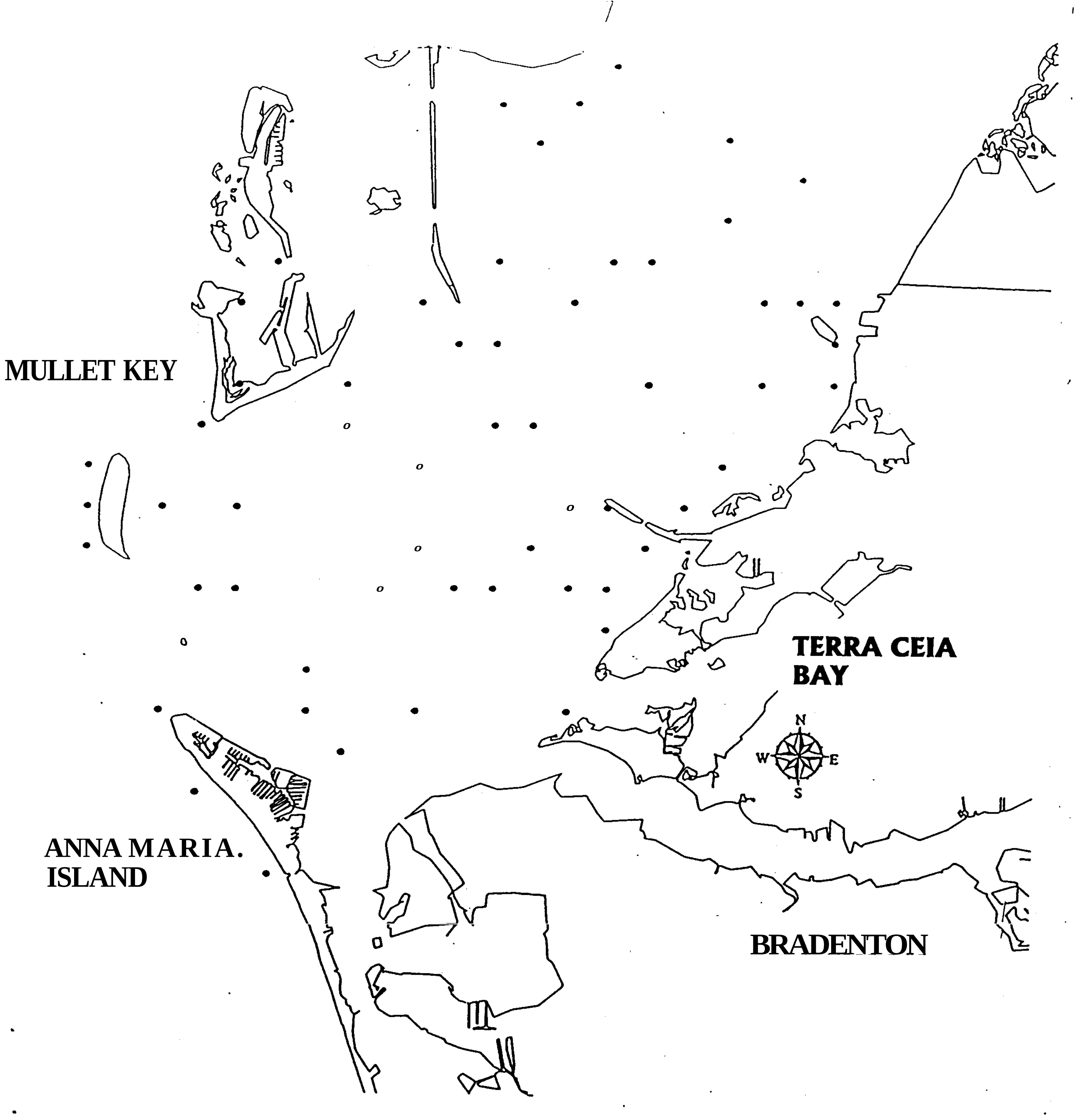


Figure 4. Location of sampling stations for sediments in the Lower Tampa Bay segment of Tampa Bay, 1993-1996.

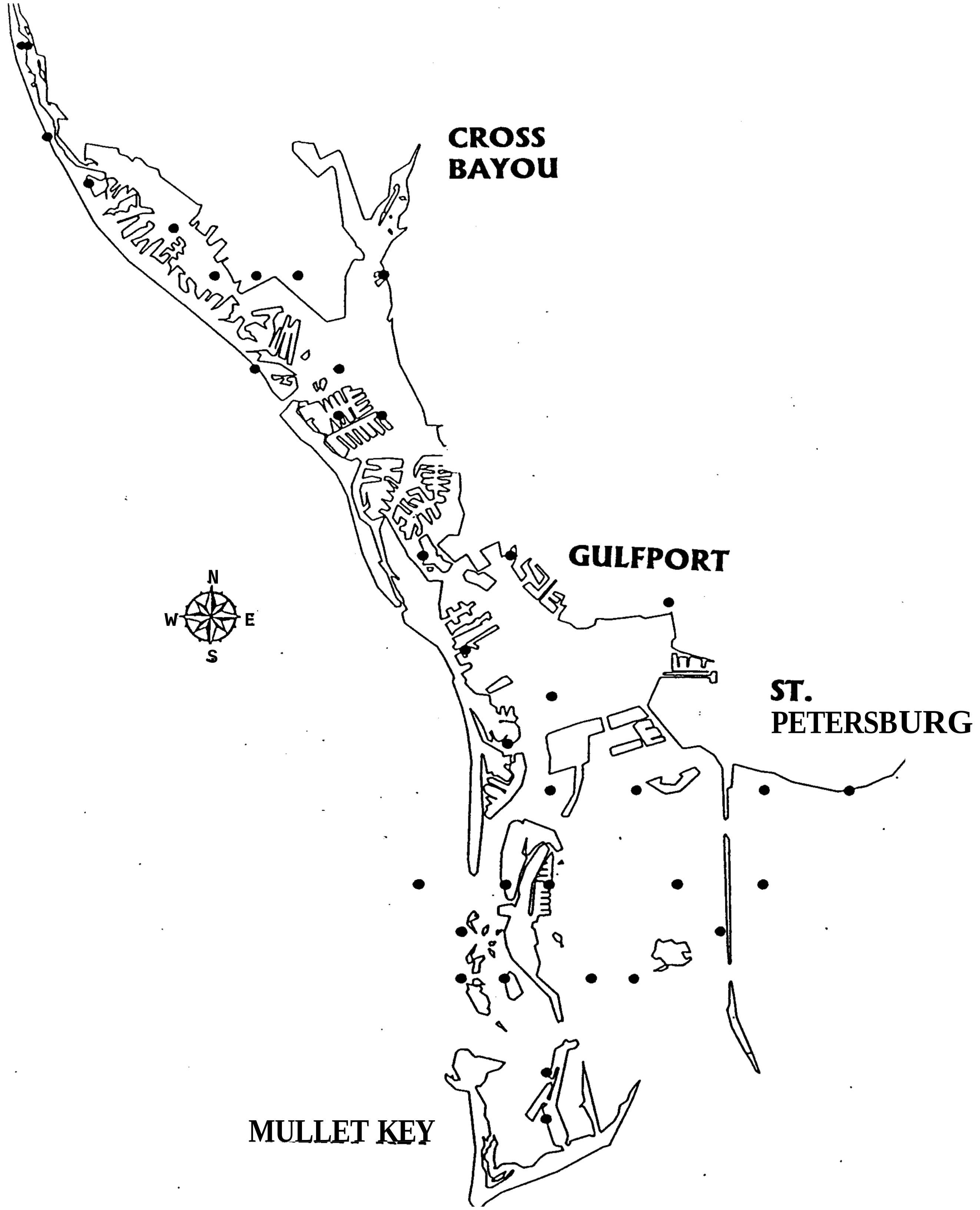


Figure 5. Location of sampling stations for sediments in the Boca Ciega Bay segment of Tampa Bay, 1995-1996.

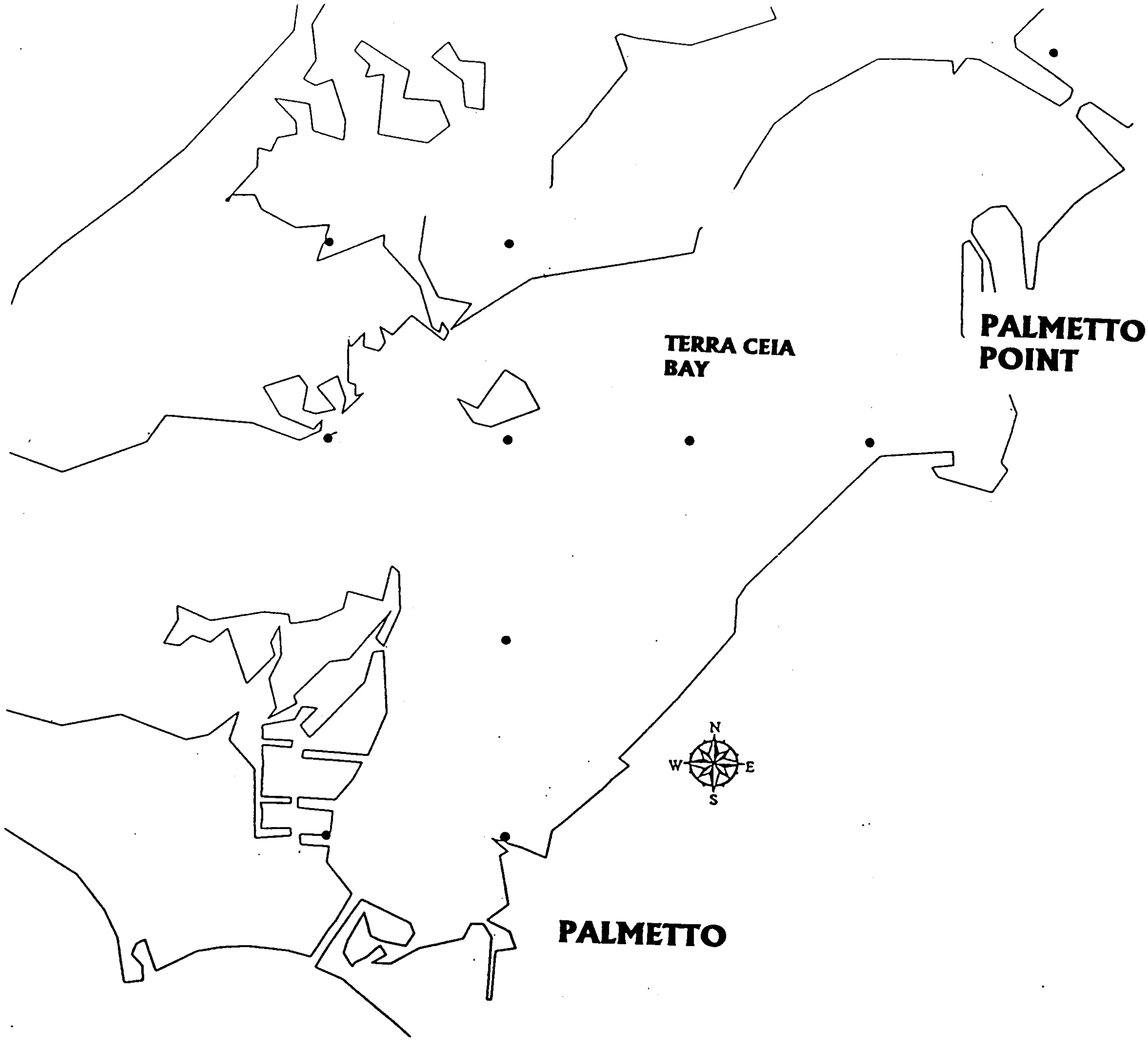


Figure 6. Location of sampling stations for sediments in the Terra Ceia Bay segment of Tampa Bay, 1993-1996.

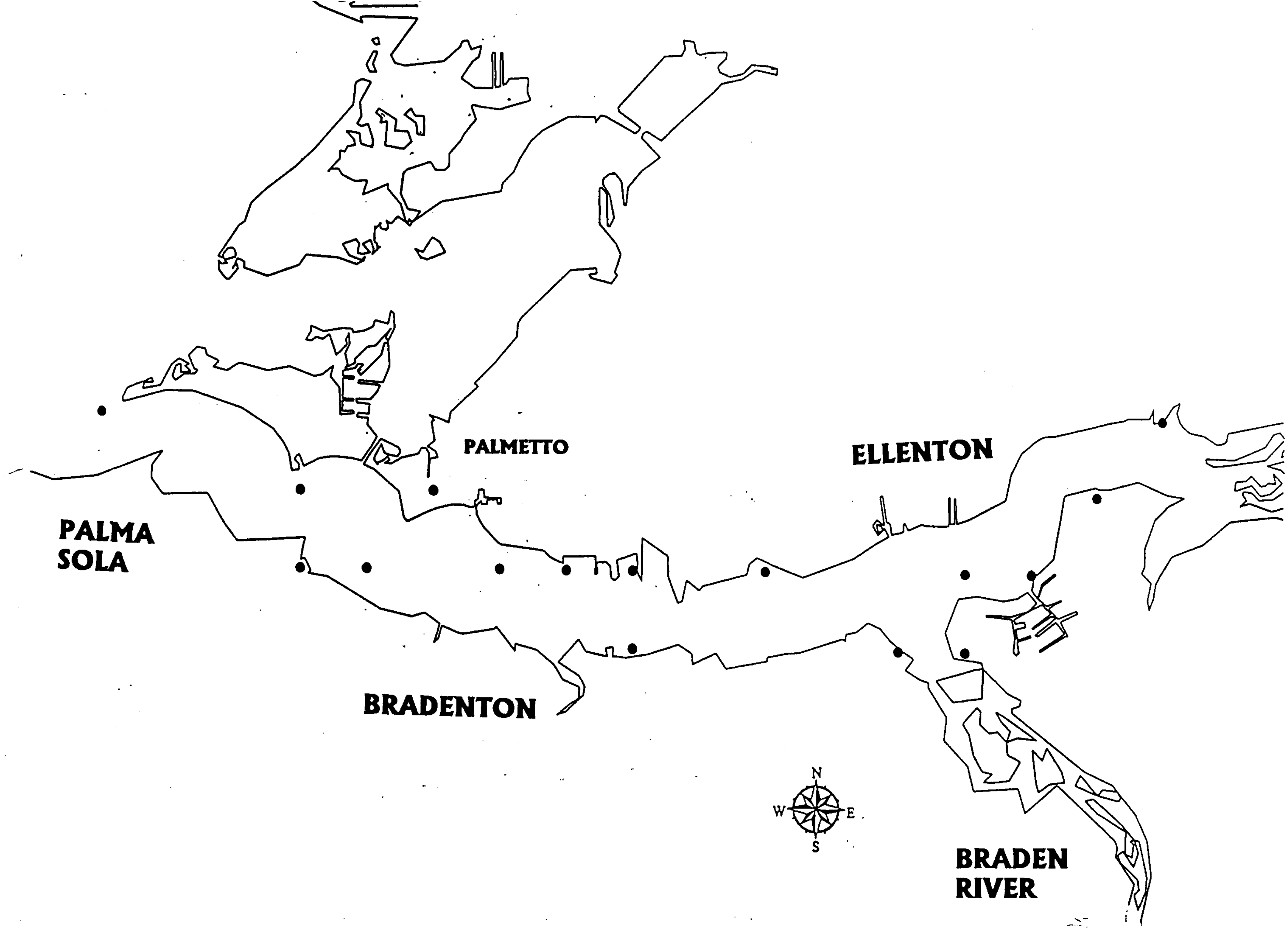


Figure 7. Location of sampling stations for sediments in the Manatee River segment of Tampa Bay, 1993-1996.

cleaned with Liquinox, rinsed in ambient bay water, and then again rinsed with pesticide grade isopropanol (Courtney *et al.* 1995).

The upper two centimeters of the sediment was removed with a Teflon trowel and spooned into a stainless steel beaker. In 1993 and 1994 these tools were cleaned with ambient bay water before use at each location (Courtney *et al.* 1993). In 1995 and 1996, both implements were cleaned with Liquinox, rinsed in ambient bay water, and then rinsed again with pesticide grade isopropanol (Courtney *et al.* 1995). In practice two to three grab samples were required to produce enough sediment for the laboratory analyses.

Once a sufficient amount of sediment was collected, the sample was homogenized by thoroughly mixing the contents of the beaker with the trowel. The mixture was then spooned into high density polyethylene jars for trace metals analysis and into 500-ml glass jars (lined with an aluminum foil barrier between the sediment sample and the lid in 1993 and 1994 and with Teflon lined caps in 1995-1996) for organic analyses. Both containers were chemically cleaned (acid wash) prior to use.

II.3. LABORATORY METHODS

Sediments were dried to a constant weight and ground. Approximately 0.4-0.5g were then subjected to complete digestion (nitric acid, hydrofluoric acid, and perchloric acid in 1993 and hydrochloric acid in 1994-1996); a microwave digester was used for 1994-1996 samples.

Metals were analyzed by inductively coupled plasma mass spectrometry in 1993. Graphite furnace atomic absorption (As, Cd, Cr, Cu, Pb, Ni, Ag, and, in 1994, Zn) (USEPA 1993) or flame atomic absorption (Al and, in 1995 and 1996, Zn) (NOAA 1993) were employed in subsequent years.

Skidaway Institute of Oceanography (Savannah, GA), courtesy of USEPA-Gulf Breeze, analyzed the 1993 sediment samples; EPCHC's laboratory staff analyzed sediment samples for 1994-1996.

QA/QC of lab analyses was evaluated using standard reference materials (1993), matrix spikes and spiked duplicates. Accuracy was determined by analyzing the reference materials; the requirement was that the results be within 80-120% of the certified values (T. Heitmuller, pers. comm. 19 Mar 1997). Precision was determined by comparing the "relative percent difference" between matrix spike duplicates and matrix duplicates; the criteria was that the average relative percent difference be <30% (T. Heitmuller, pers. comm. 19 Mar 1997).

The method of determining the percentage of silt + clay (%SC) in the sediments is described in Courtney *et al.* (1993).

II.4. DATA ANALYSES

Data from the 1995 Hillsborough, Palm, Alafia, and Little Manatee river samples were pooled with samples collected in 1996 from these specific strata. Data from these rivers were treated in a descriptive manner only; inferential statistics were not applied to these data.

Analysis of variance (ANOVA) was used to test for equality of segment means for the %SC and for each of the trace metals (Neter *et al.* 1985). Where the bay segment means were not equal ($p < .05$), Bonferroni comparisons were made to determine which segment means differed (Neter *et al.* 1985).

The association between %SC and the metals concentration of that sample was evaluated with linear regression and correlation (Neter *et al.* 1985). The %SC was arcsine transformed and the metal concentrations were log„ transformed to normalize variances for each of these statistical analyses (Neter *et al.* 1985).

Three sediment quality assessment guidelines (SQAGs) (MacDonald 1995) were applied to these data: a measure of anthropogenic enrichment, a measure of contamination by individual metals, and an integrated measure of contamination for all of the metals. Anthropogenic enrichment of sediments was determined using the metal:aluminum normalization developed by Schropp *et al.* (1990) for Florida estuarine sediments. Upper and lower confidence limits for sediments not enriched and indicative of "background" conditions were established for a suite of metals (arsenic, cadmium, chromium, copper, lead, nickel, and zinc). Values falling above the upper confidence limits are indicative of anthropogenic enrichment; values falling below the lower confidence limits may represent laboratory error. This normalization is not available for silver.

"Marginal" and "subnominal" sediments were designated by comparing concentrations with the Threshold Effects Level (TEL) and Predicted Effects Level (PEL) concentrations developed by MacDonald Environmental Services, Ltd. (1994) for Florida estuarine sediments. Both the TEL and PEL were based upon an assessment of integrated biological and chemical data, including bioassays and field studies. The TEL is defined as the concentration (of a metal in this case) below which adverse biological effects are never observed. The PEL is defined as the concentration (of a metal) above which adverse biological effects are likely.

Recent studies have shown that there is generally a high probability of biological effects when metal concentrations exceed the "Effects Range Median" (ERM) (Long et al. 1995b), a contaminant concentration which is similar to the PEL (Table 1). The likelihood of biological effects is quite low when metal concentrations are less then the "Effects Range Low" (ERL) (Long et al. 1995b), a contaminant concentration which is similar to the TEL (Table 1).

Sediments were designated as "marginal" if a metal concentration exceeded the TEL and was less than the PEL. Sediments were designated as "subnominal" if a metal concentration exceeded the PEL.

Another approach in identifying contaminated sediments is to compute the ratios of individual metal concentrations to the PEL and then avaerage these over all metals (E. Long, pers. comm. 11 Aug. 1997). For Tampa Bay, a PEL quotient of 1.6 has been proposed as an Assessment Target (MacDonald 1997). This metric better addresses the overall impact of mixtures of contaminants then do the other two SQAGs.

Cumulative distibution functions were plotted, by bay segment for each metal and for the PEL quotient, to permit areal estimates of "marginal" and "subnominal" bay bottom.

Table 1. Summary of TEL[a] ERL[b], PEL[a], and ERM[b] concentrations (ppm) of trace metals.

METAL	TEL	ERL	PEL	ERM
Arsenic	7.2	33.0	41.6	85.0
Cadmium	0.68	5.0	4.2	9.0
Chromium	52.3	80.0	160.0	145.0
Copper	18.7	70.0	108.0	390.0
Lead	30.2	35.0	112.0	110.0
Nickel	15.9	30.0	42.8	50.0
Silver	0.73	1.0	1.77	2.2
Zinc	124.0	120.0	271.0	270.0

[a] after MacDonald Environmental Services, Ltd. (1994)

[b] after Long & Morgan (1990)

SECTION III

RESULTS

III.1. PERCENT SILT + CLAY & METAL CONCENTRATIONS

The mean %SC was significantly different ($F_{6,471}=22.5; p<.001$) between bay segments (Hillsborough, Palm, Alafia, and Little Manatee river sediments were not considered in the ANOVA). Hillsborough Bay sediments had the highest mean %SC of the seven bay segments; the mean %SC for the other six bay segments were similar (Figure 8).

Concentrations of each of the metals were positively associated with %SC (Table 2). The weakest association was with arsenic and the strongest associations were with silver and cadmium (Table 2).

Table 2. Summary of linear regression analyses: Association of metal concentrations ($\log_{10}$ n+ 1 ppm) with the percentage of silt+clay (arcsine %SC$^{.5}$): All bay segments. Tampa Bay, 1993-1996.

Metal	Constant	*%SC* Coefficient	F	df	r^2
Arsenic	0.14	0.62	97***	1,403	0.19
Cadmium	-0.05	0.55	520***	1,403	0.56
Chromium	0.51	1.77	324***	1,403	0.44
Copper	0.23	1.58	274***	1,403	0.41
Lead	0.06	1.90	405***	1,403	0.50
Nickel	0.12	1.55	339***	1,403	0.46
Silver	-0.02	0.22	567***	1,403	0.58
Zinc	0.21	2.23	341***	1,403	0.46

***$p<.001$

III.2 STATUS OF THE BAY SEGMENTS

III.2.1. Old Tampa Bay: More than half of Old Tampa Bay has sediments with <5% silt+clay and approximately 9% of this bay segment was composed of fine-grained sediments (>20% silt+clay) (Figure 9). Metal:aluminum ratios showed that Old Tampa Bay sediments were not generally enriched by any of the metals (Figure 10). There was, however, evidence of contamination by each of the eight metals studied (Figure 11). Approximately 5% (4 mi^2) of Old Tampa Bay sediments were "marginal" (Figure 12) and approximately 1% (0.8 mi^2) were "subnominal" (Figure 13). The PEL quotients were all below the threshold level of

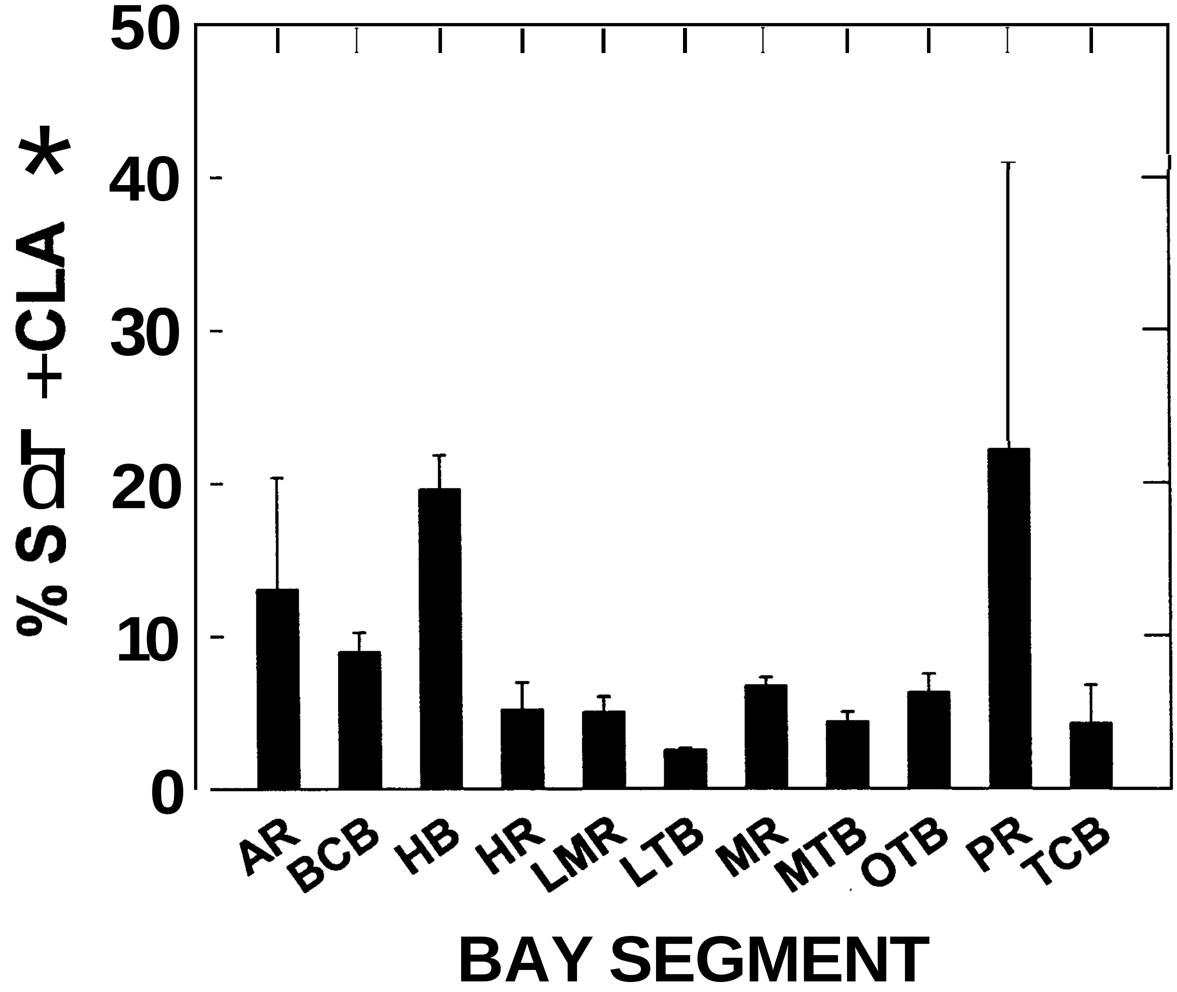


Figure 8. Mean (and standard error) % silt+clay by bay segment. Tampa Bay, 1993-1996.

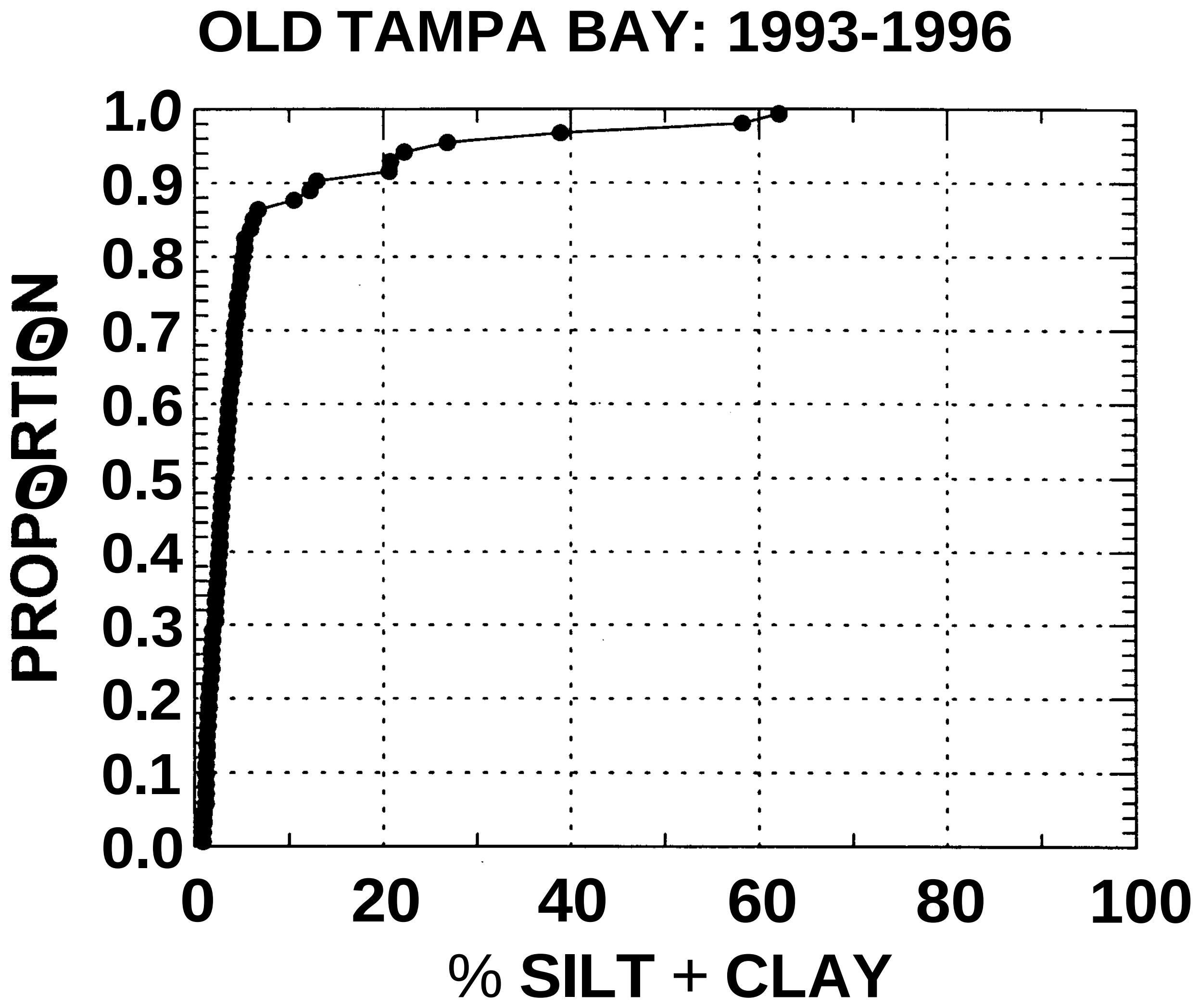
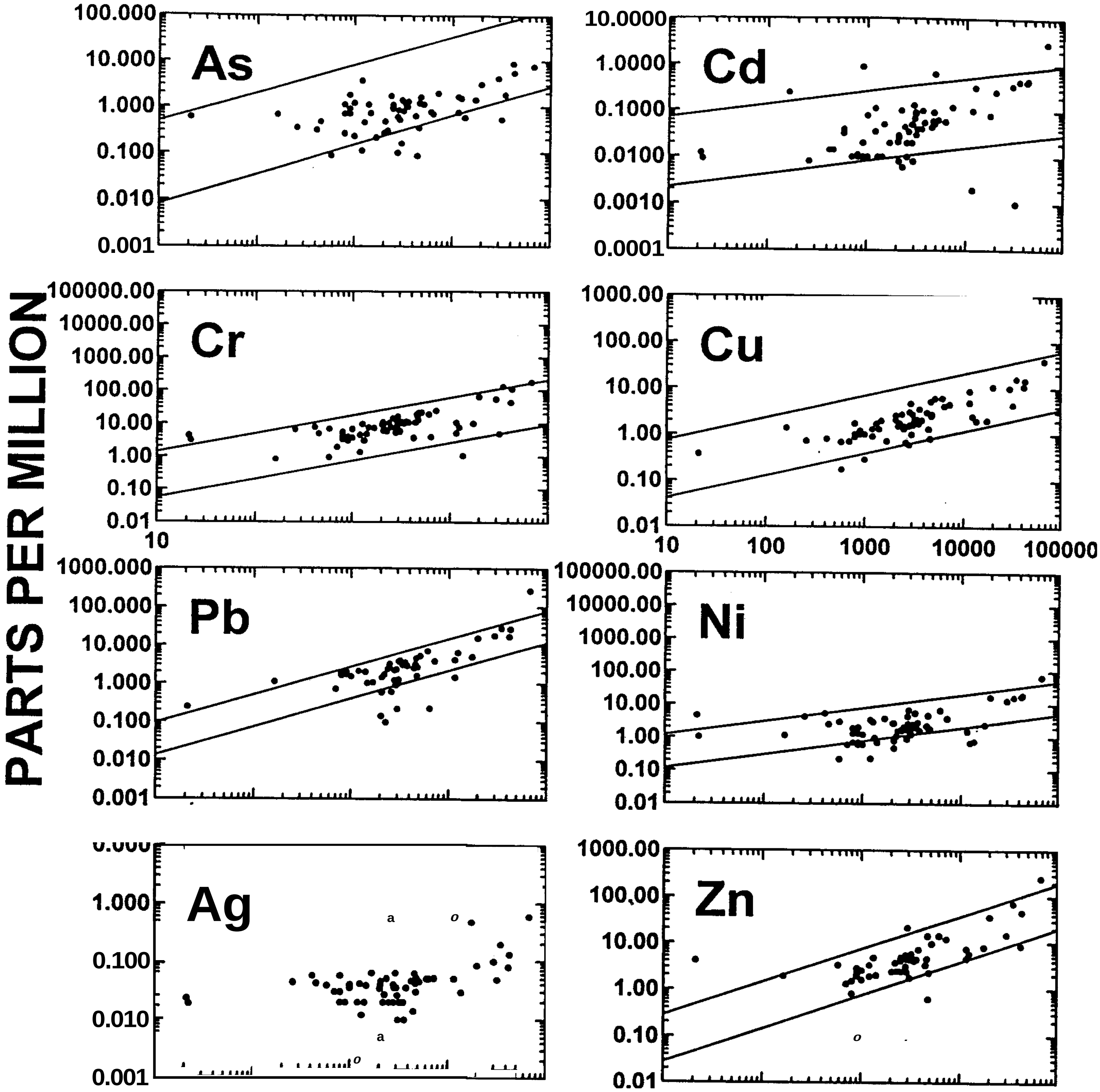


Figure 9. Cumulative proportion of the % Silt+Clay in Old Tampa Bay segment sediments, 1993-1996.

OLD TAMPA BAY: 1993-1996



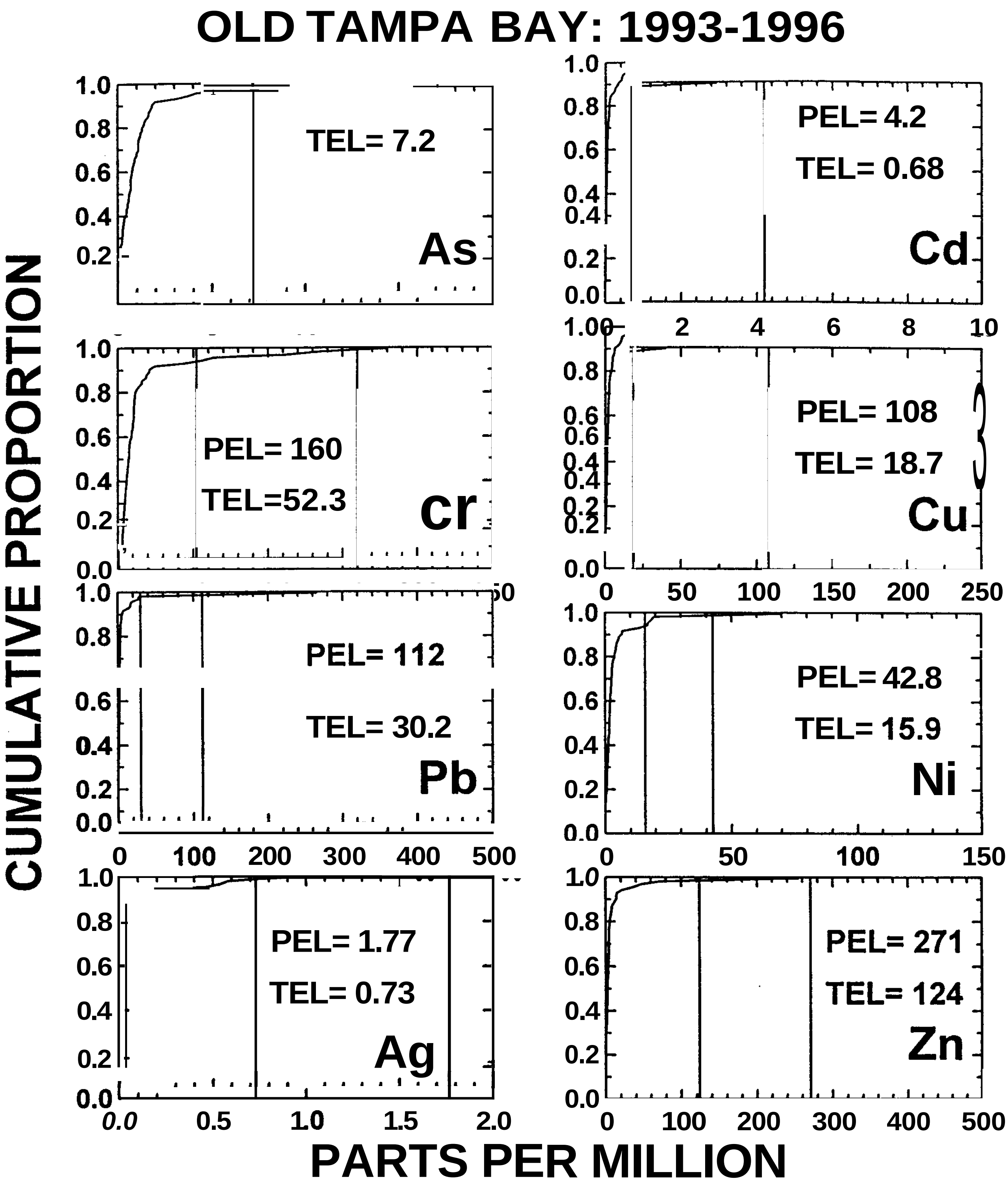


Figure 11. Cumulative proportions of trace metals in the Old Tampa Bay segment, 1993-1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely.

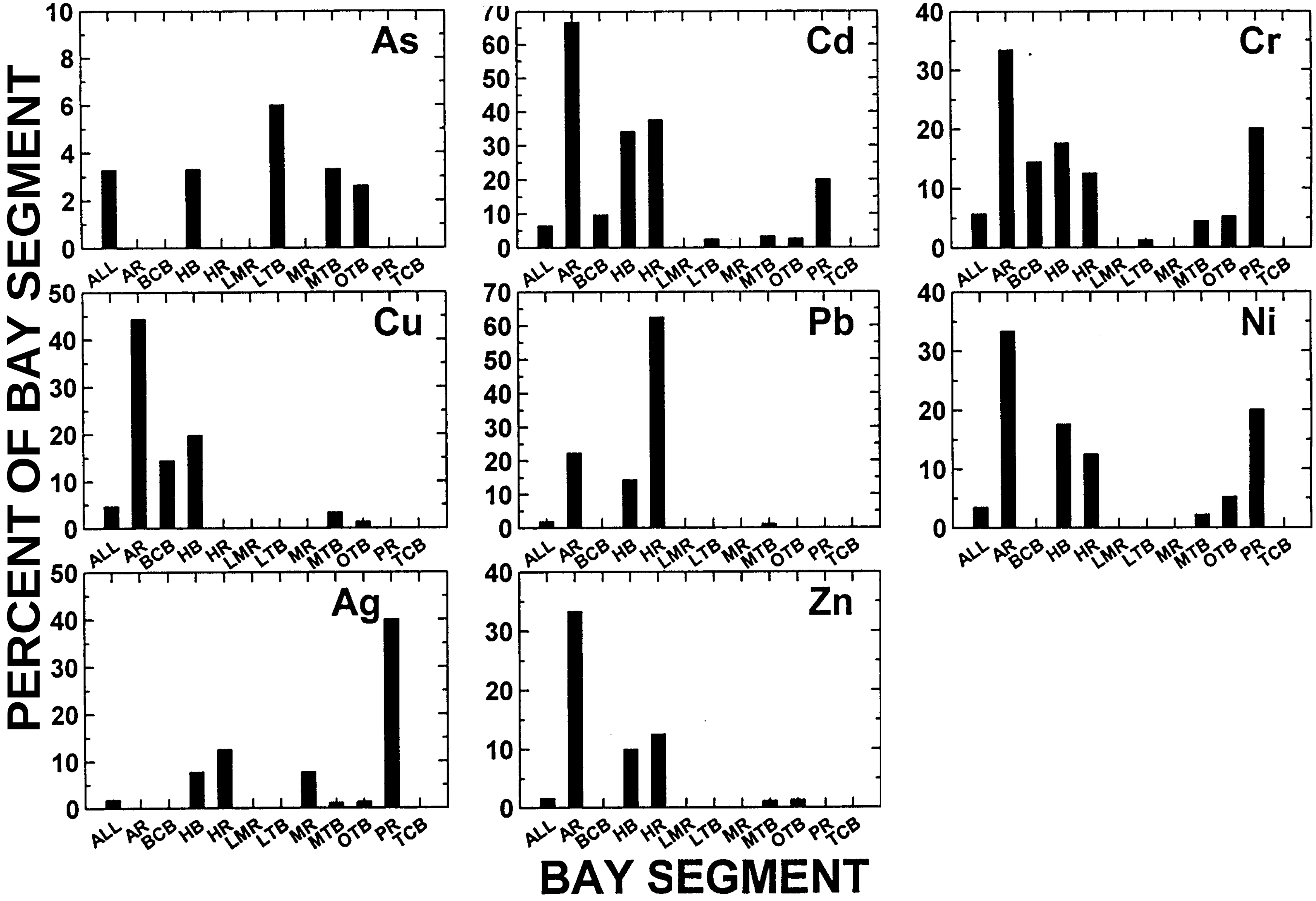


Figure 12. Percentage of bay segments with "marginal" (metal concentration >TEL<PEL) sediment quality. Tampa Bay, 1993-1996.

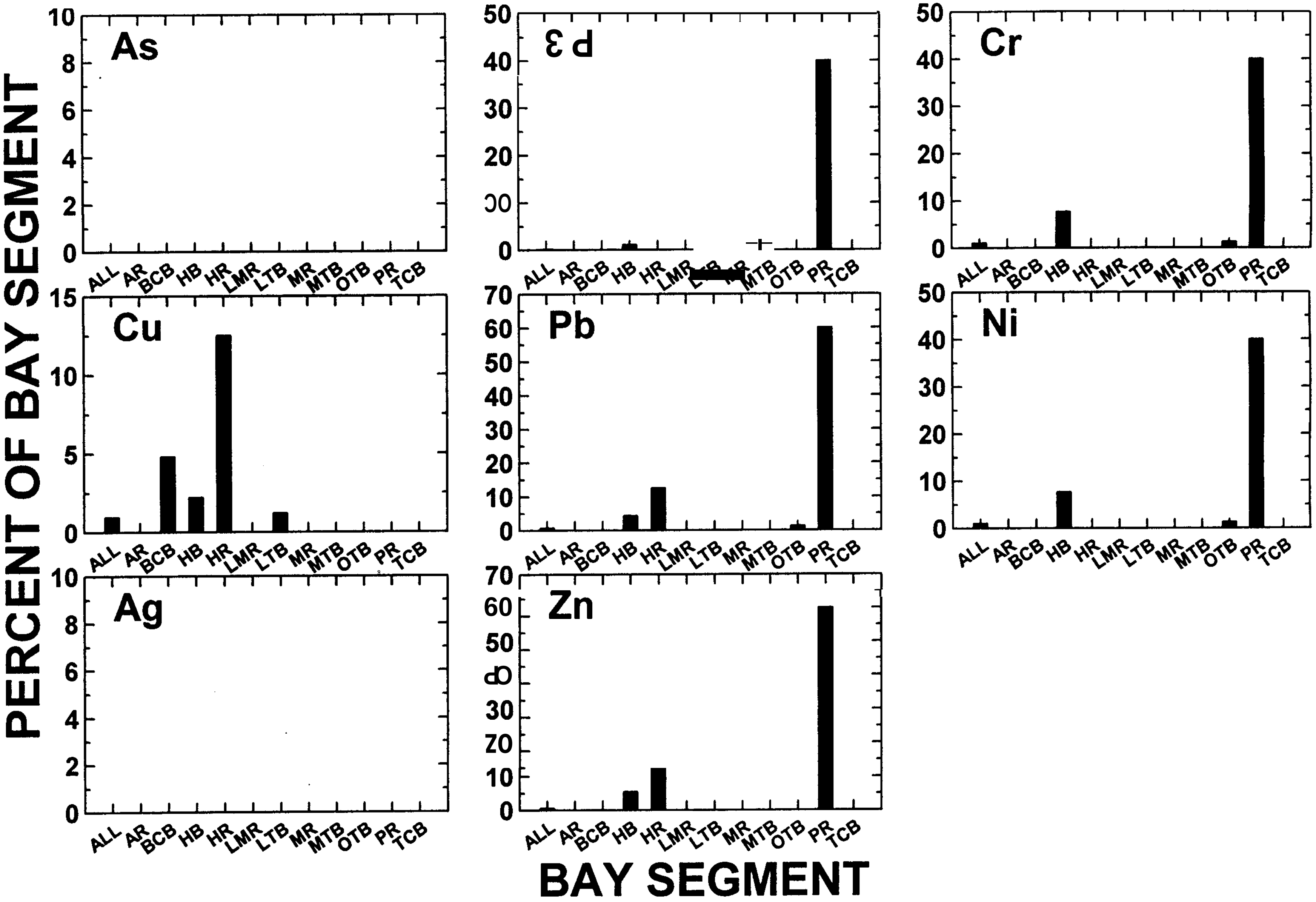


Figure 13. Percentage of bay segments with "subnominal" (metal concentration >PEL) sediment quality. Tampa Bay, 1993-1996.

1.6 (Figure 14); Old Tampa Bay sediments were generally among the lower ranked bay segments in terms of mean PEL quotients (Figure 15).

III.2.2. Hillsborough Bay: Approximately 25 % of Hillsborough Bay had sediments with a >20% silt+clay fraction, and almost half of this bay segment had sediments with < 10% silt+clay(Figure 16). A large fraction of Hillsborough Bay was enriched by cadmium and zinc, with lesser areas enriched by chromium, copper, lead, and nickel; there was no evidence of enrichment by arsenic (Figure 17). Concentrations of cadmium, chromium, copper, lead, nickel, silver, and zinc were significantly higher in this bay segment than in the other bay segments (Table 3). Sediments were marginally (>TEL<PEL) contaminated by each of the metals, but particularly by cadmium (>30% or > 12mi^2) (Figures 12 and 18). Approximately 8% (3 mi^2) of Hillsborough Bay was subnominal for chromium and nickel, with lesser areas subnominal for cadmium, copper, lead, and zinc (Figures 13 and 18). The PEL quotient for Hillsborough Bay showed that only a single sample exceeded the threshold value of 1.6 (Figure 19). The mean PEL quotient was the highest of the seven primary bay segments; only the three rivers draining into Hillsborough Bay had higher mean quotients (Figure 15).

III.2.2.1 Hillsborough River. Eight samples were analyzed for sediment contaminants in the Hillsborough River proper during 1995 and 1996. The silt+clay composition of the sediments sampled ranged from 0 to near 20% (Figure 20). Sediments were generally enriched by cadmium, copper, lead, and zinc (Figure 21). there was evidence that sediments were marginally contaminated by cadmium, chromium, nickel, lead and silver, and at least one site was subnominal for copper, lead and zinc (Figure 22). On an areal basis, this abbreviated data set suggests that up to 62% of the Hillsborough River may have sediments of "marginal" quality (Figure 12) and 12.5% of the river has "subnominal" sediments (Figure 13). None of the Hillsborough River sediment samples exceeded the PEL quotient threshold (Figure 23) although the mean PEL quotient was second only to the Palm River (Figure 15).

III.2.2.2 Palm River. Five samples, two in 1995 and three in 1996, were analyzed for sediment contaminants. The silt+clay fraction exceeded 40% in two of the samples and

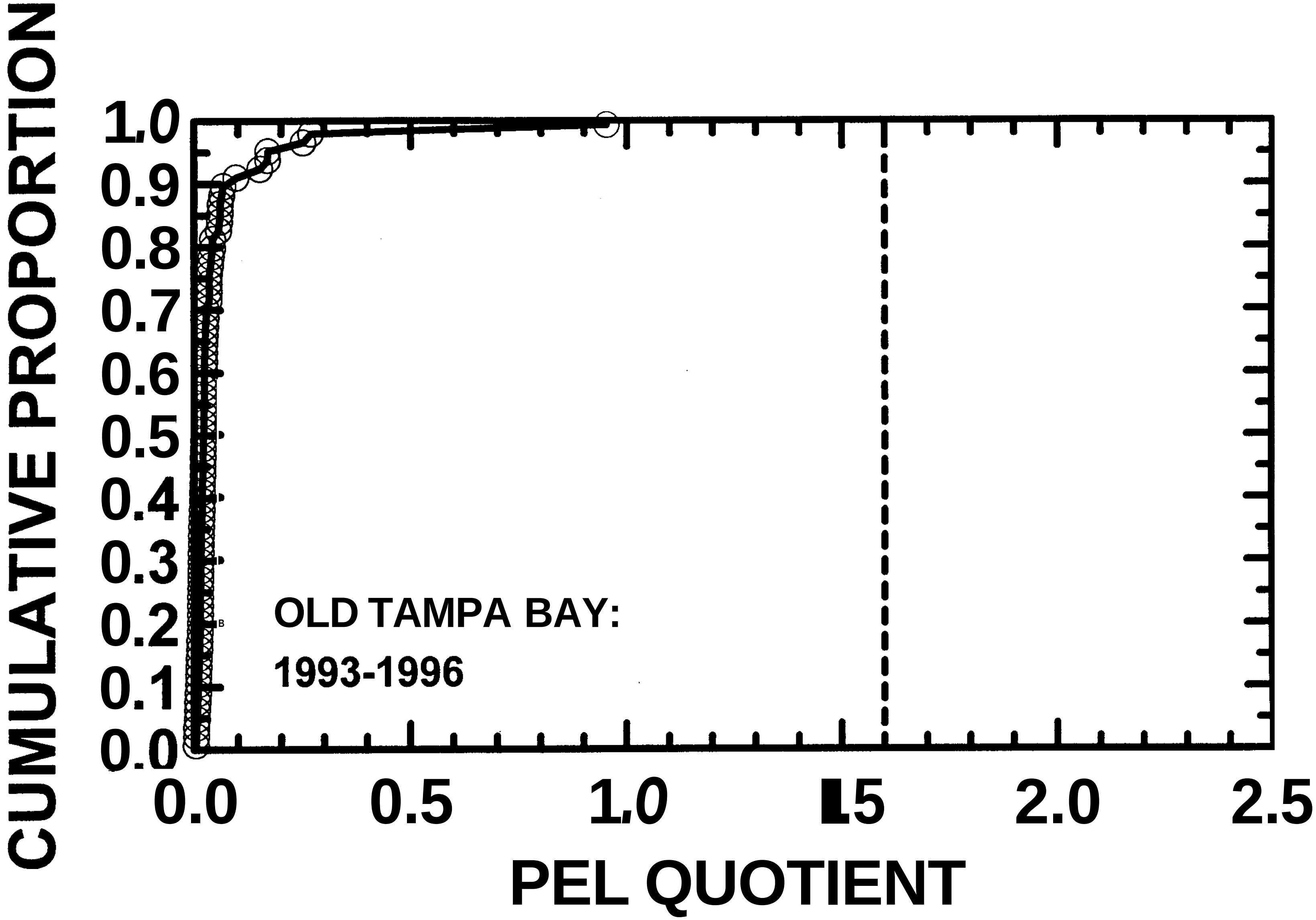


Figure 14. Cumulative proportion of the average PEL quotient for trace metals in the Old Tampa Bay segment, 1993-1996. Vertical line demarcates the threshold above which toxic effects are likely.

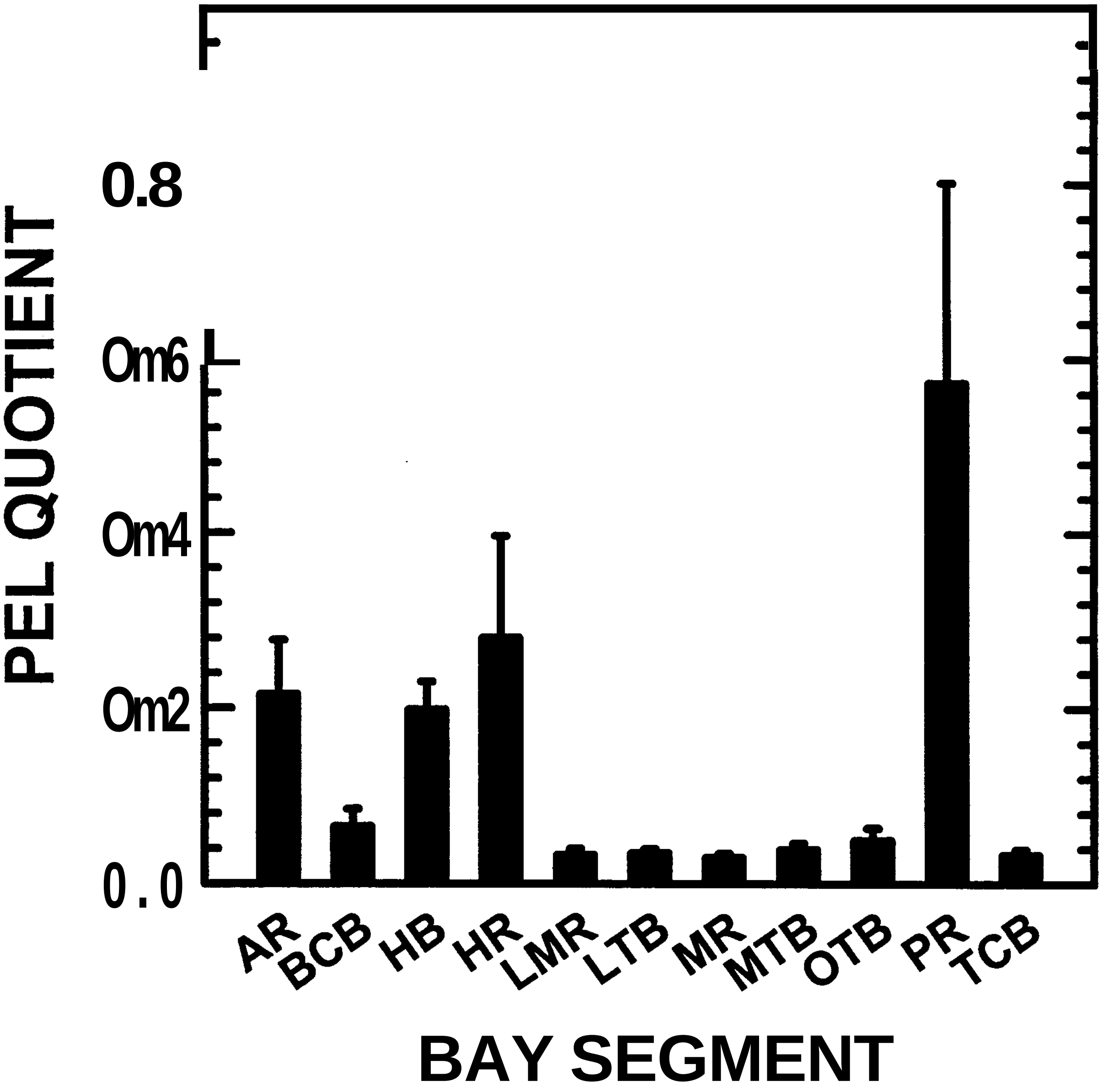


Figure 15. Mean (and standard error) of the PEL quotient for metals, by bay segment. Tampa Bay, 1993-1996.

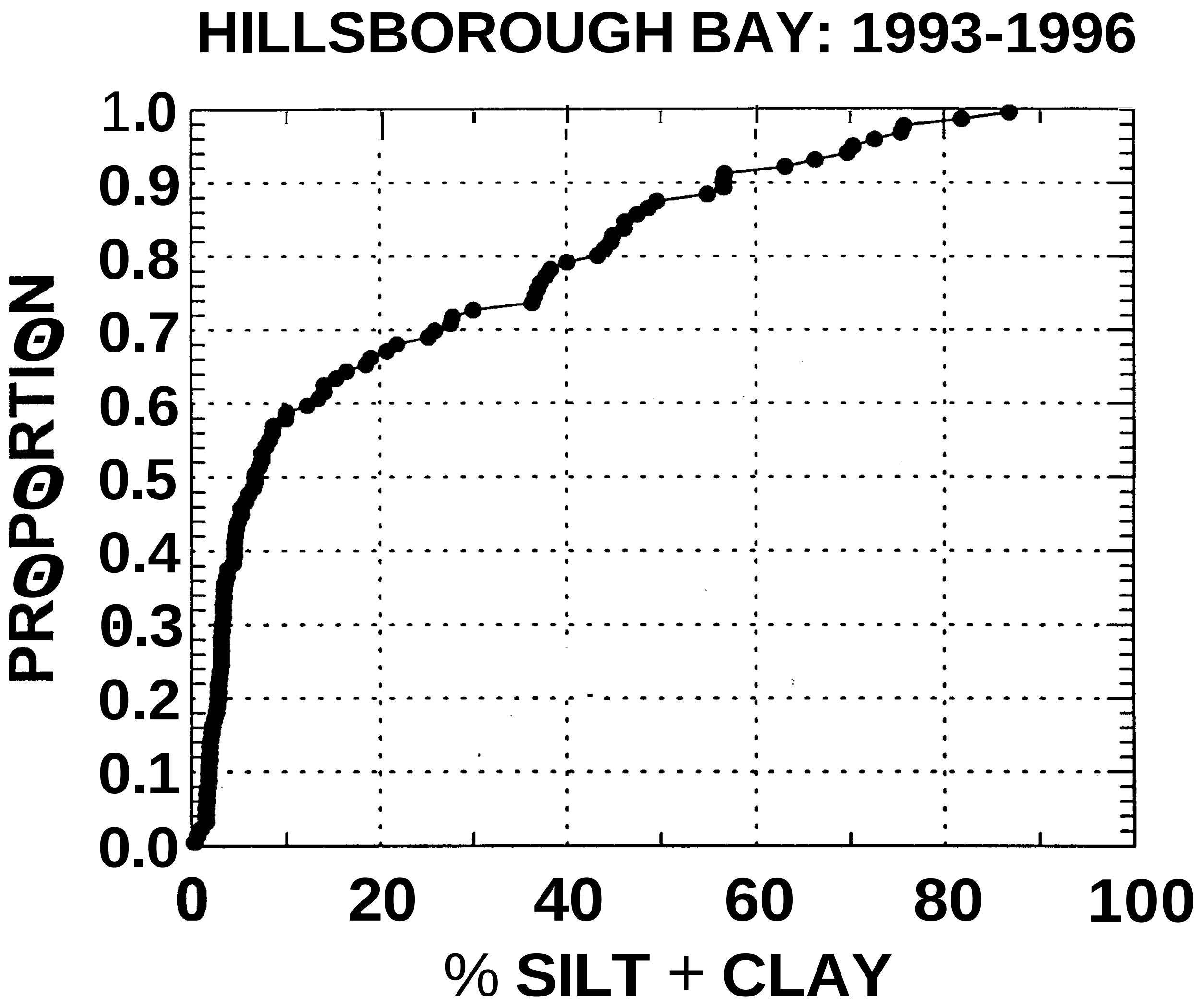


Figure 16. Cumulative proportion of the % Silt+Clay in Hillsborough Bay sediments, 1993-1996.

HILLSBOROUGH BAY: 1993-1996

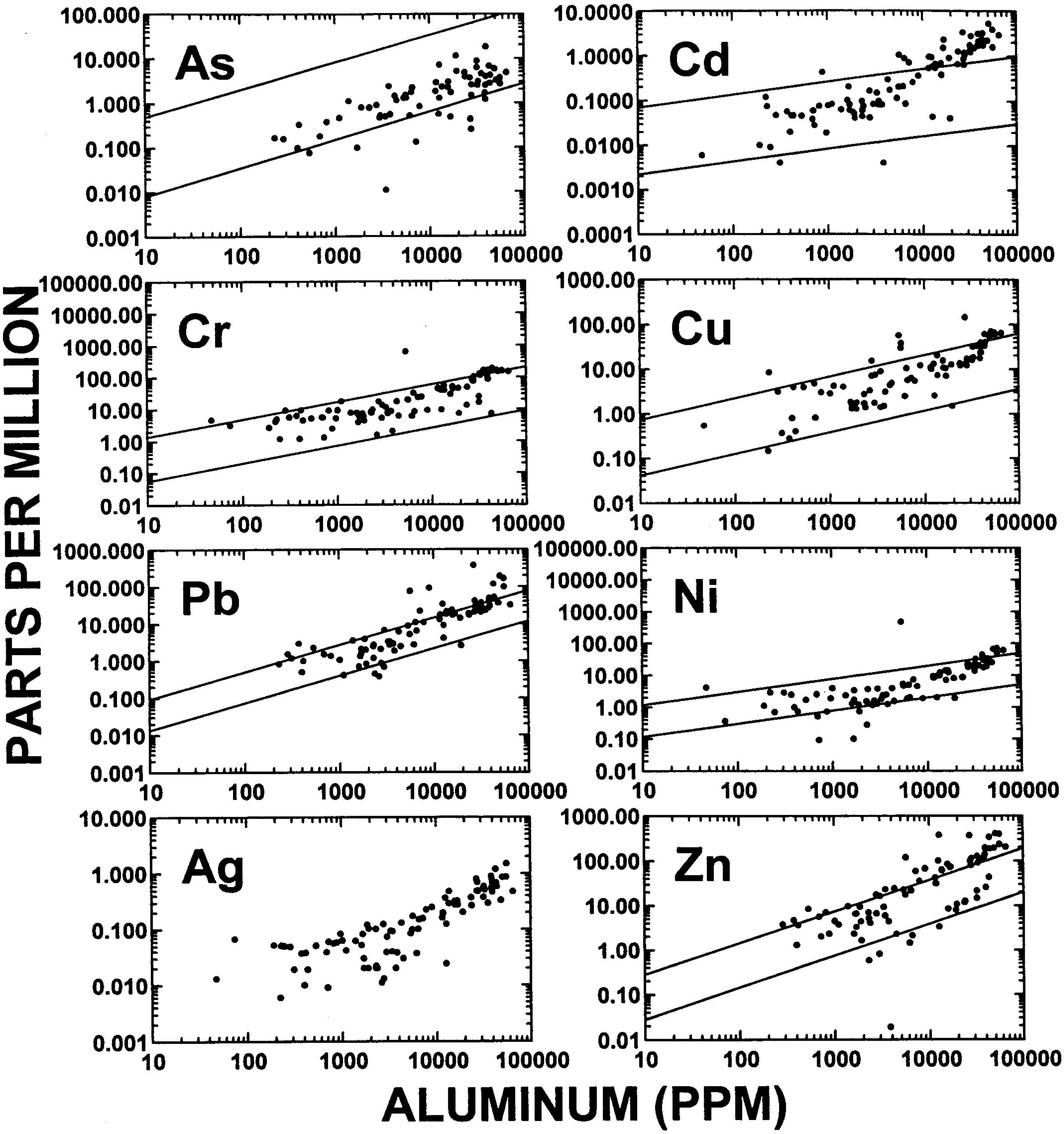


Figure 17. Trace metal concentrations vs. aluminum. Hillsborough Bay segment, 1993-1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error.

Table 3. Summary of mean trace metal concentrations (ppm): By bay segment. Tampa Bay, 1993-1996.

A. Mean Concentration by Bay Segment

	AG	AS	CD	CR	CU	NI	PB	ZN
OTB	0.07	1.00	0.12	14.57	3.11	3.64	6.27	8.42
HB	0.24	1.81	0.74	45.54	14.55	15.64	22.64	57.45
HR	0.15	1.60	0.87	23.06	40.45	6.40	90.21	118.46
PR	0.48	1.95	2.74	101.31	38.10	34.81	96.32	257.60
AR	0.24	1.21	1.85	53.42	14.74	11.54	16.34	64.29
MTB	0.05	1.37	0.12	9.41	3.13	2.52	3.24	7.57
LMR	0.04	0.26	0.07	7.25	10.47	1.12	0.92	10.96
LTB	0.04	2.04	0.11	8.02	5.13	1.77	2.38	3.98
BCB	0.05	1.26	0.19	15.02	21.25	2.01	3.48	15.48
TCB	0.04	2.18	0.12	8.34	6.38	0.96	1.10	4.88
MR	0.06	0.28	0.06	4.28	8.23	0.98	1.68	12.18

OTB= Old Tampa Bay
HB= Hillsborough Bay
HR= Hillsborough River (1995-1996)
PR= Palm River (1995-1996)
AR= Alafia River (1995-1996)
MTB= Middle Tampa Bay
LMR= Little Manatee River (1995-1996)
LTB= Lower Tampa Bay
BCB= Boca Ciega Bay (1996)
TCB= Terra Ceia Bay (1996)
MR= Manatee River (1996)

B. ANOVA Results

	F	df	Bonferroni test results
Arsenic	3.9**	6,385	TCB LTB HB MTB BCB OTB MR
Cadmium	17.6***	6,385	HB > BCB TCB OTB MTB LTB MR
Chromium	10.7***	6,382	HB > BCB OTB MTB TCB LTB MR
Copper	14.2***	6,382	HB BCB MR TCB LTB MTB OTB
Lead	14.5***	6,385	HB > OTB BCB MTB LTB MR TCB
Nickel	10.4***	6,382	HB > OTB MTB BCB LTB MR TCB
Silver	18.6***	6,385	HB > OTB MR MTB BCB LTB TCB
Zinc	15.9***	6,385	HB BCB MR OTB MTB TCB LTB

** $p<.01$ *** $p<.001$

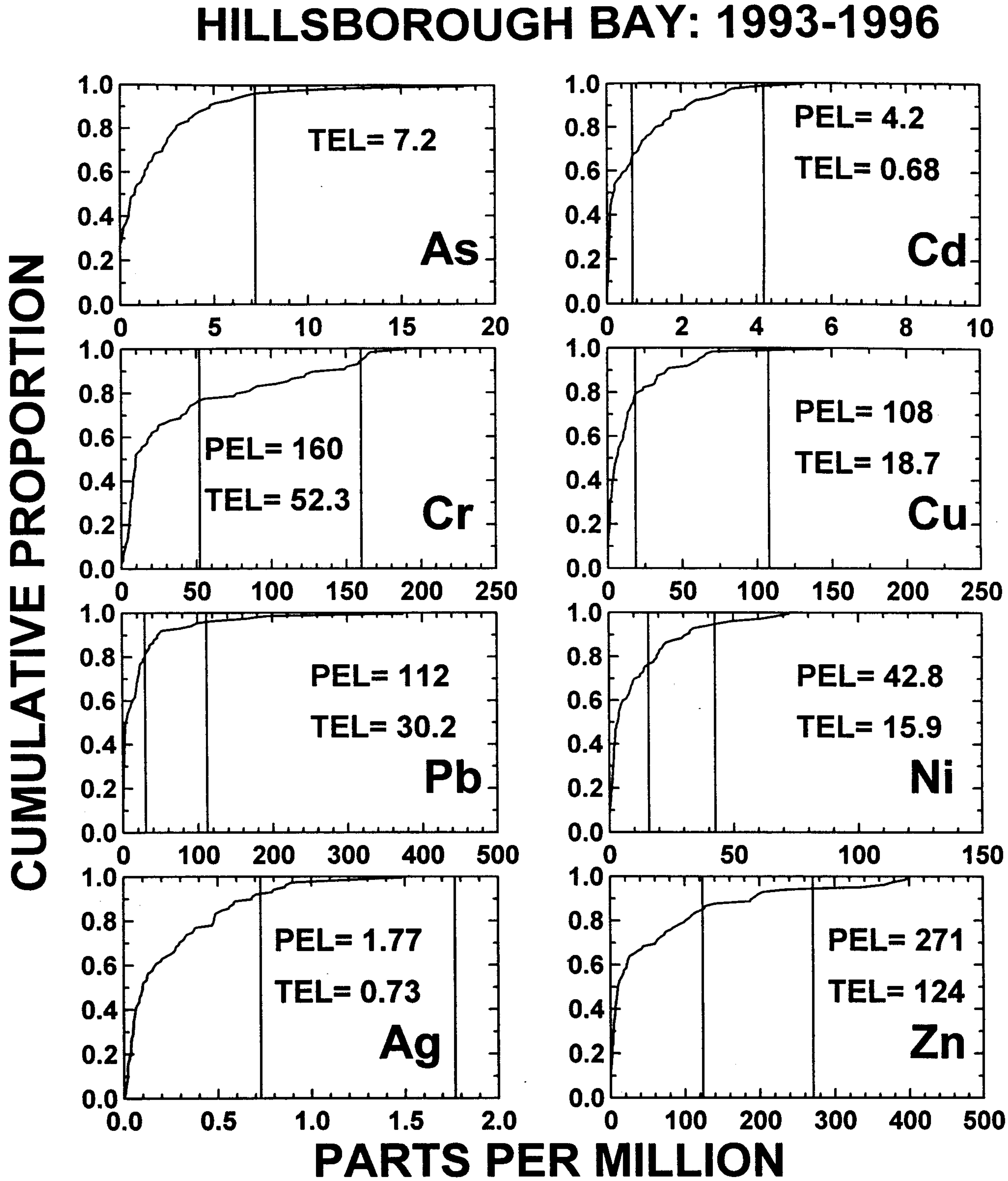


Figure 18. Cumulative proportions of trace metals in the Hillsborough Bay segment, 1993-1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely.

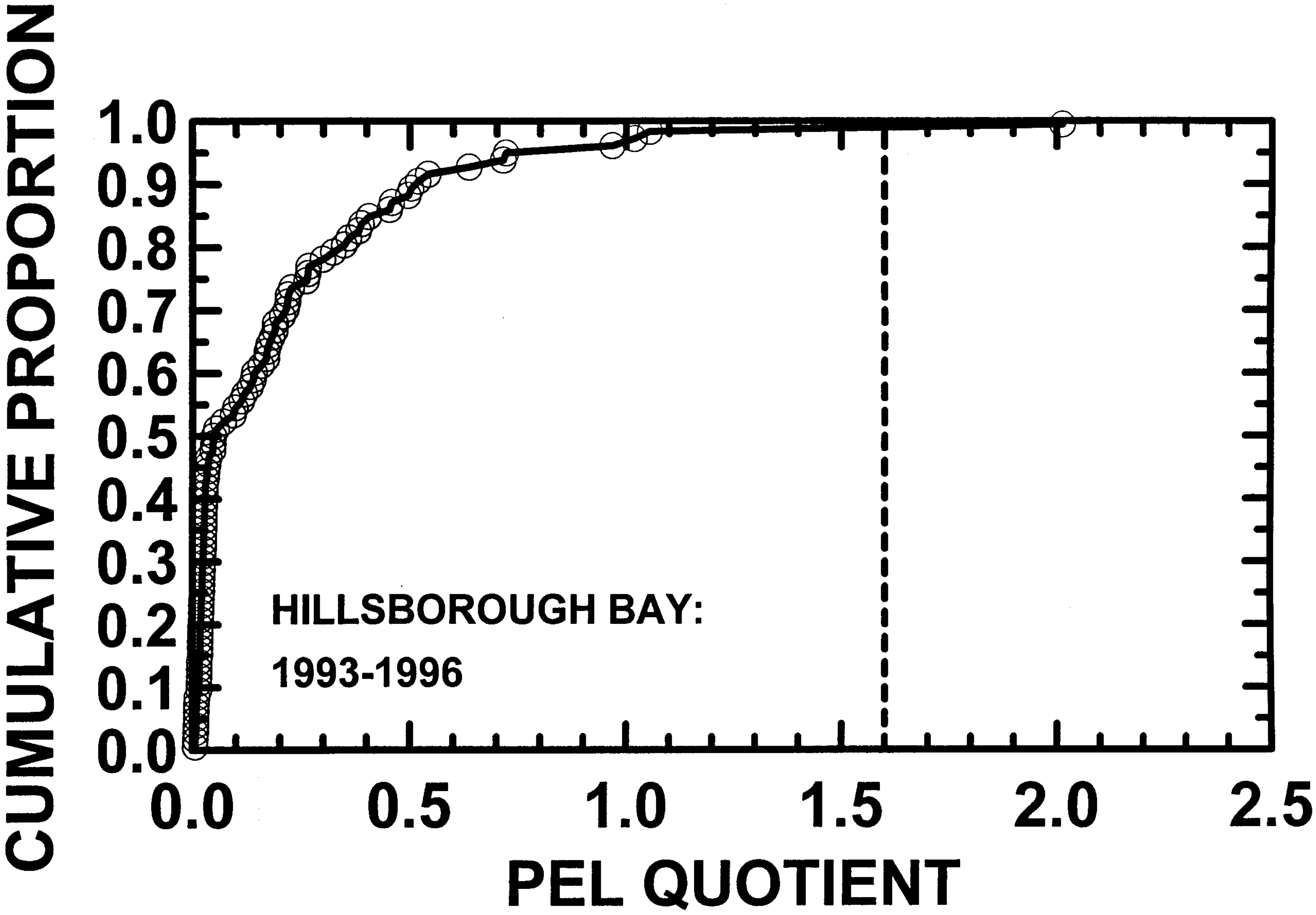


Figure 19. Cumulative proportion of the average PEL quotient for trace metals in the Hillsborough Bay segment, 1993-1996. Vertical line demarcates the threshold above which toxic effects are likely.

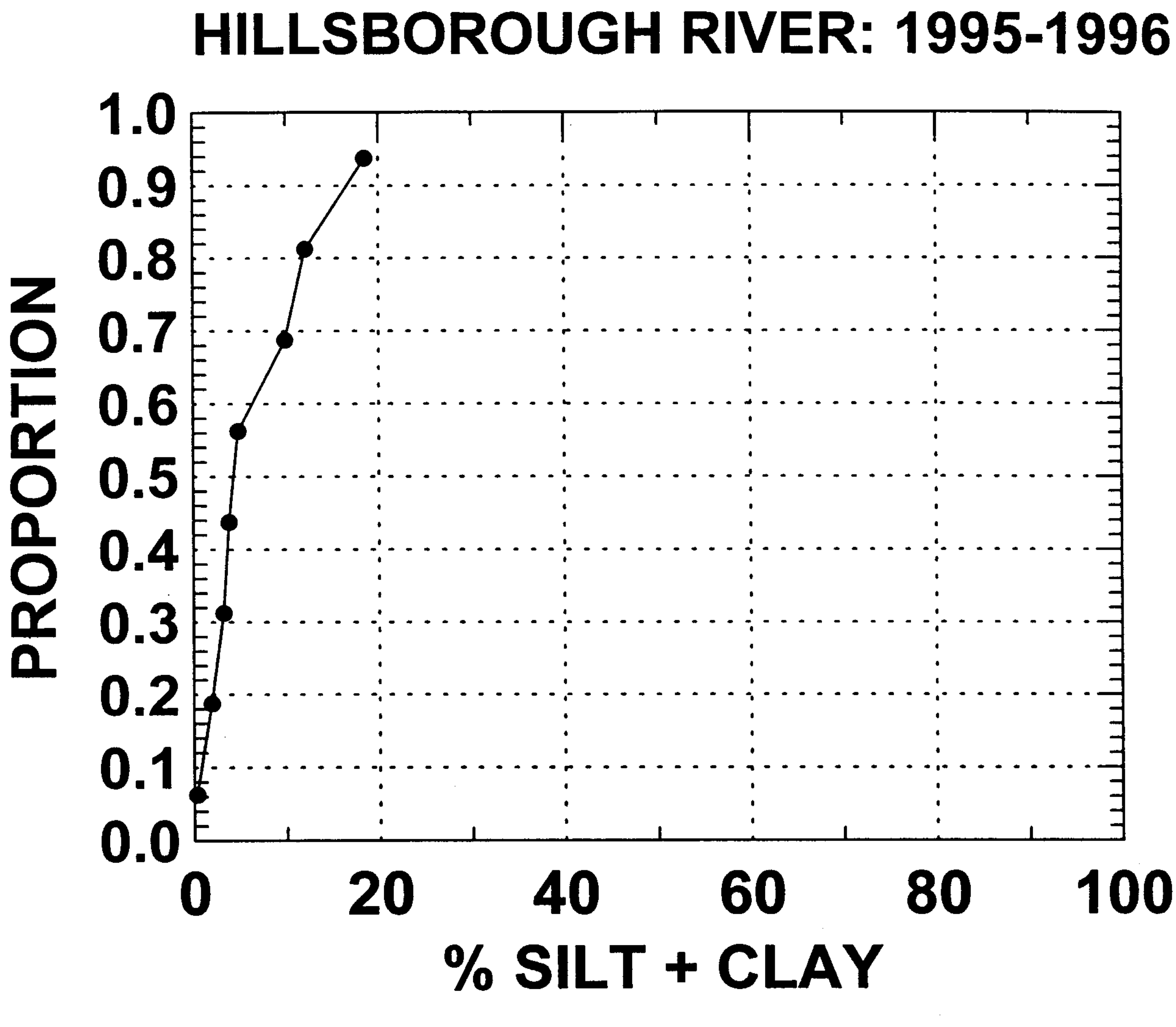


Figure 20. Cumulative proportion of the % Silt+Clay in Hillsborough River sediments, 1995-1996.

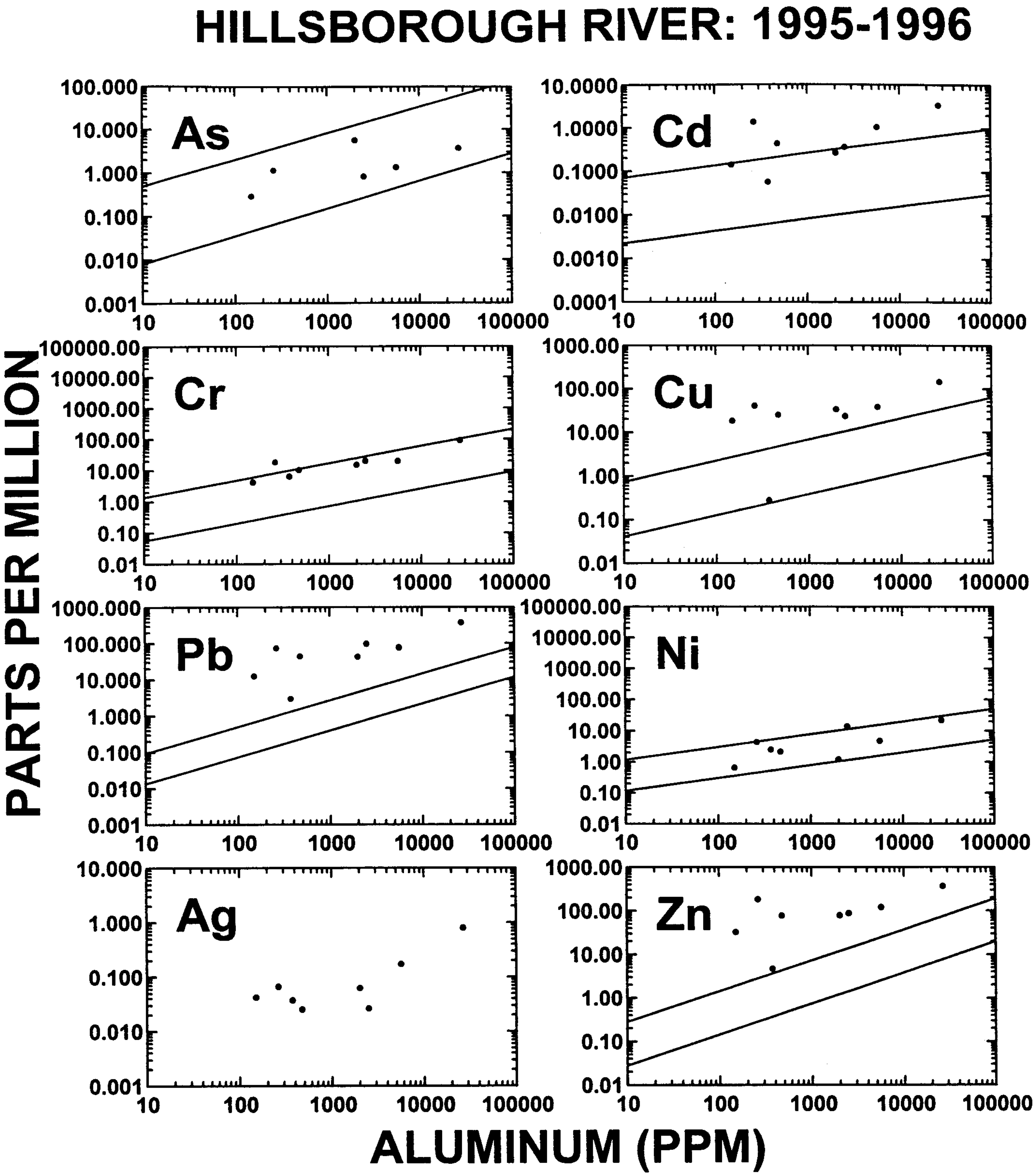


Figure 21. Trace metal concentrations vs. aluminum. Hillsborough River, 1995-1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error.

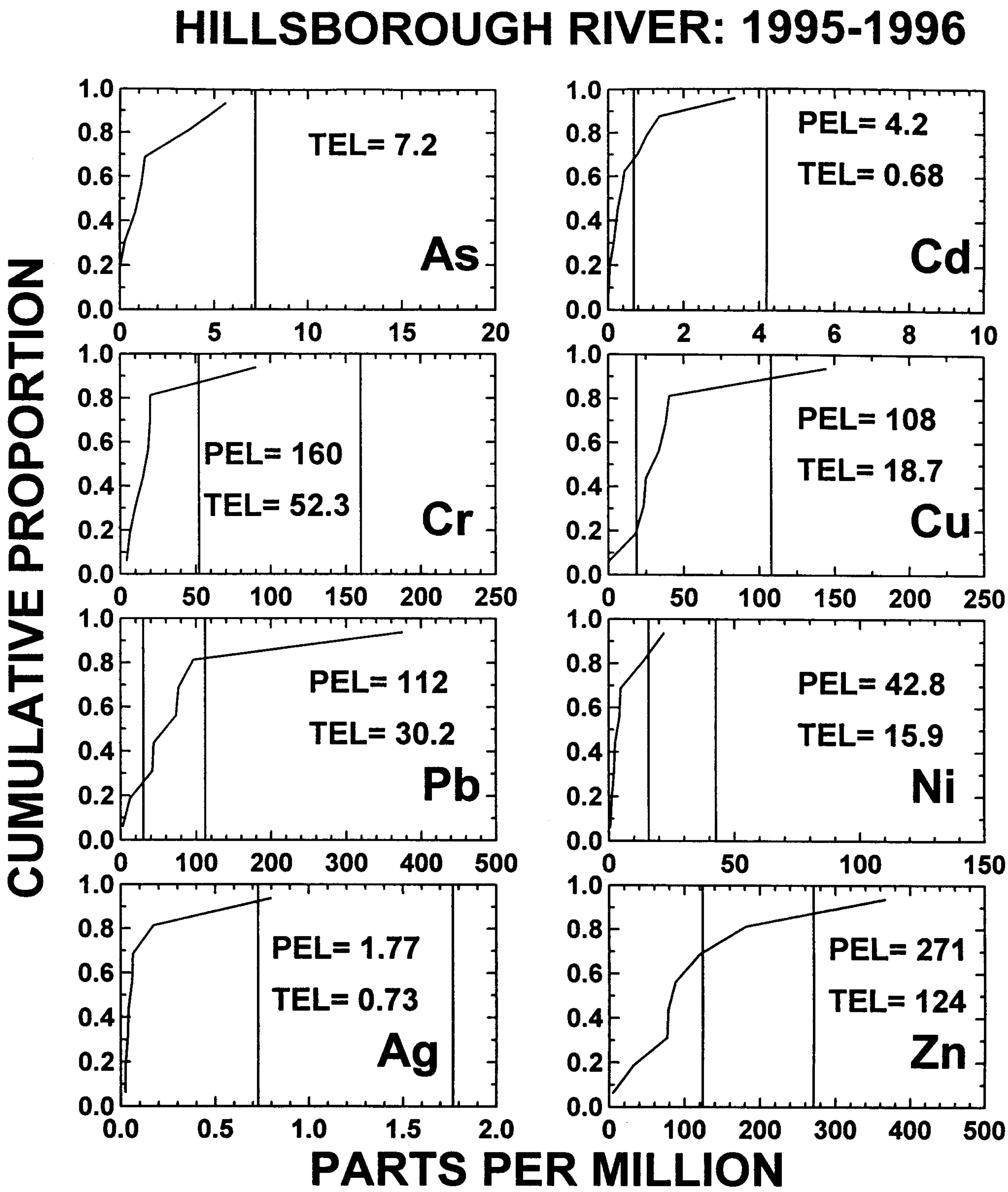


Figure 22. Cumulative proportions of trace metals in the Hillsborough River, 1995-1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely.

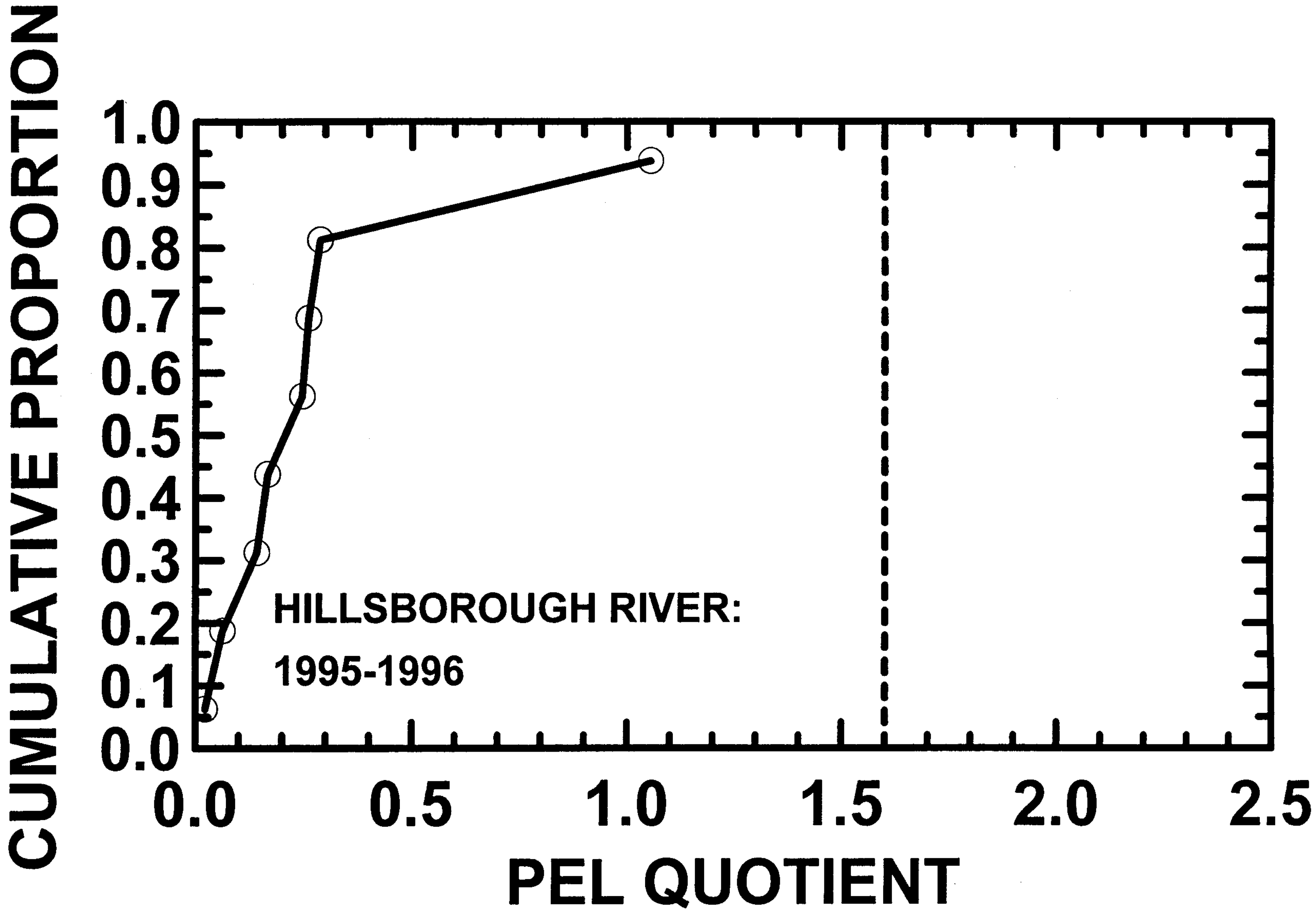


Figure 23. Cumulative proportion of the average PEL quotient for trace metals in the Hillsborough River, 1995-1996. Vertical line demarcates the threshold above which toxic effects are likely.

was < 10% in the remaining three (Figure 24). Meta1:aluminum ratio data are shown in Figure 25. Arsenic was the only metal which did not exceed either a TEL or a PEL (Figure 26). The Palm River, albeit with a very small database, had the highest overall mean PEL quotient for metals (Figure 15) although no sample had a quotient much higher than 1.0.

III.2.2.3 <u>Alafia River</u>. Eleven samples were analyzed for trace metals during 1995-1996. One-third of the sediments had a silt+clay content >=20% (Figure 28). More than 70% of the samples showed evidence of enrichment by cadmium and zinc (Figure 29); enrichment by other metals was infrequent. At least half of the sites were "marginal" with respect to cadmium concentrations; a smaller percentage of the Alafia River was marginally contaminated by copper, chromium, lead, nickel and zinc (Figures 12 and 30). The PEL quotients for the Alafia River samples were all <0.5 (Figure 31), although the mean quotient was the third highest in the study area (Figure 15).

III.2.3. Middle Tampa Bay: The majority of Middle Tampa Bay had sediments of low (<5%) %SC (Figure 32), although there were several sites (e.g.,Apollo Beach canals) with >20% silt+clay. There was little evidence of anthropogenic enrichment of this bay segment by any of the metals (Figure 33). Marginally contaminated sediments constituted only a small fraction of Middle Tampa Bay (Figures 12 and 34) and only zinc ever exceeded the PEL (Figure 29). The PEL quotients for Middle Tampa Bay never exceeded 0.5 (Figure 35) and the mean quotient was <0.1 (Figure 15).

III.2.3.1 <u>Little Manatee River</u>. The silt+clay component of the Little Manatee River sediments ranged up to less than 10% (Figure 36). There was little evidence of enrichment (Figure 37) and no evidence of contamination (Figure 38). The PEL quotients for the Little Manatee River never exceeded 0.1 (Figure 39) and the mean quotient was <0.1 (Figure 15).

III.2.4. Lower Tampa Bay: The %SC of Lower Tampa Bay sediments was uniformly low (<l0%) (Figure 40). Anthropogenic enrichment by each of the metals occurred at only a small fraction of locations in Lower Tampa Bay (Figure 41). Less than 10% (9.5 mi^2 of Lower Tampa Bay was marginally contaminated by arsenic, cadmium, and

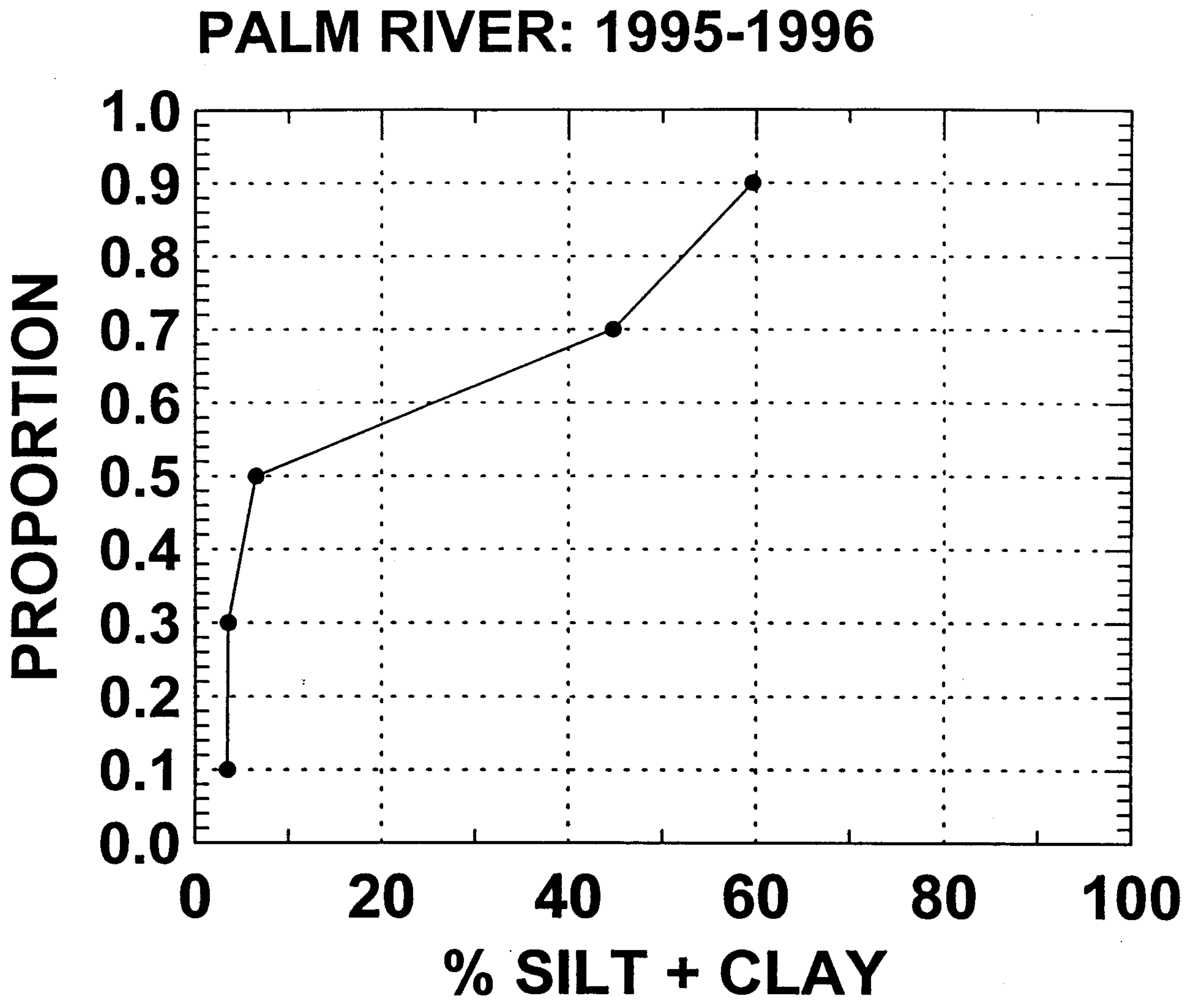


Figure 24. Cumulative proportion of the % Silt+Clay in Palm River sediments, 1995-1996.

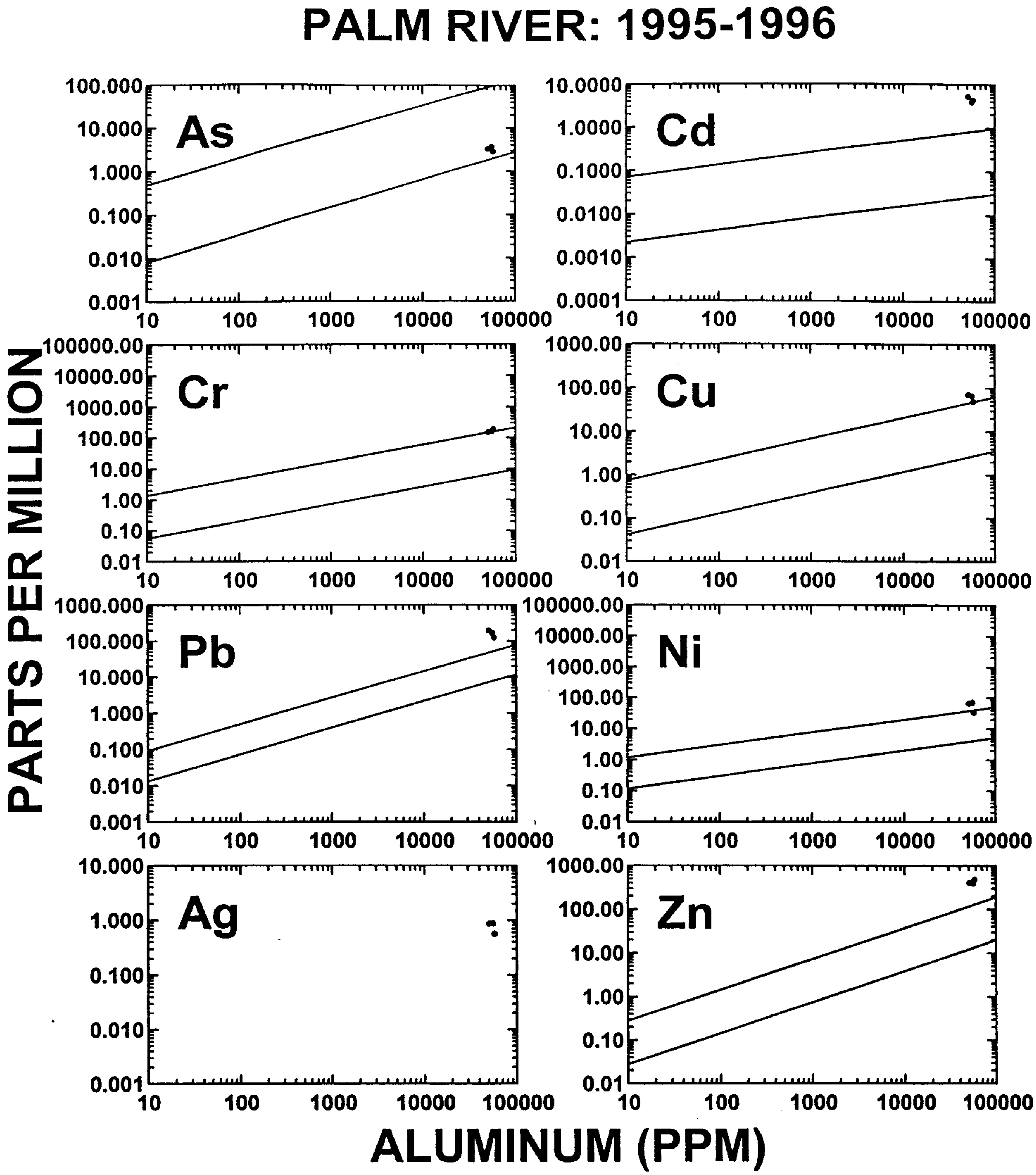


Figure 25. Trace metal concentrations vs. aluminum. Palm River, 1995-1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error.

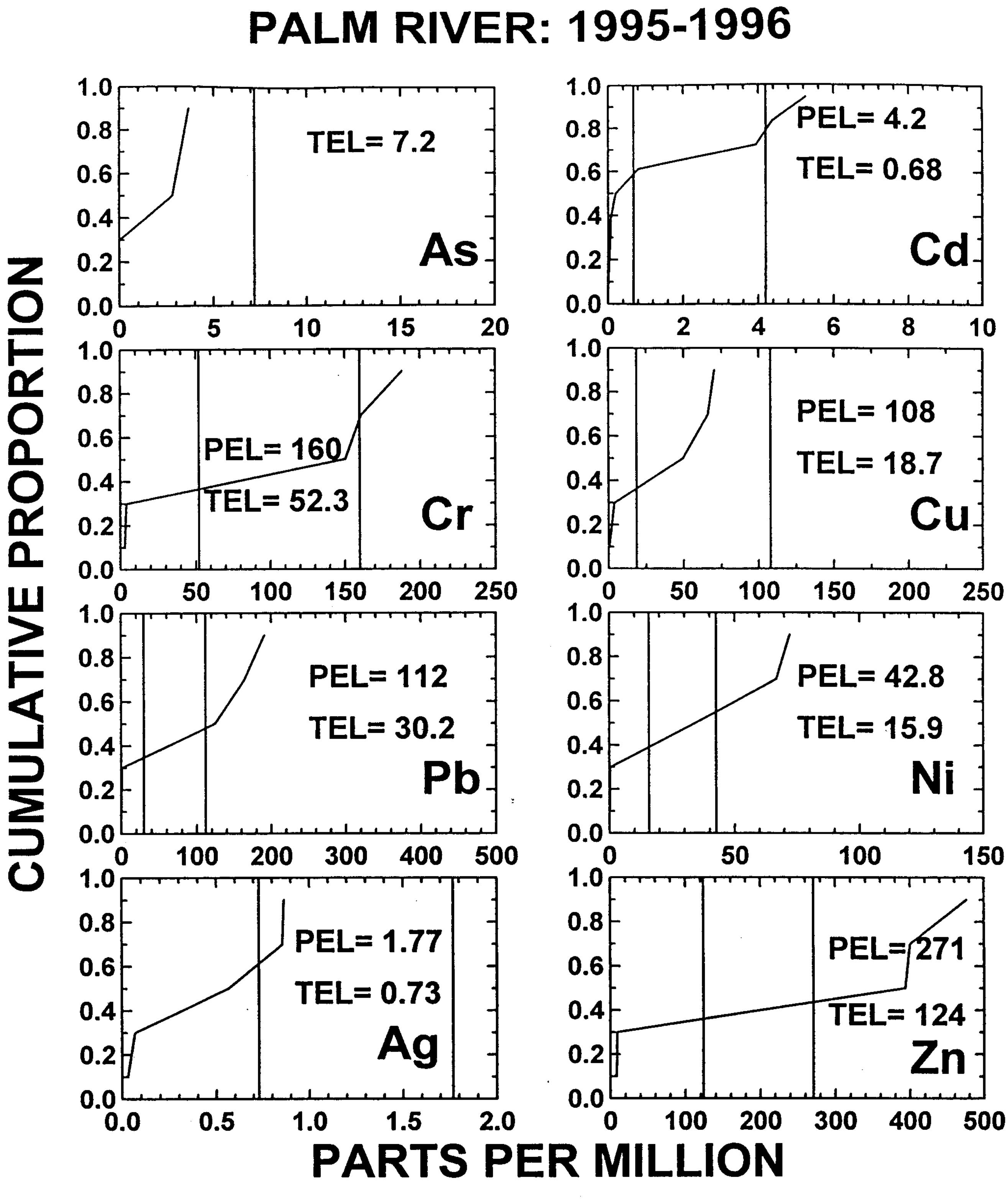


Figure 26. Cumulative proportions of trace metals in the Palm River, 1995-1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely.

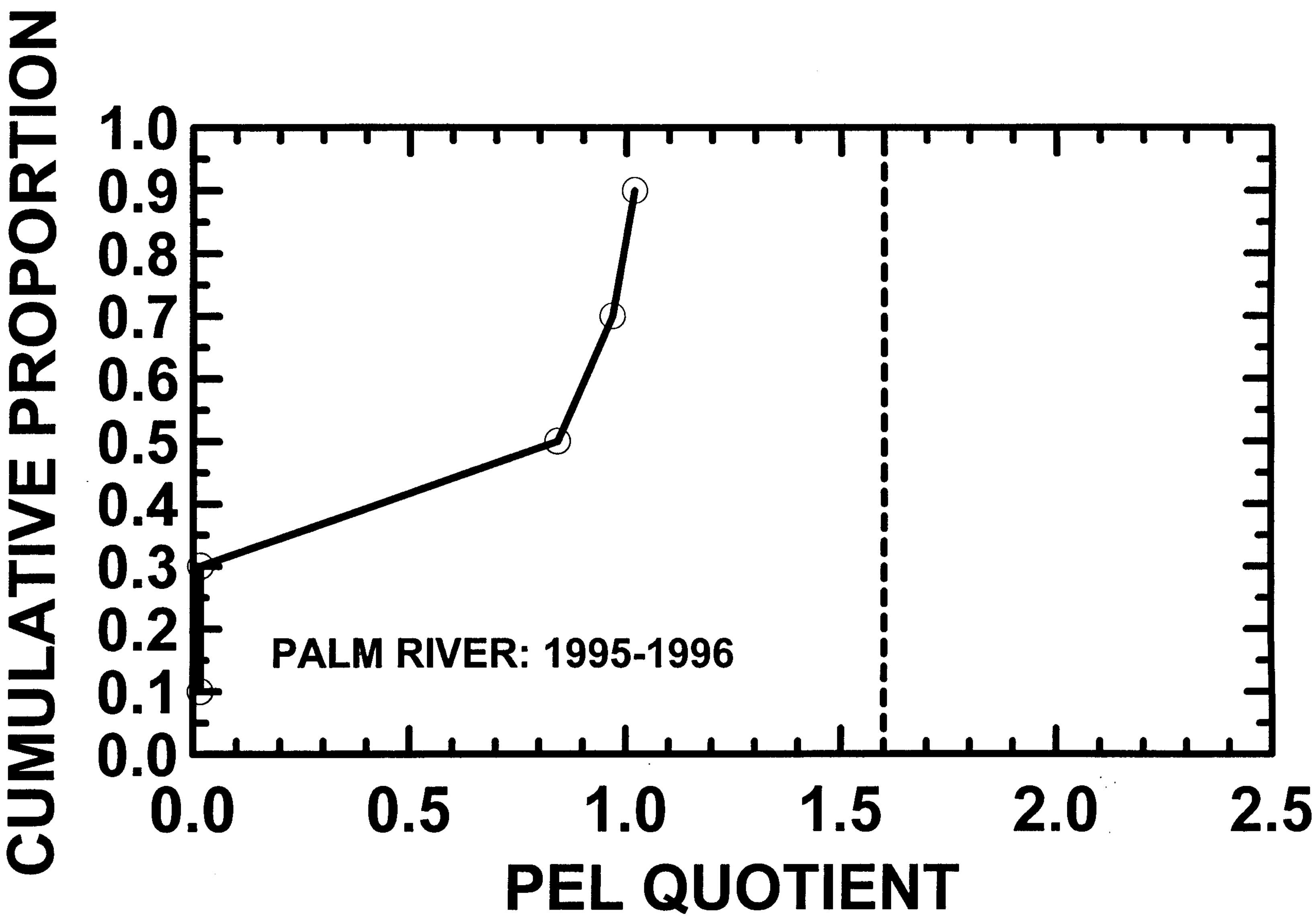


Figure 27. Cumulative proportion of the average PEL quotient for trace metals in the Palm River, 1995-1996. Vertical line demarcates the threshold above which toxic effects are likely.

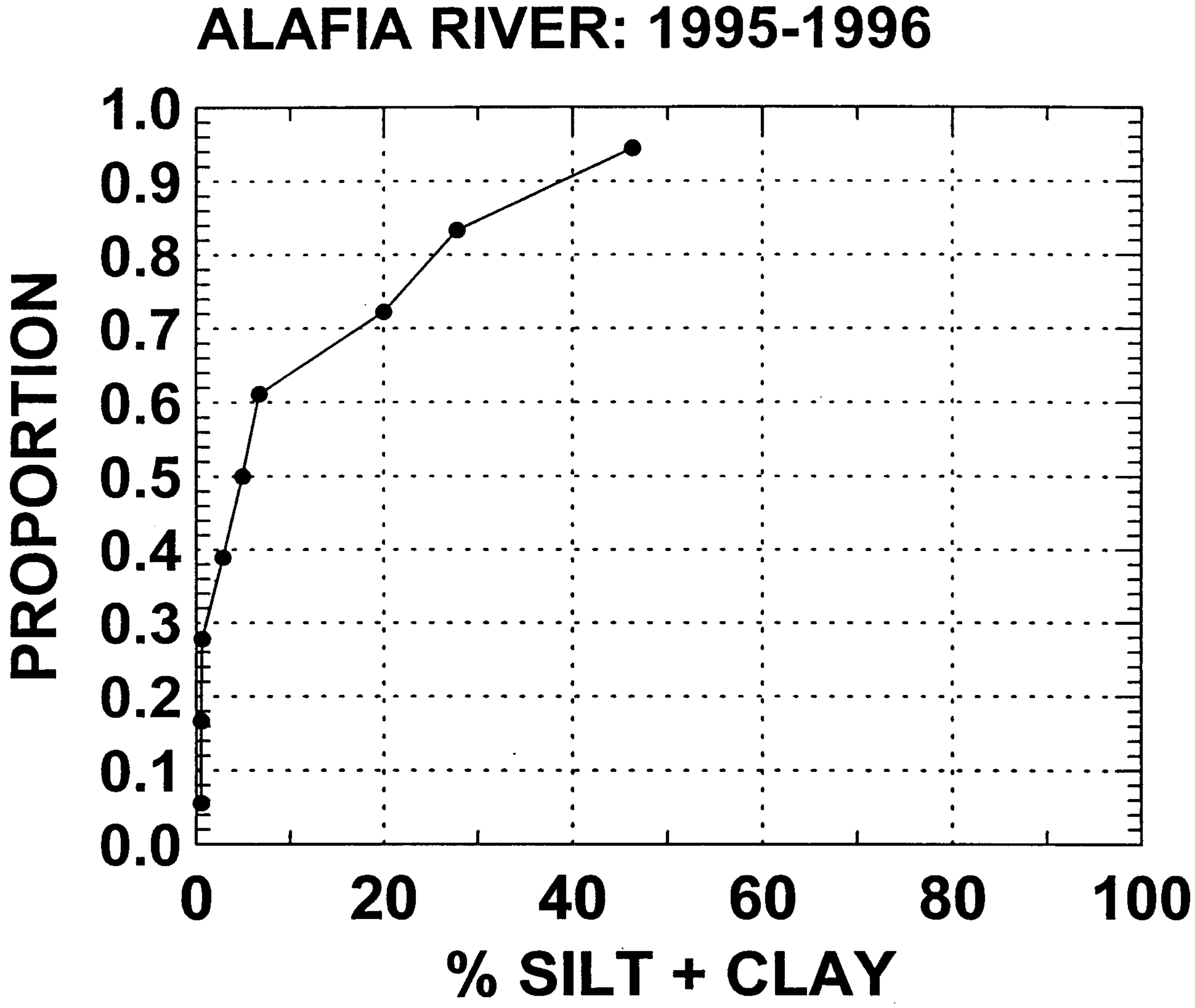


Figure 28. Cumulative proportion of the % Silt+Clay in Alafia River sediments, 1995-1996.

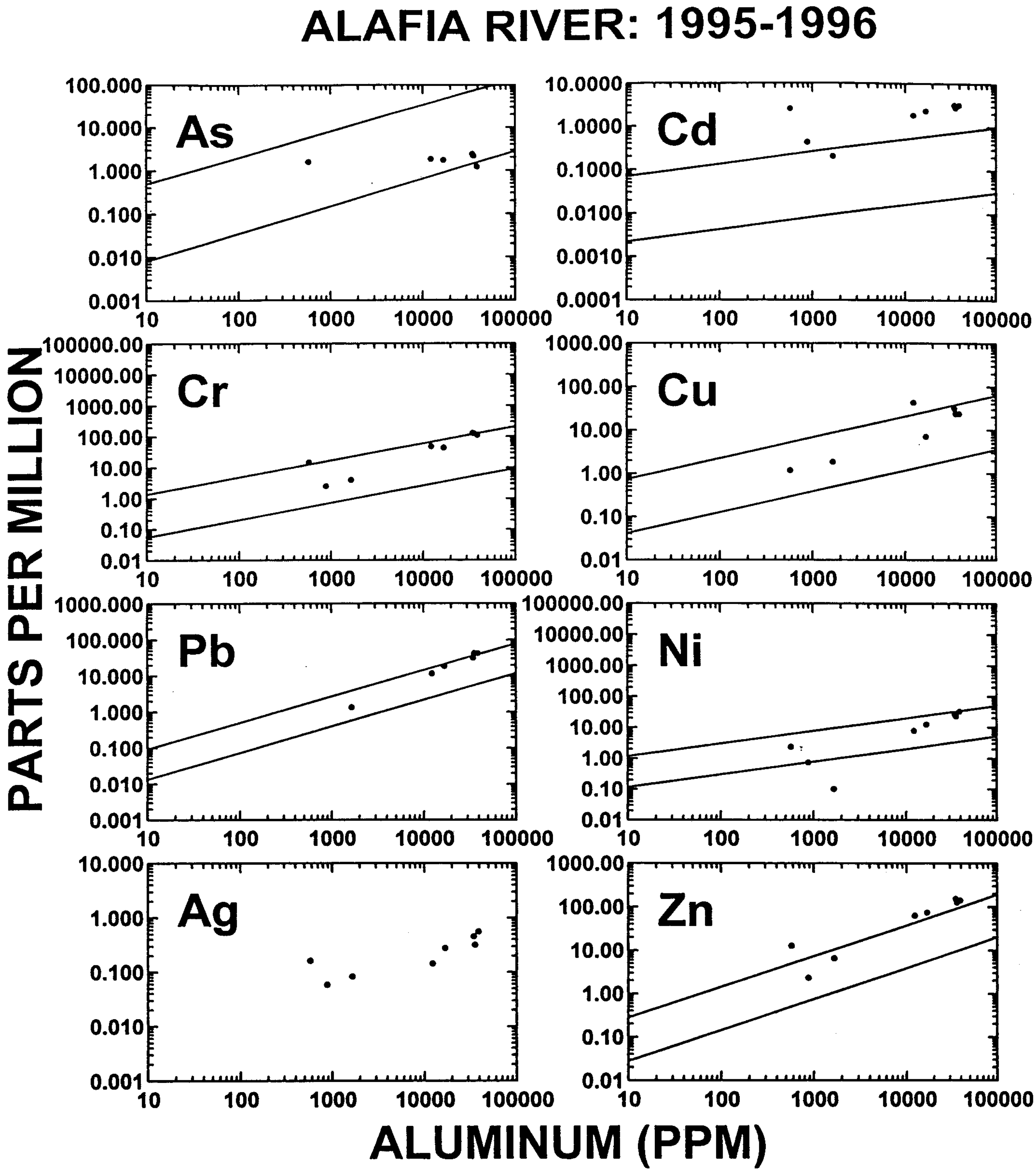


Figure 29. Trace metal concentrations vs. aluminum. Alafia River, 1995-1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error.

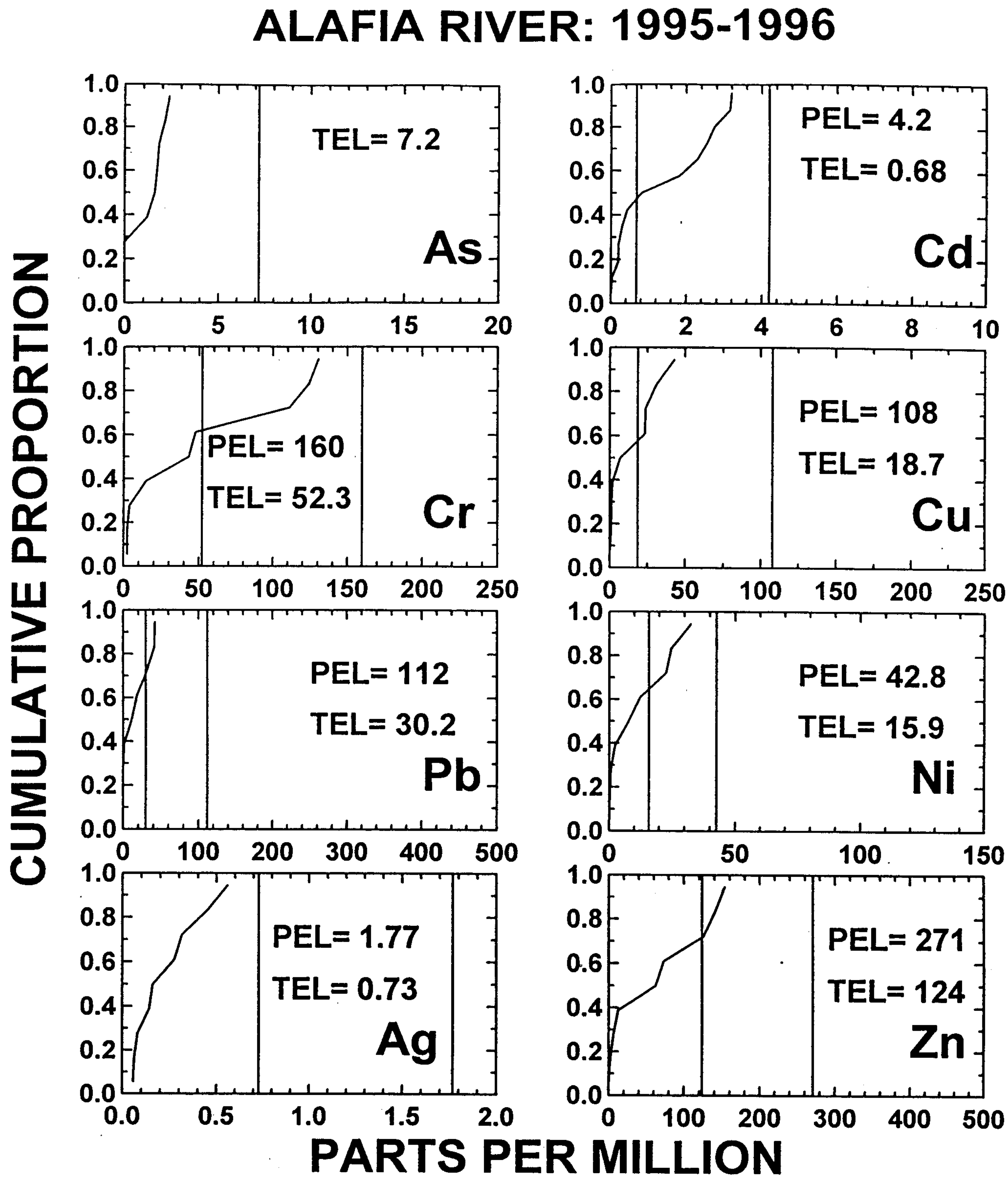


Figure 30. Cumulative proportions of trace metals in the Alafia River, 1995-1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely.

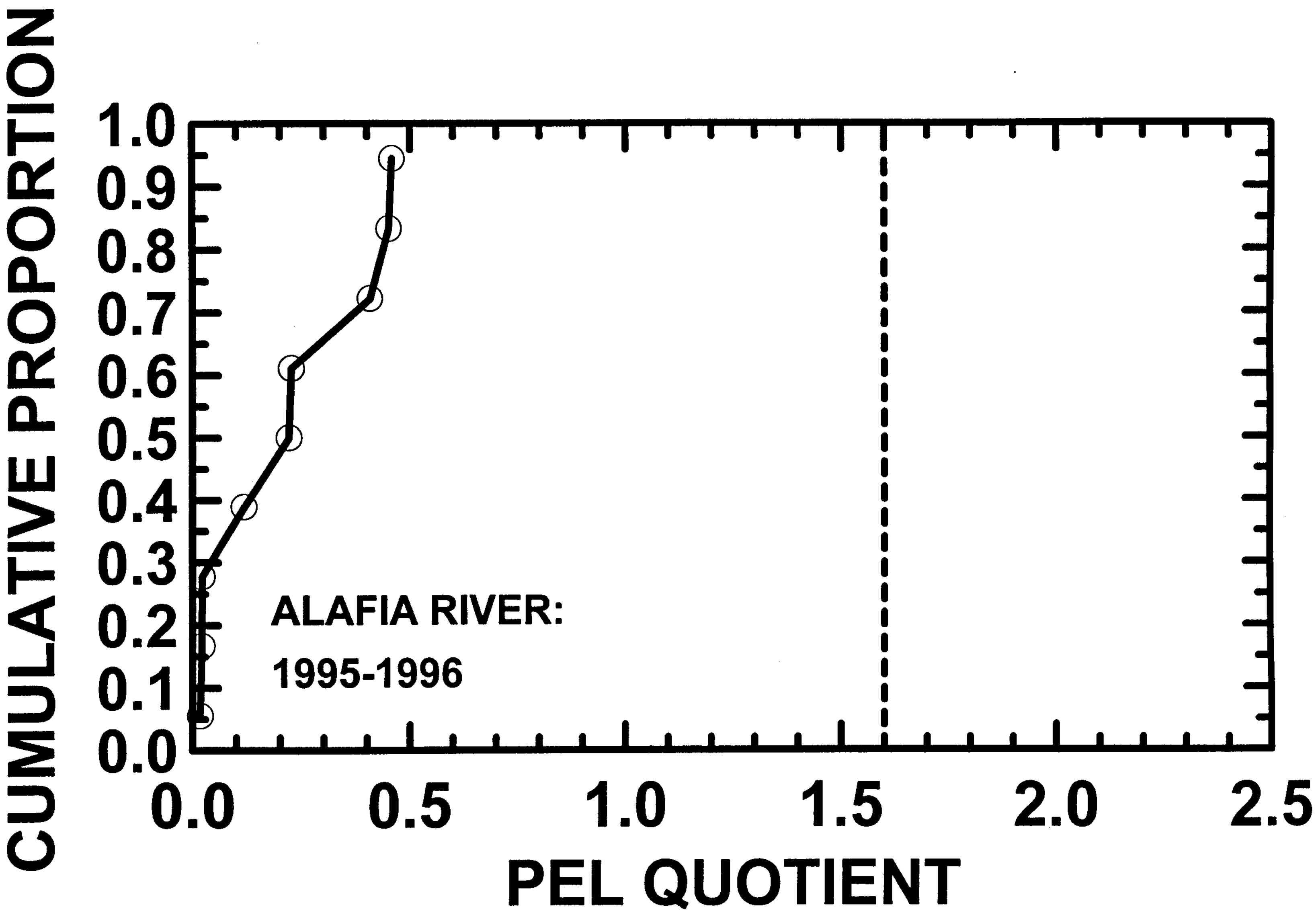


Figure 31. Cumulative proportion of the average PEL quotient for trace metals in the Alafia River, 1995-1996. Vertical line demarcates the threshold above which toxic effects are likely.

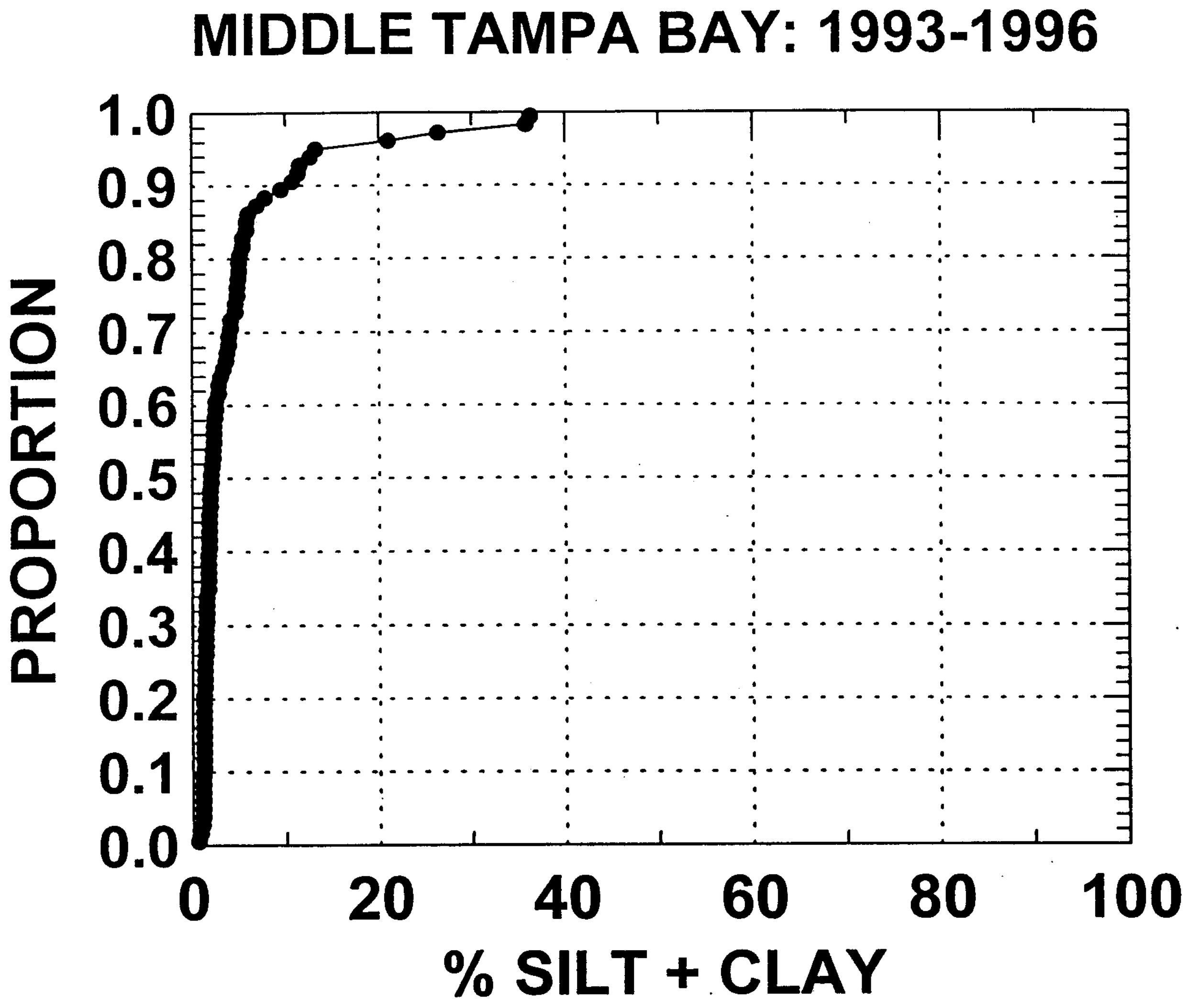


Figure 32. Cumulative proportion of the % Silt+Clay in Middle Tampa Bay sediments, 1993-1996.

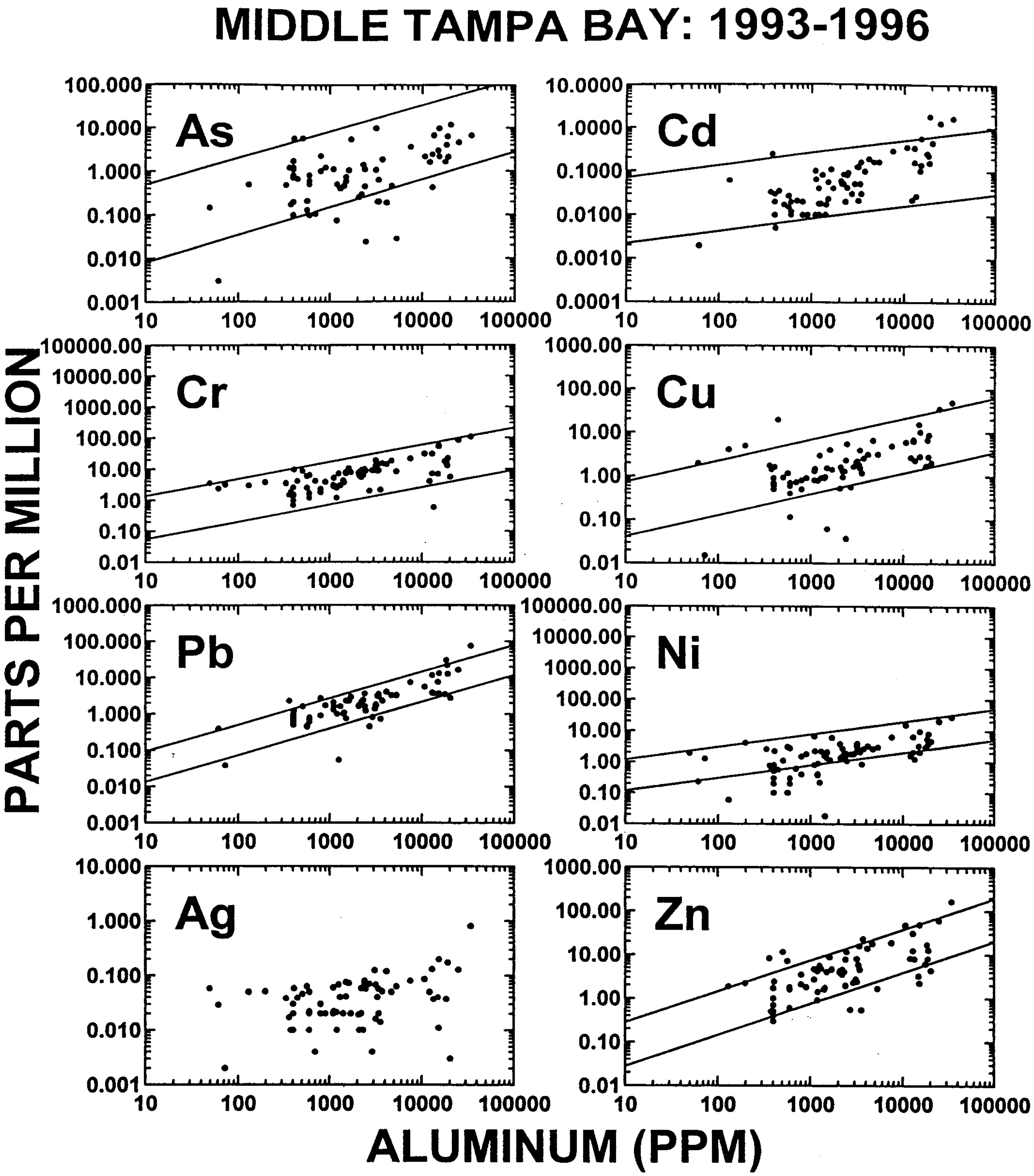


Figure 33. Trace metal concentrations vs. aluminum. Middle Tampa Bay, 1993-1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error.

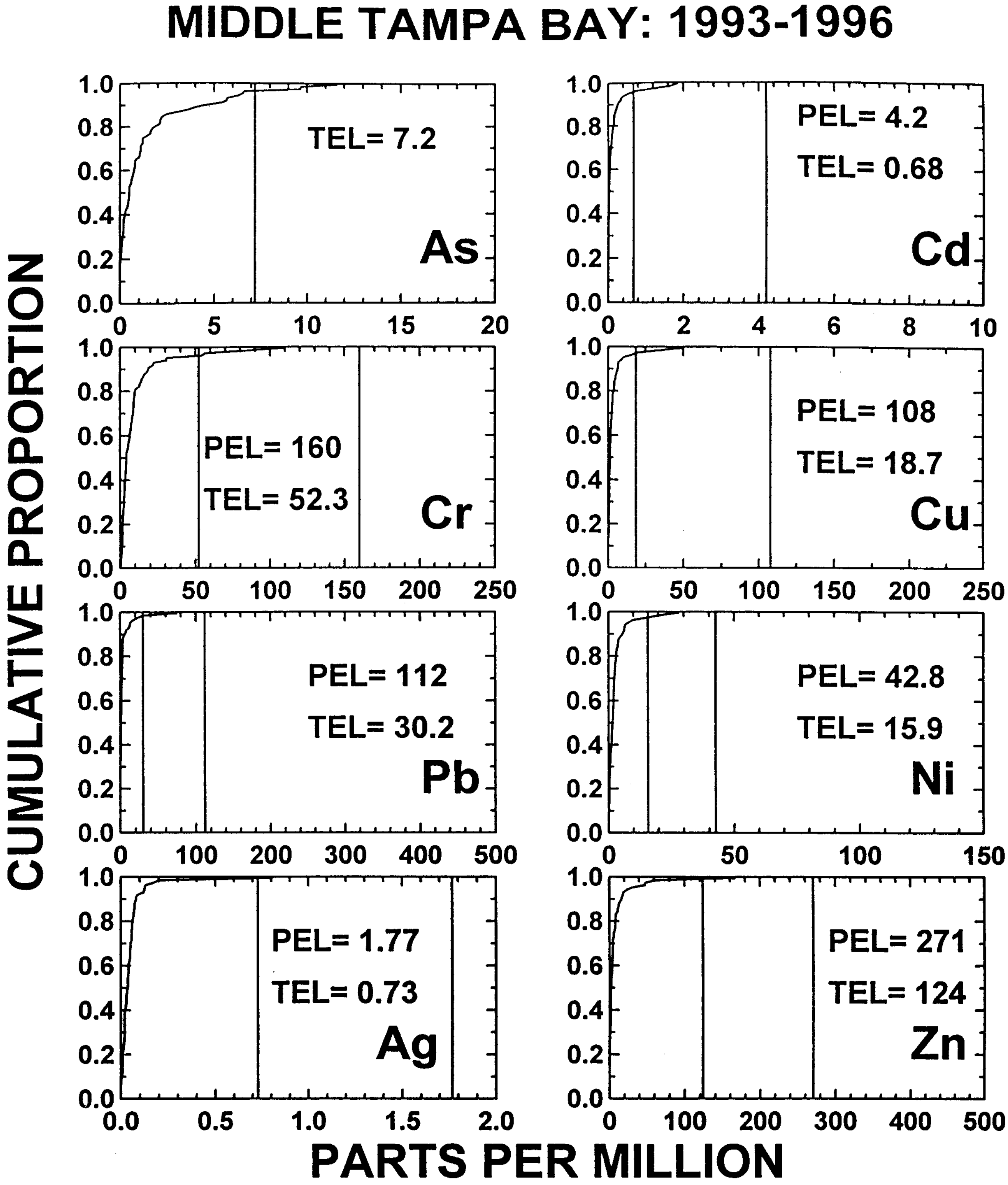


Figure 34. Cumulative proportions of trace metals in Middle Tampa Bay, 1993-1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely.

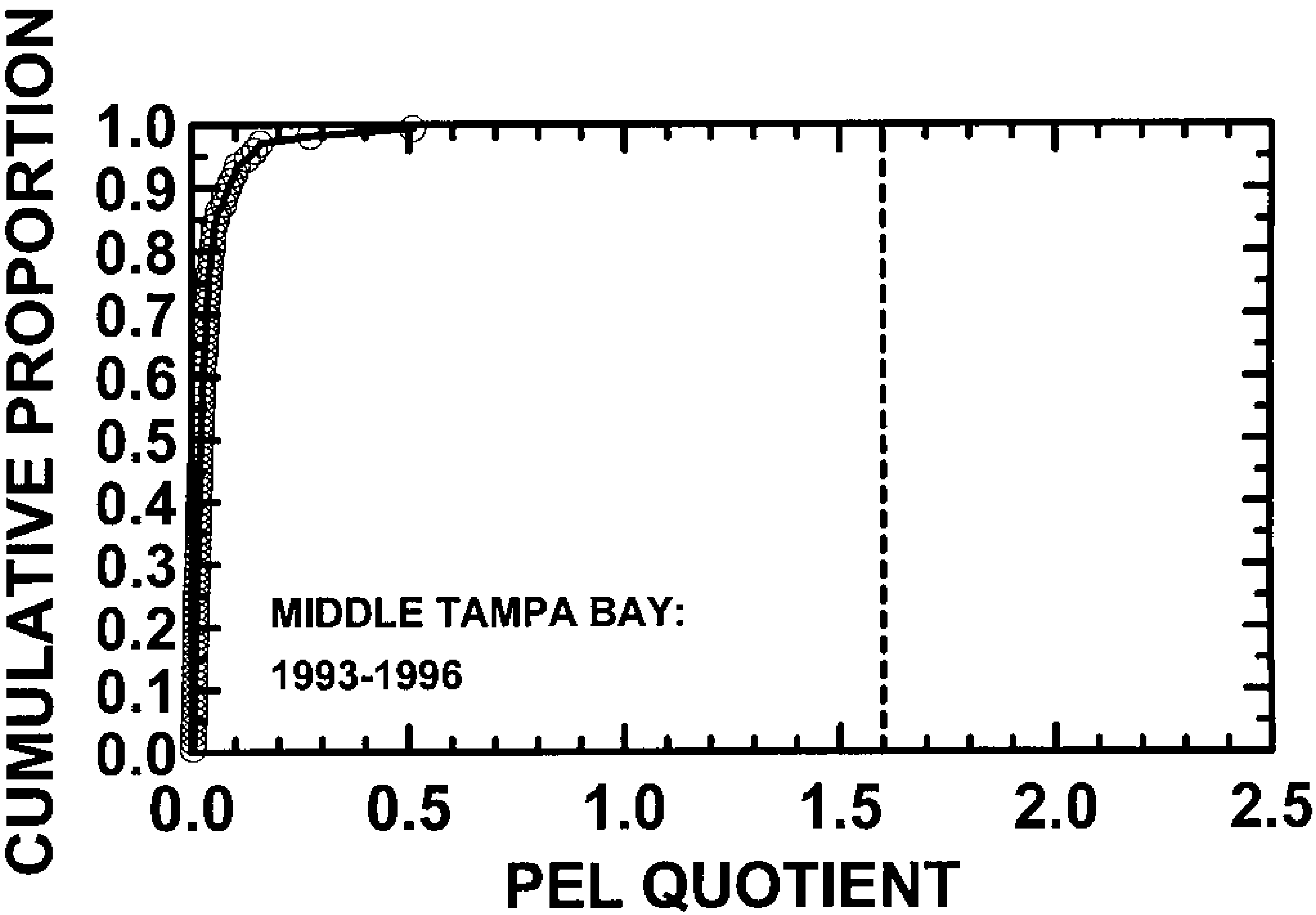


Figure 35. Cumulative proportion of the average PEL quotient for trace metals in the Middle Tampa Bay segment, 1993-1996. Vertical line demarcates the threshold above which toxic effects are likely.

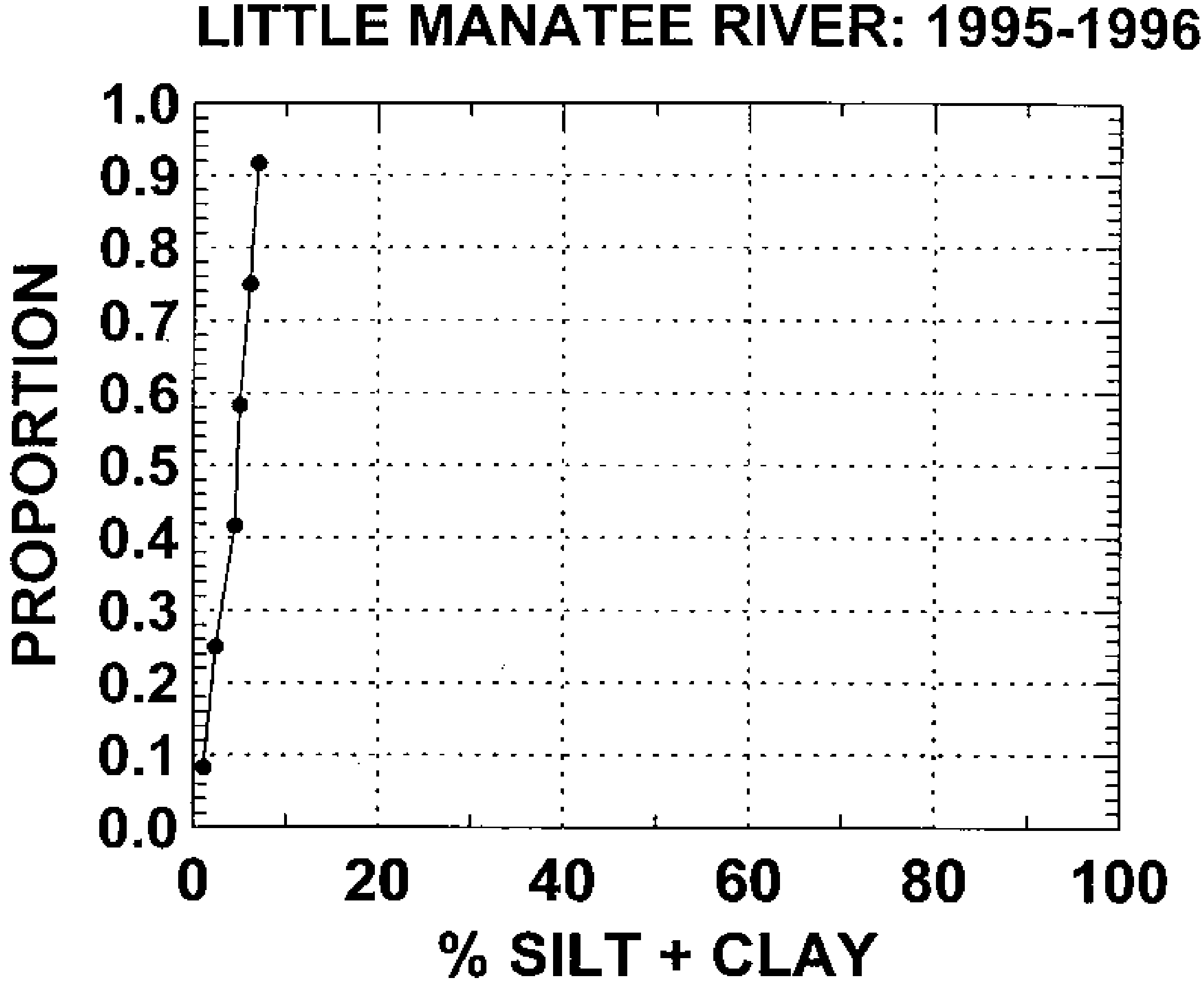


Figure 36. Cumulative proportion of the % Silt+Clay in Little Manatee River sediments, 1995-1996.

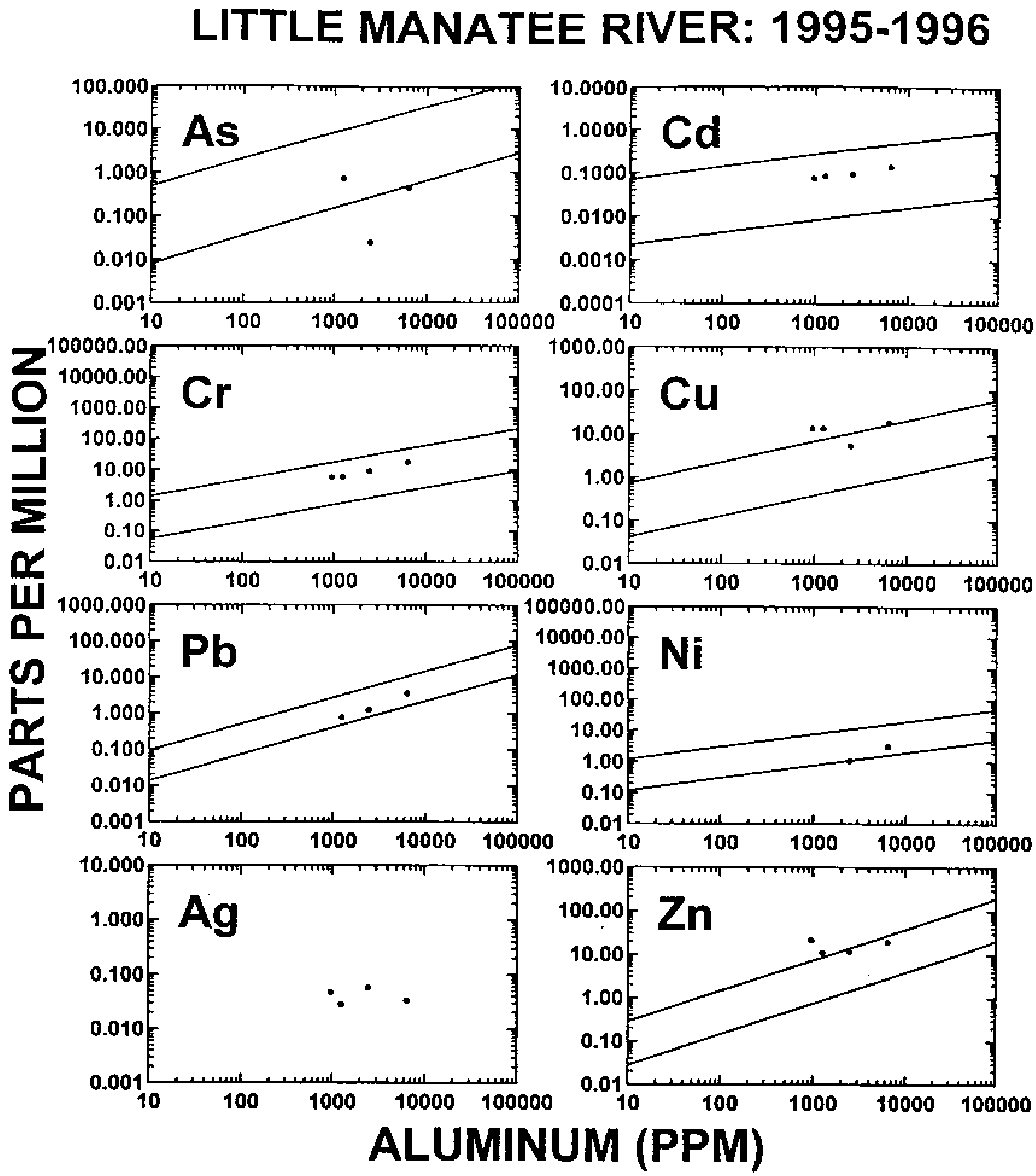


Figure 37. Trace metal concentrations vs. aluminum. Little Manatee River, 1995-1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error.

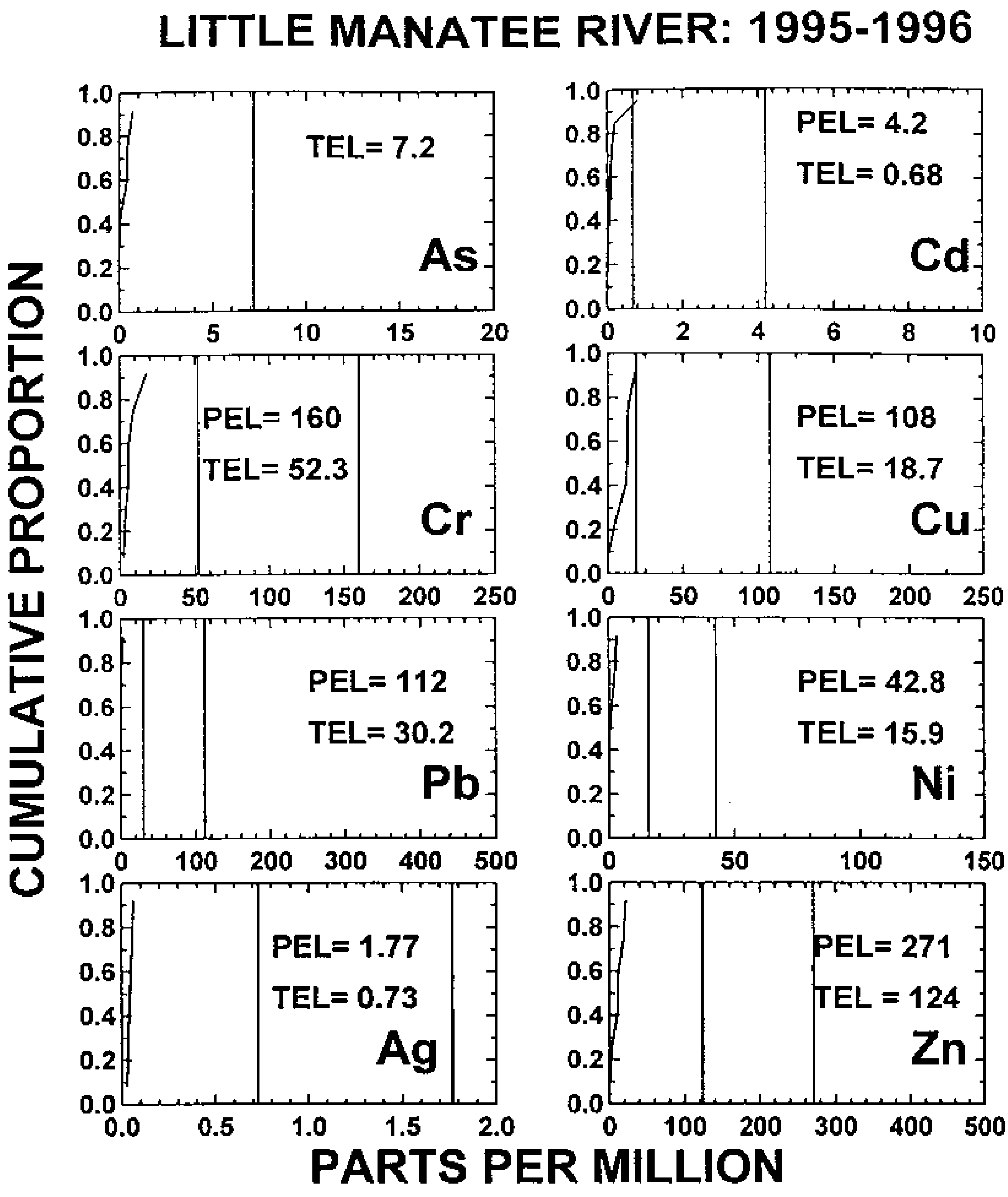


Figure 38. Cumulative proportions of trace metals in the Little Manatee River, 1995-1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely.

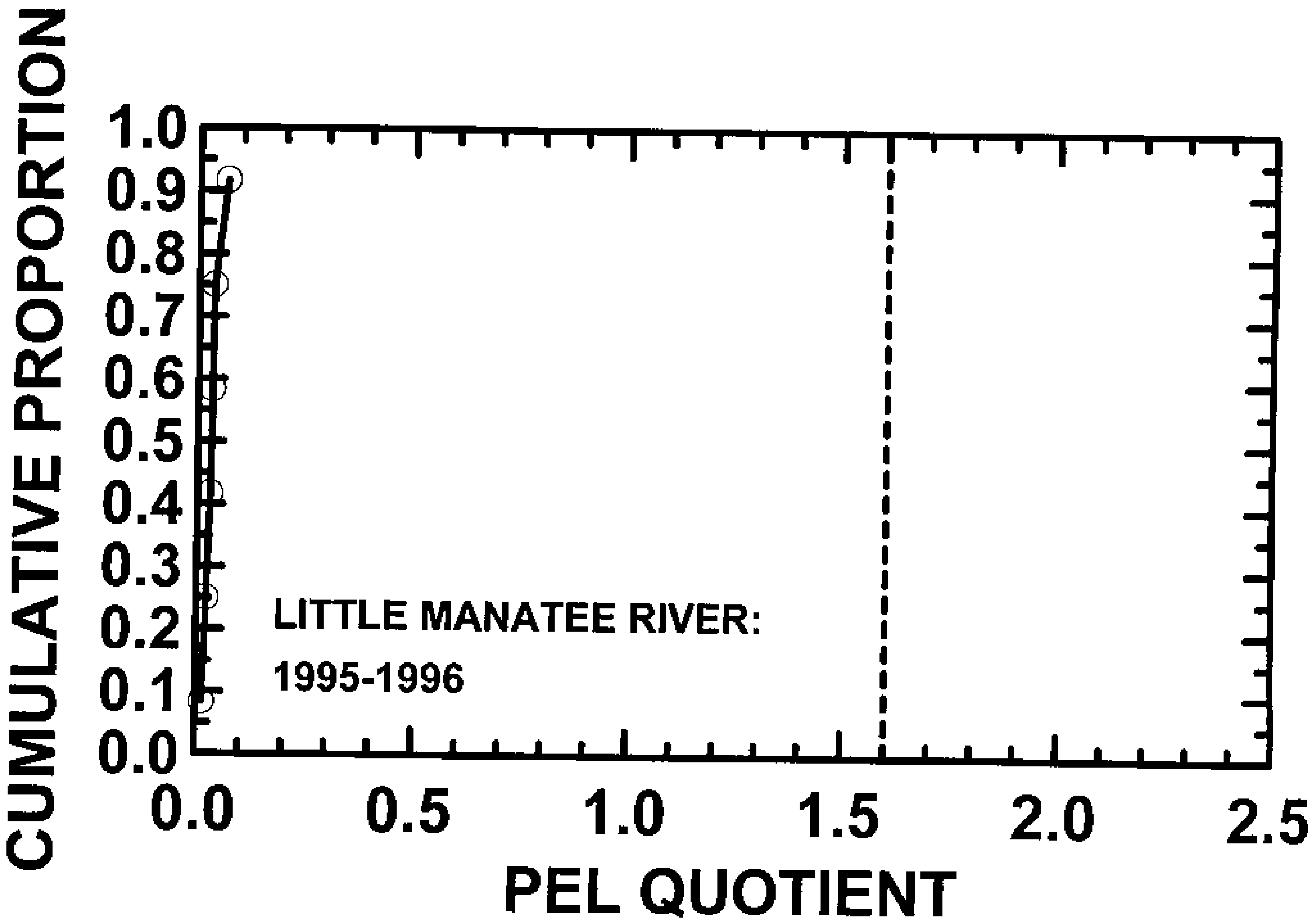


Figure 39. Cumulative proportion of the average PEL quotient for trace metals in the Little Manatee River, 1995-1996. Vertical line demarcates the threshold above which toxic effects are likely.

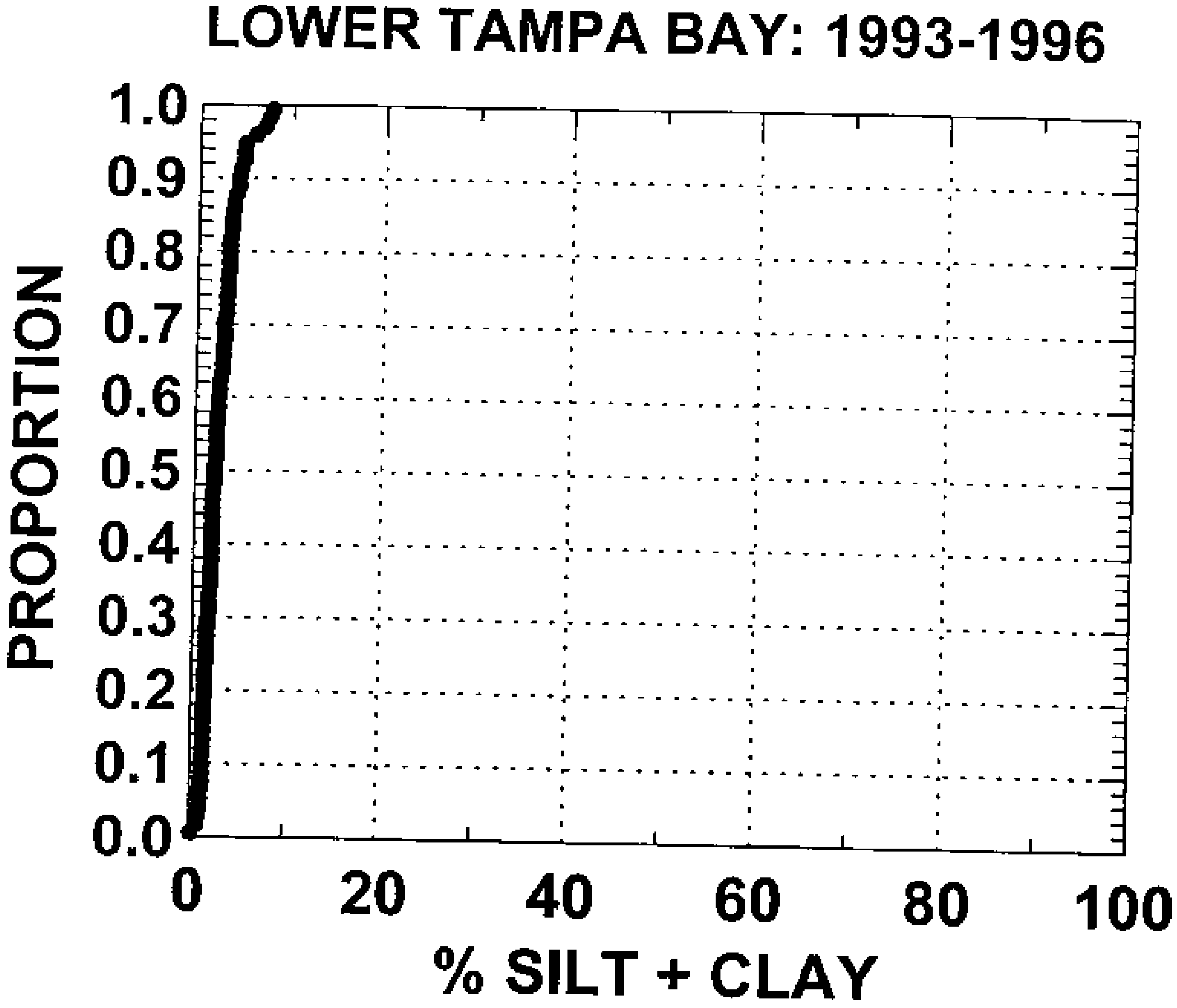


Figure 40. Cumulative proportion of the % Silt+Clay in Lower Tampa Bay sediments, 1995-1996.

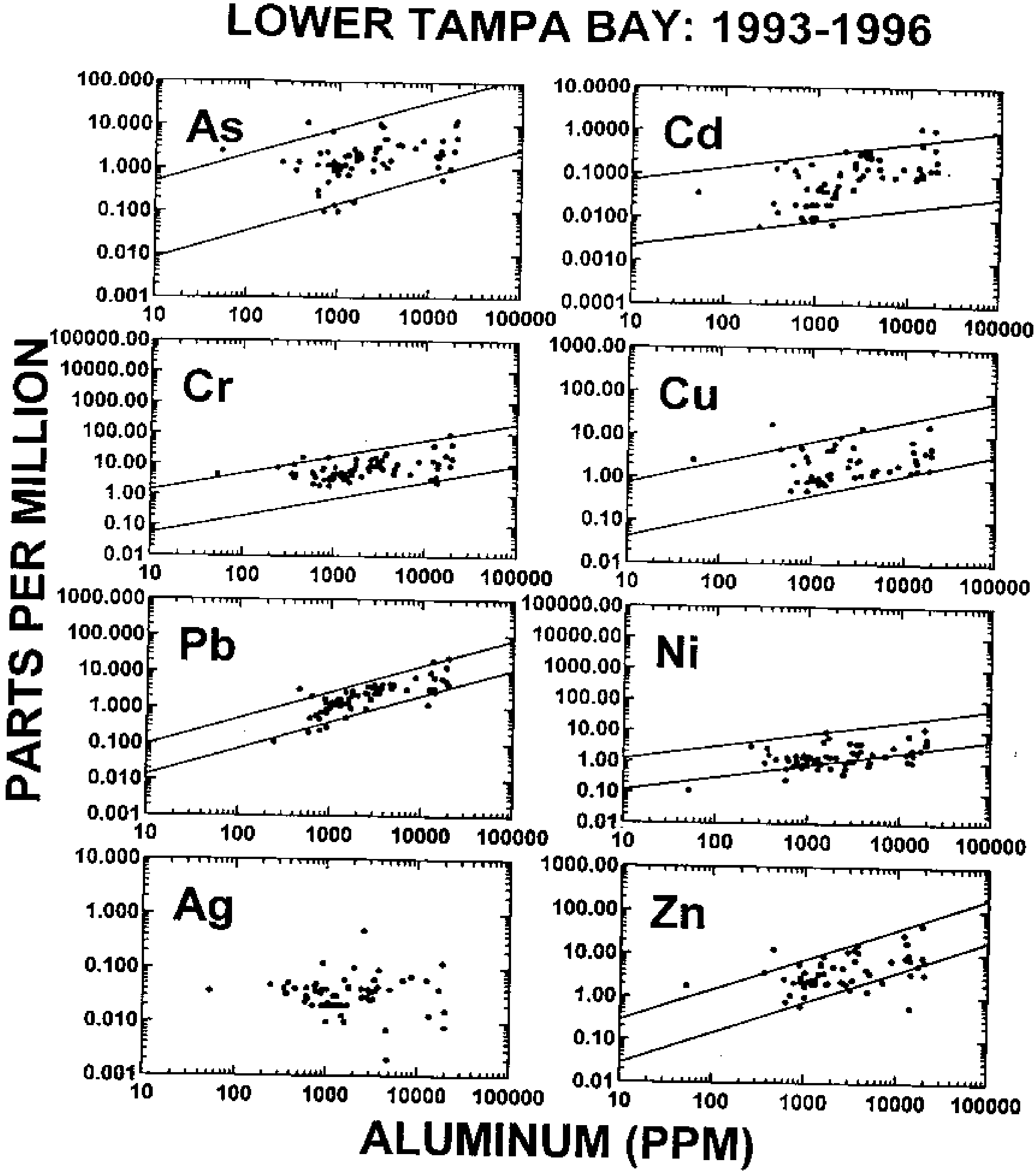


Figure 41. Trace metal concentrations vs. aluminum. Lower Tampa Bay, 1993-1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error.

chromium (Figures 12 and 42); the copper concentration at station 96LTB01 (off Pt. Pinellas) exceeded the PEL (>200 ppm) (Figure 42). PEL quotients for this bay segment were all <0.3 (Figure 43) and the mean quotient was the second lowest of the seven bay segments (Figure 15).

III.2.5. Boca Ciega Bay: Grain size data (1995 and 1996) showed that approximately 10% of Boca Ciega Bay had sediments with >20% silt+clay (Figure 44). There was some evidence of cadmium, copper, and zinc enrichment (Figure 45). Cadmium, chromium, and copper concentrations exceeded the TEL at two to three sites (Figure 46); there was evidence of copper contamination (>PEL) at station 96BCB31 (in the Bird Key Middle Grounds just west of Indian Key). PEL quotients were all <0.5 (Figure 47) and the mean PEL quotient was ranked fifth out of the seven primary bay segments (Figure 15).

III.2.6. Terra Ceia Bay: Sediments in the seven Terra Ceia Bay samples were generally of low (<5%) silt+clay content (Figure 48). Enrichment by copper and zinc was evident at only a single station (Figure 49). Sediments in Terra Ceia Bay were judged to be "nominal" (all metal concentrations <TEL) (Figures 12 and 50). PEL quotients were uniformly low in Terra Ceia Bay (Figures 15 and 51).

III.2.7. Manatee River: Approximately half of the Manatee River sediments had <10% silt+clay and no areas sampled had more than 20% silt+clay (Figure 52). Manatee River sediment metal concentrations were generally within normal background levels (Figure 53) with copper-enriched sediments detected at only a single location. The Manatee River segment of Tampa Bay was judged to have "nominal" sediments throughout (Figure 54). PEL quotients were uniformly low in the Manatee River (Figures 15 and 55).

III.2.8. Synthesis: Six percent (25 mi^2) of Tampa Bay sediments were estimated to be of "marginal" quality. Metals contributing to this pattern include arsenic (3.3% or 13 mi^2), cadmium (6.4% or 25 mi^2), chromium (5.7% or 23 mi^2), copper (4.6% or 18.3 mi^2), and nickel (3.5% or 14 mi^2) (Figure 12). "Subnominal" sediments constituted a considerably smaller fraction (0-1%) of the bay (Figure 13).

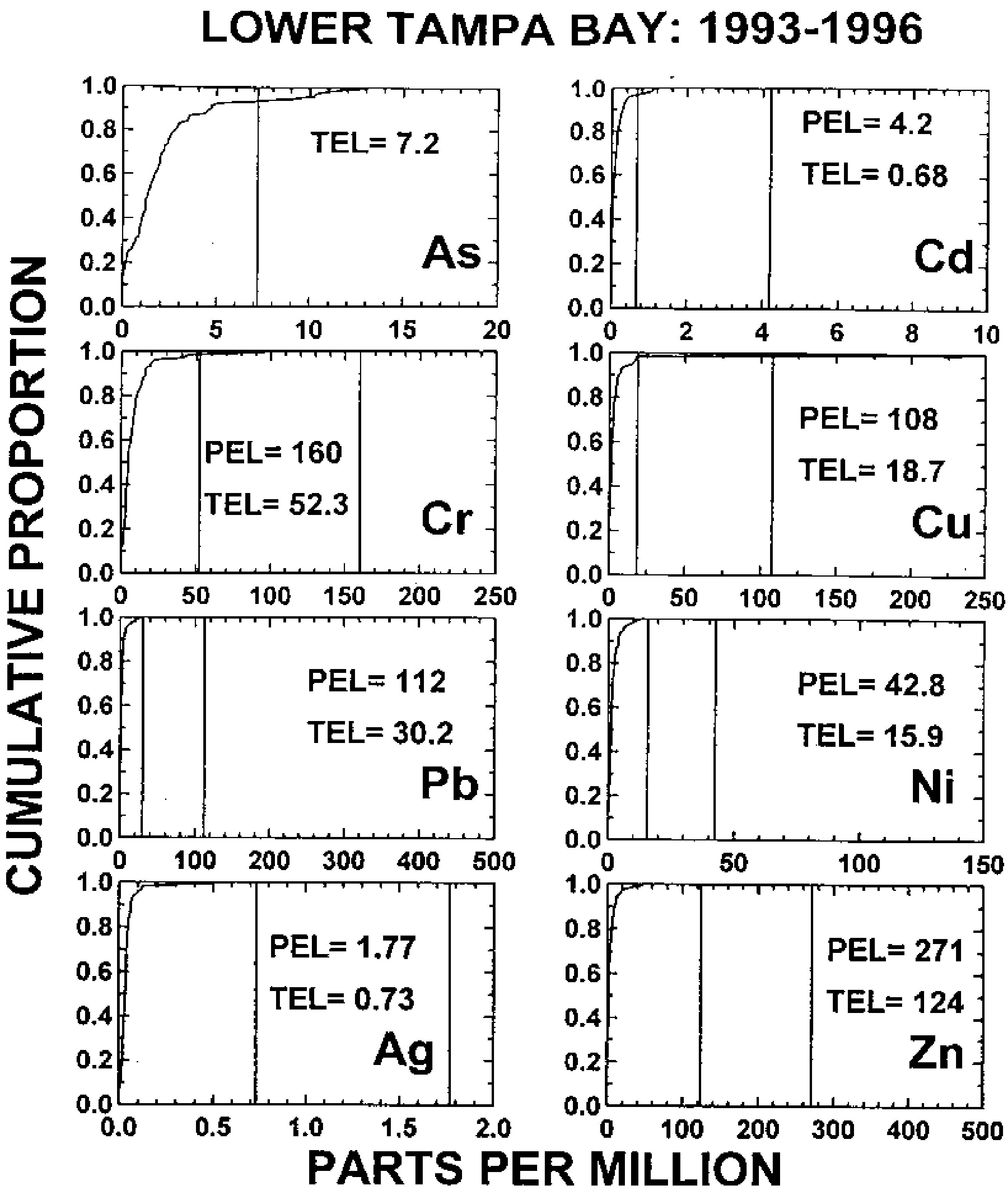


Figure 42. Cumulative proportions of trace metals in Lower Tampa Bay, 1993-1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely.

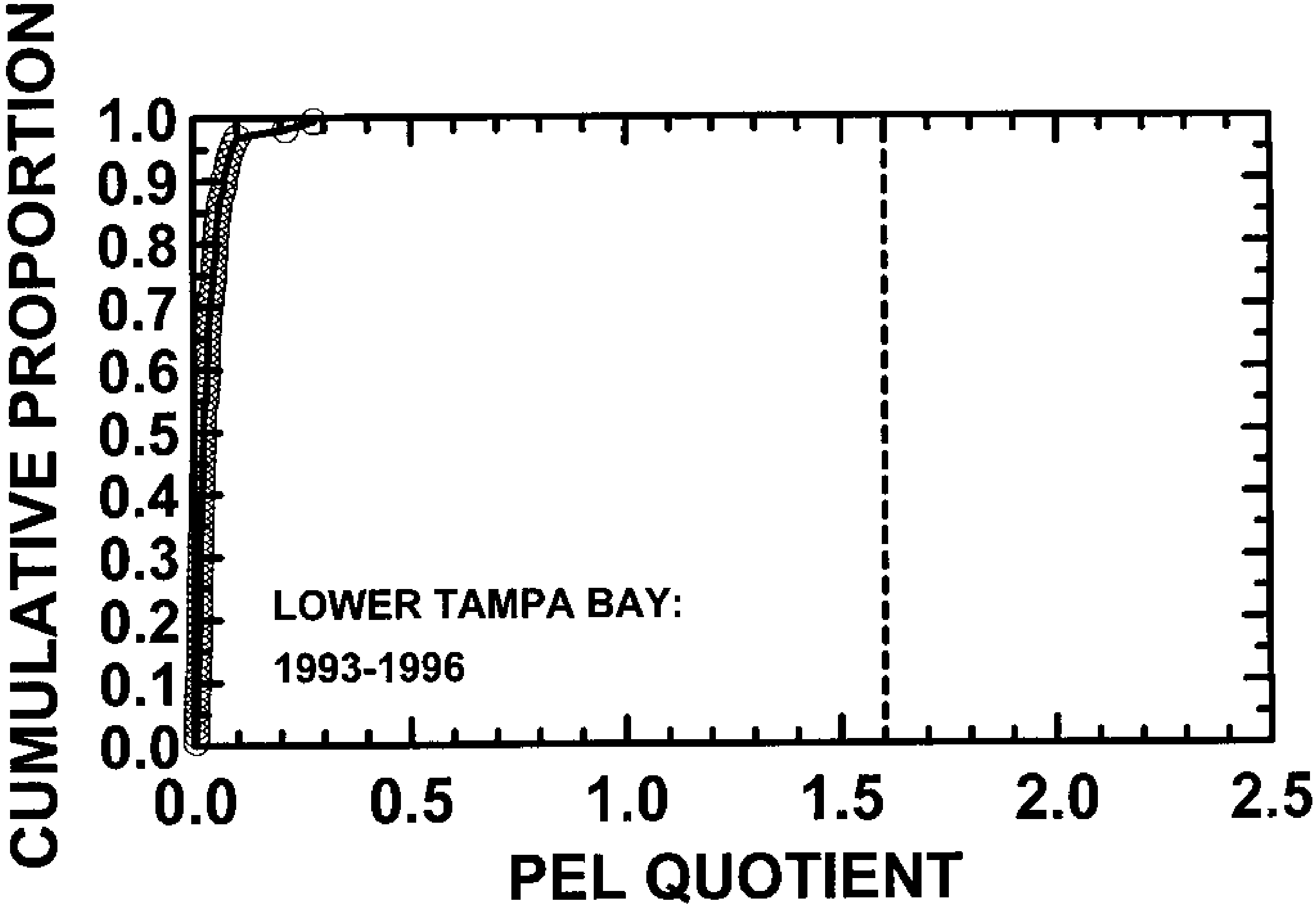


Figure 43. Cumulative proportion of the average PEL quotient for trace metals in the Lower Tampa Bay segment, 1993-1996. Vertical line demarcates the threshold above which toxic effects are likely.

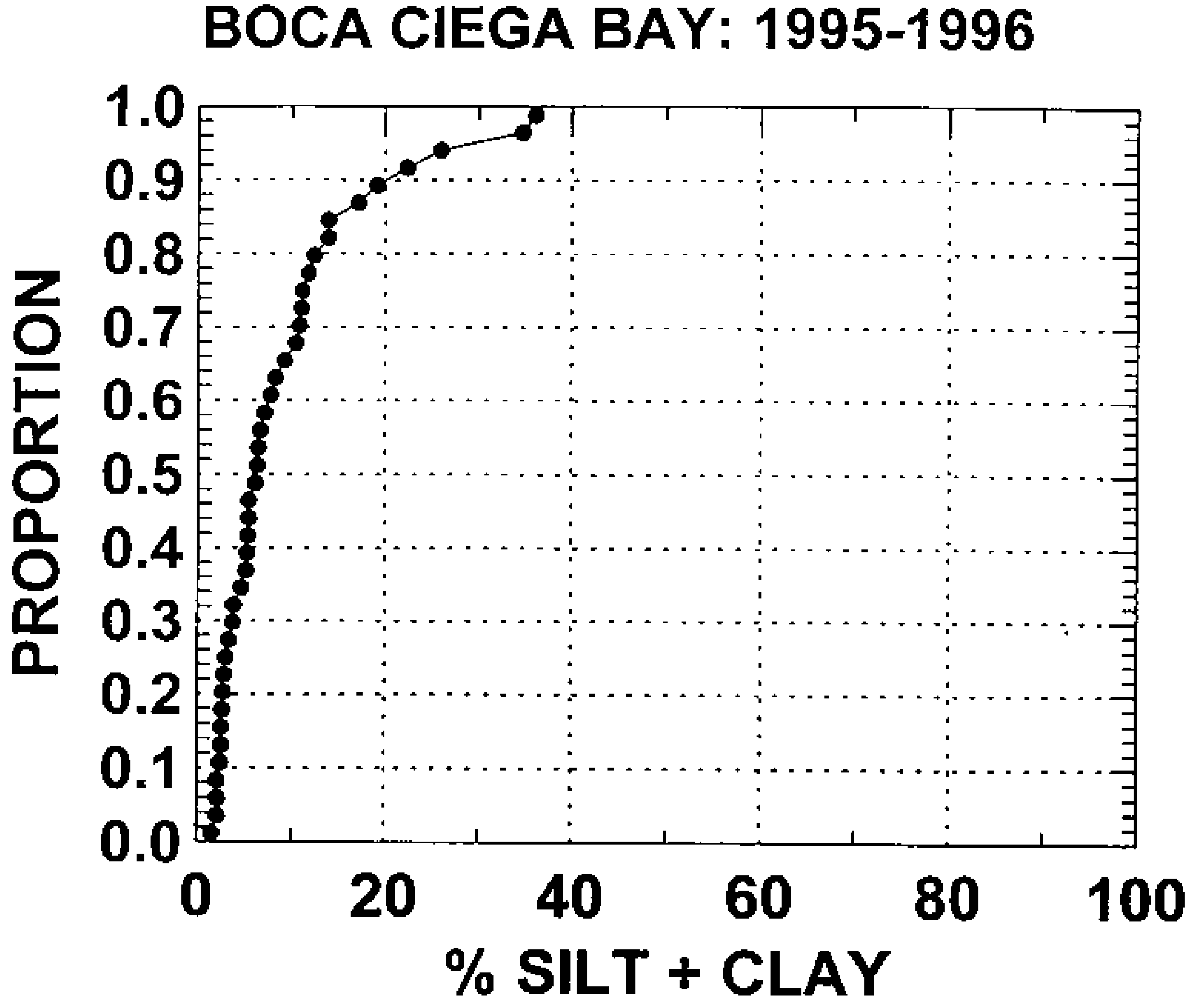


Figure 44. Cumulative proportion of the % Silt+Clay in Boca Ciega Bay sediments, 1995-1996.

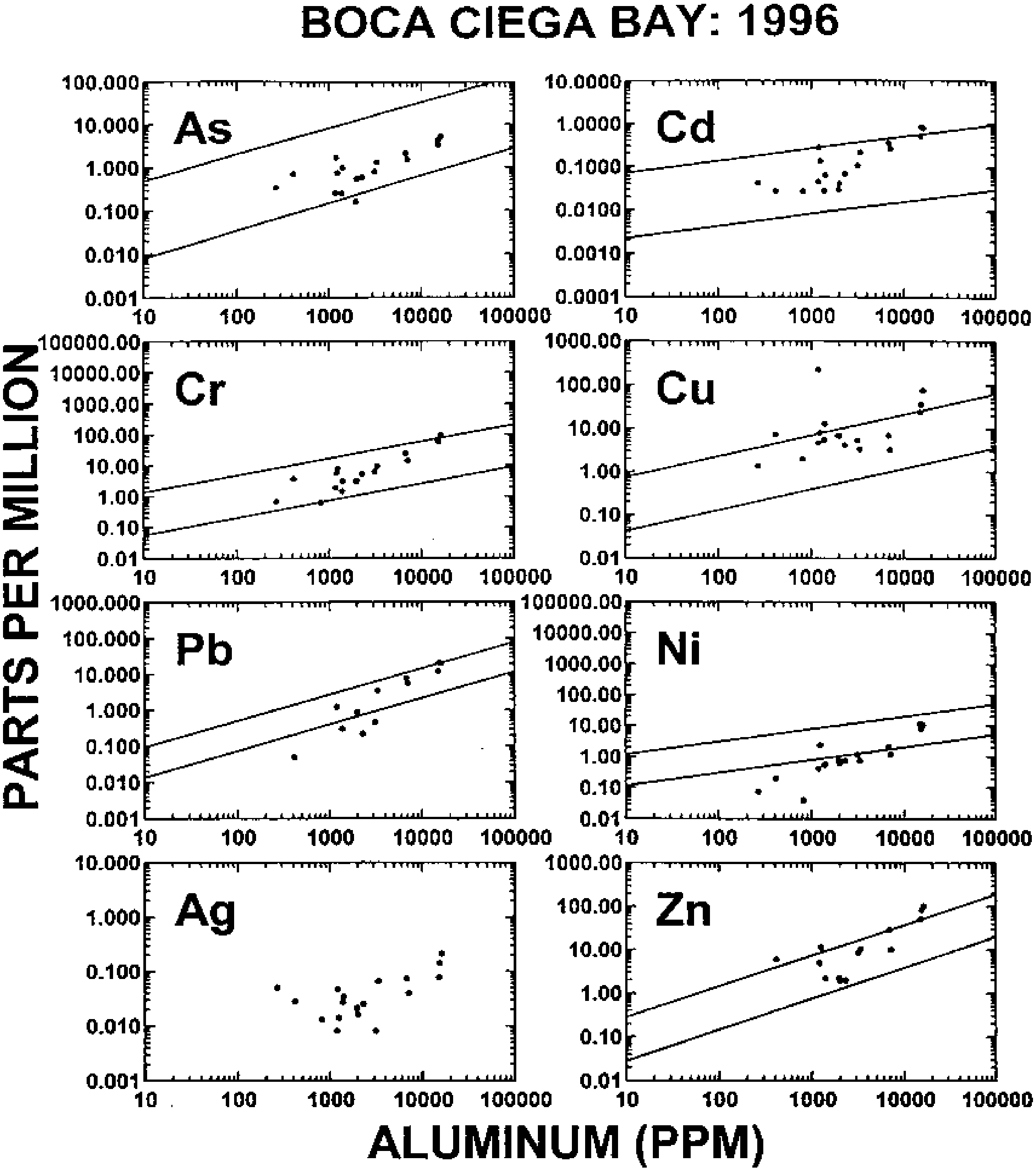


Figure 45. Trace metal concentrations vs. aluminum. Boca Ciega Bay segment, 1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error.

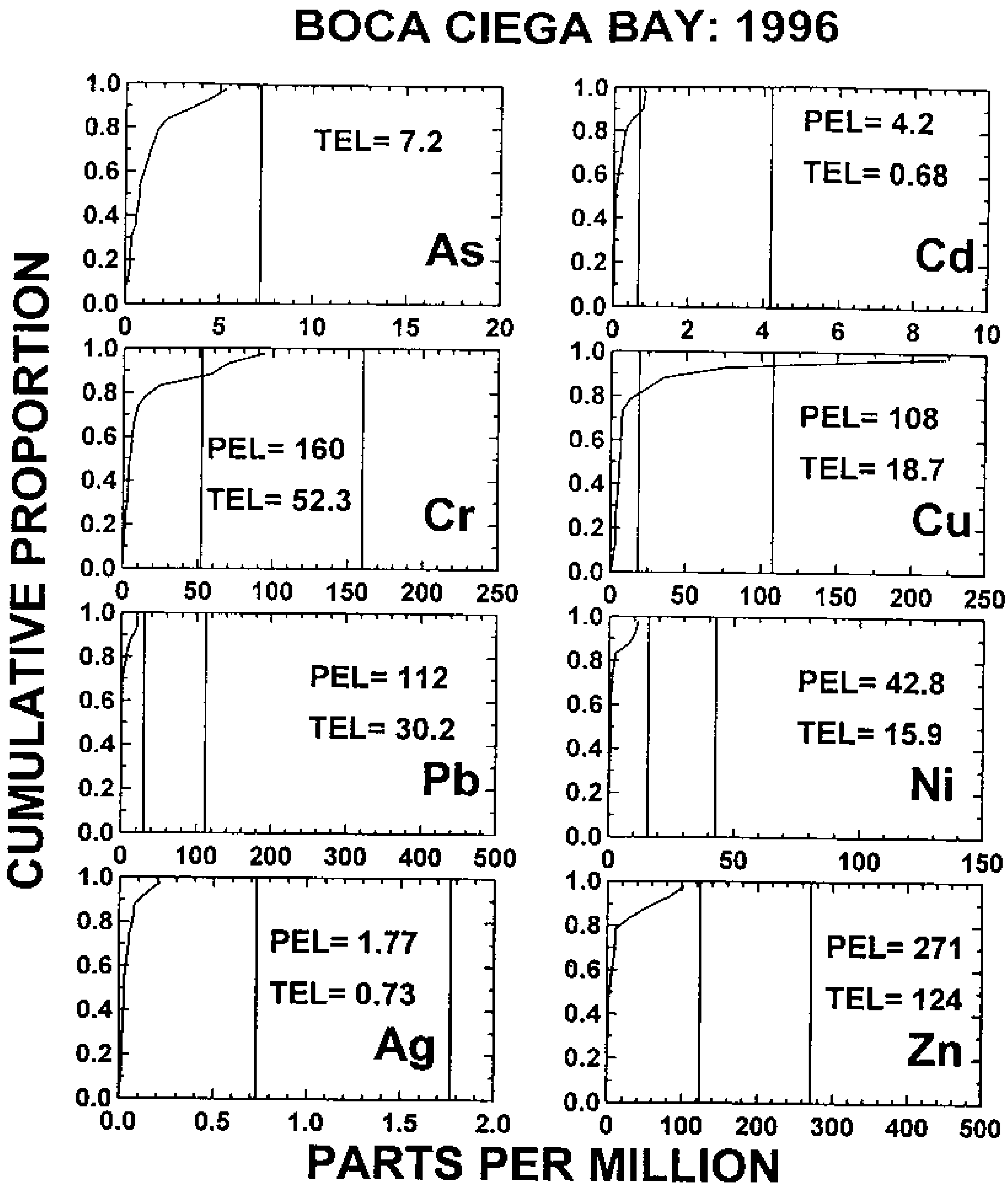


Figure 46. Cumulative proportions of trace metals in the Boca Ciega Bay segment, 1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely.

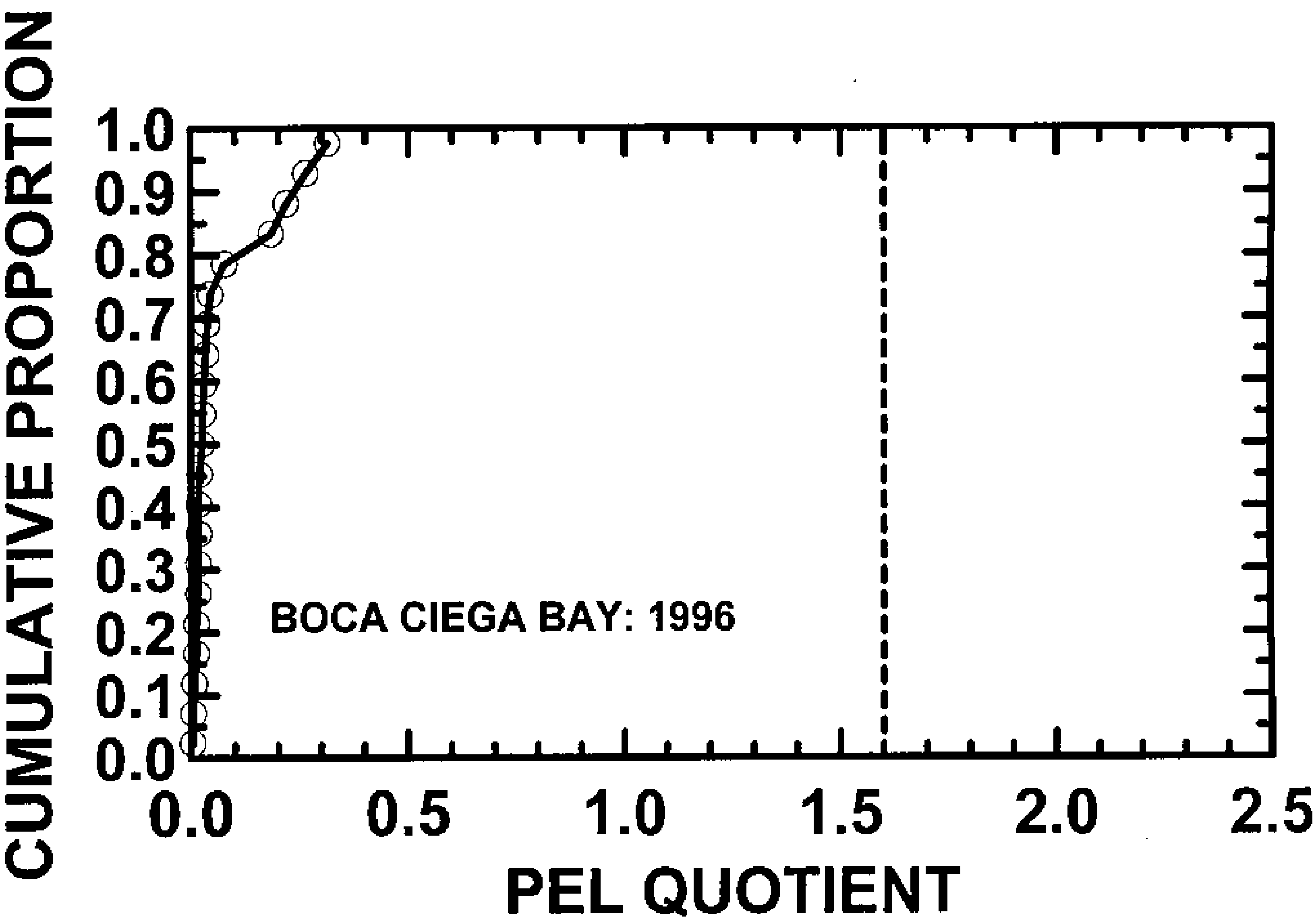


Figure 47. Cumulative proportion of the average PEL quotient for trace metals in the Boca Ciega Bay segment, 1996. Vertical line demarcates the threshold above which toxic effects are likely.

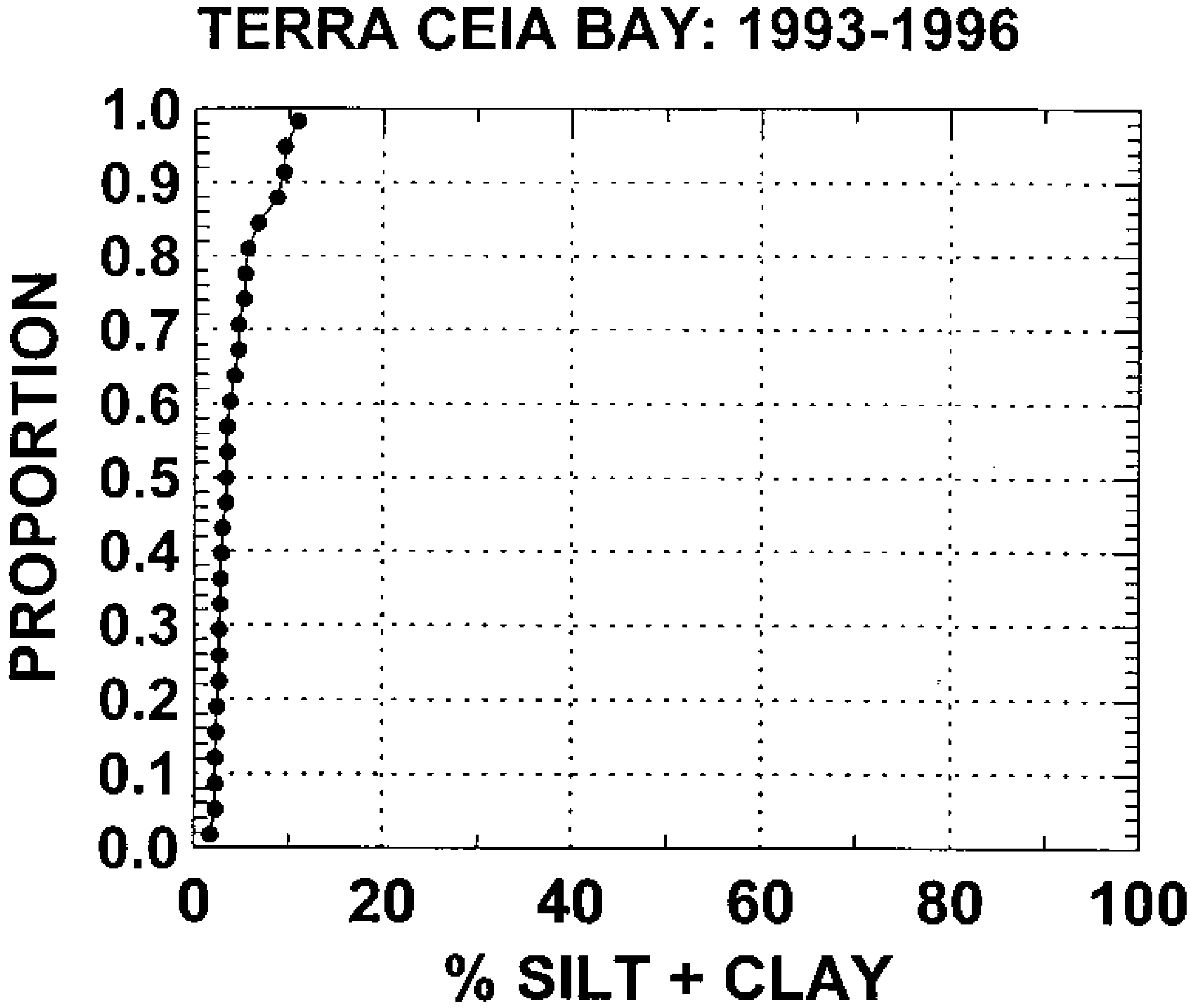


Figure 48. Cumulative proportion of the % Silt+Clay in Terra Ceia Bay sediments, 1993-1996.

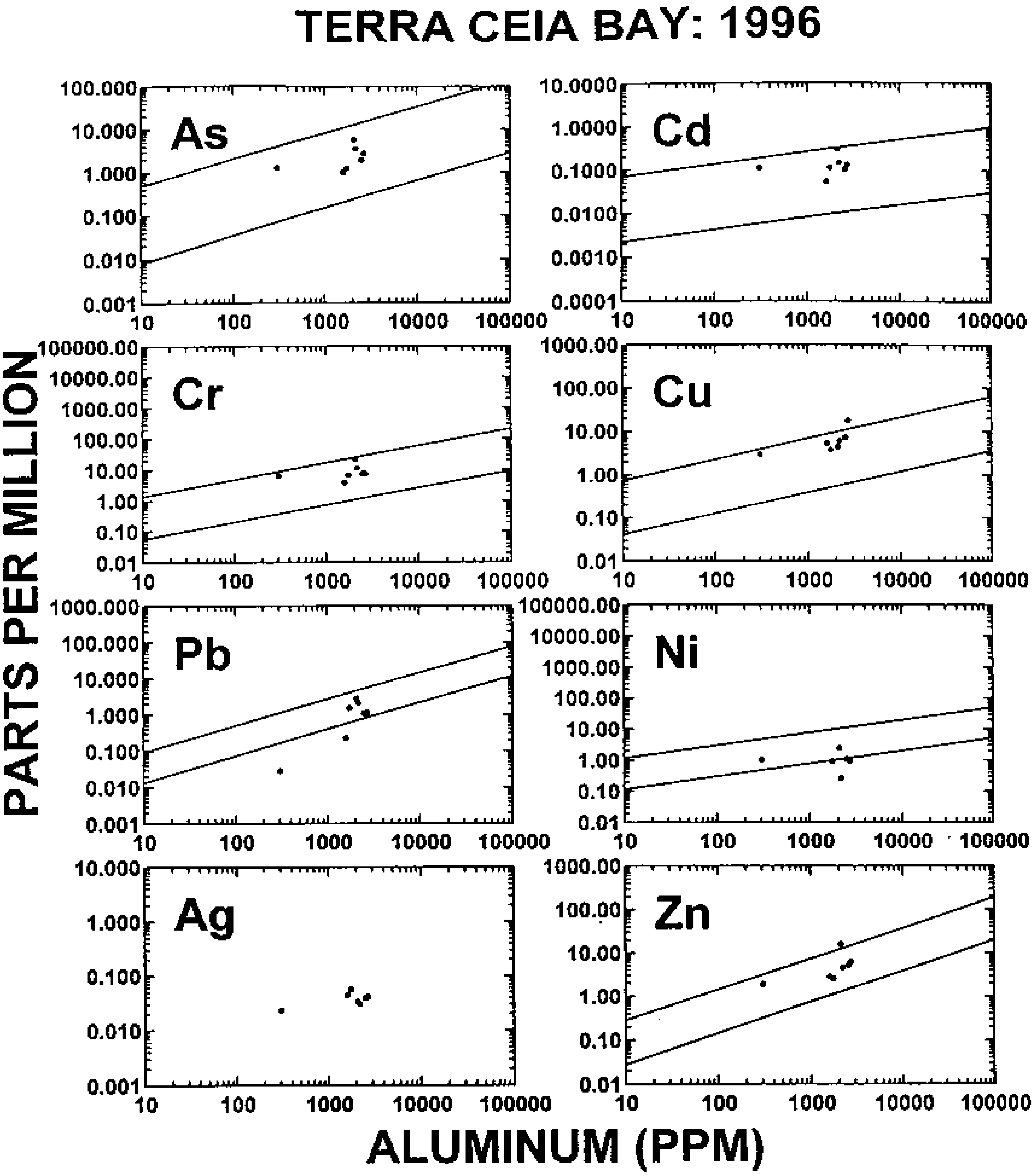


Figure 49. Trace metal concentrations vs. aluminum. Terra Ceia Bay segment, 1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error.

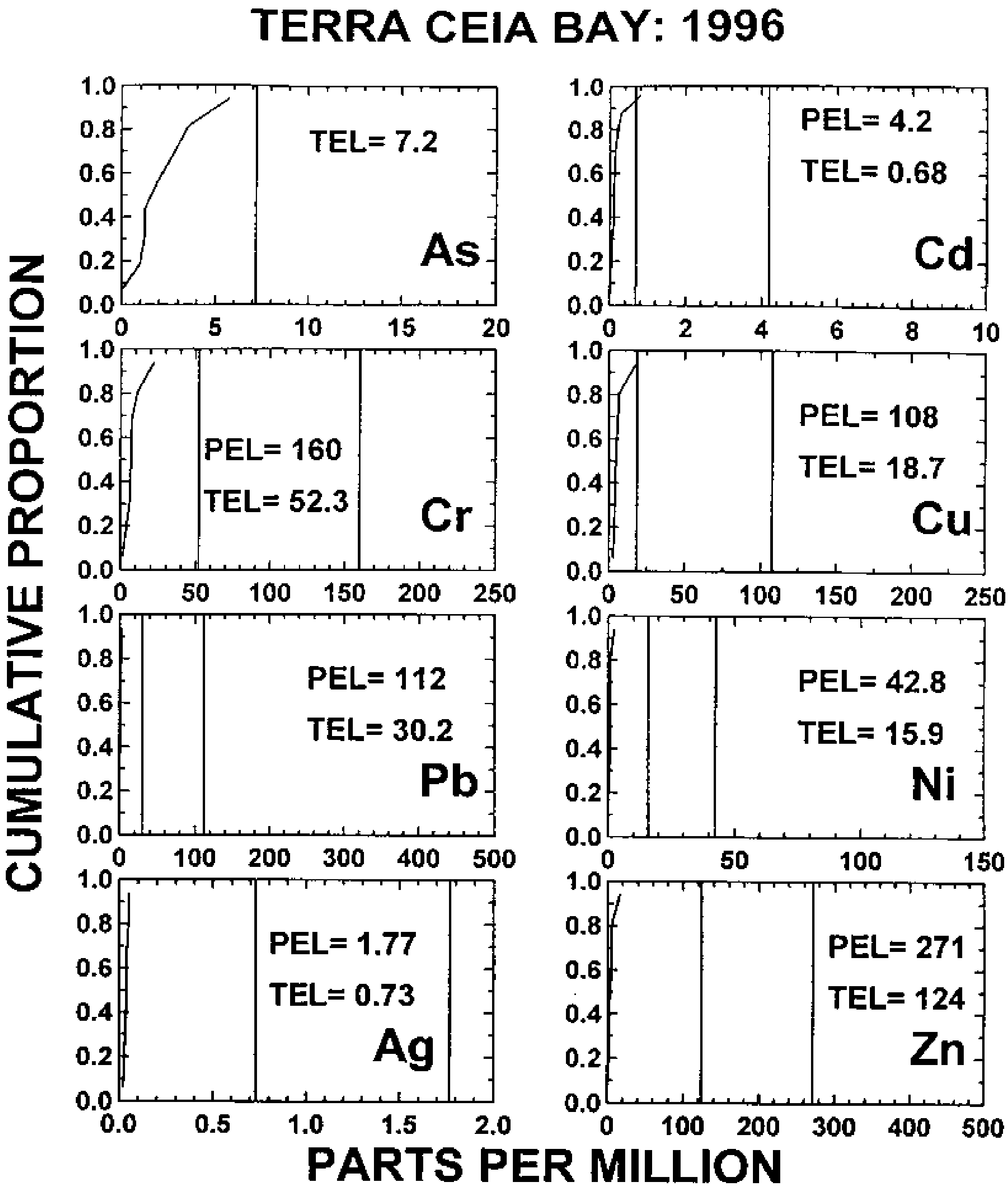


Figure 50. Cumulative Proportions of Trace Metals in the Terra Ceia Bay segment, 1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely.

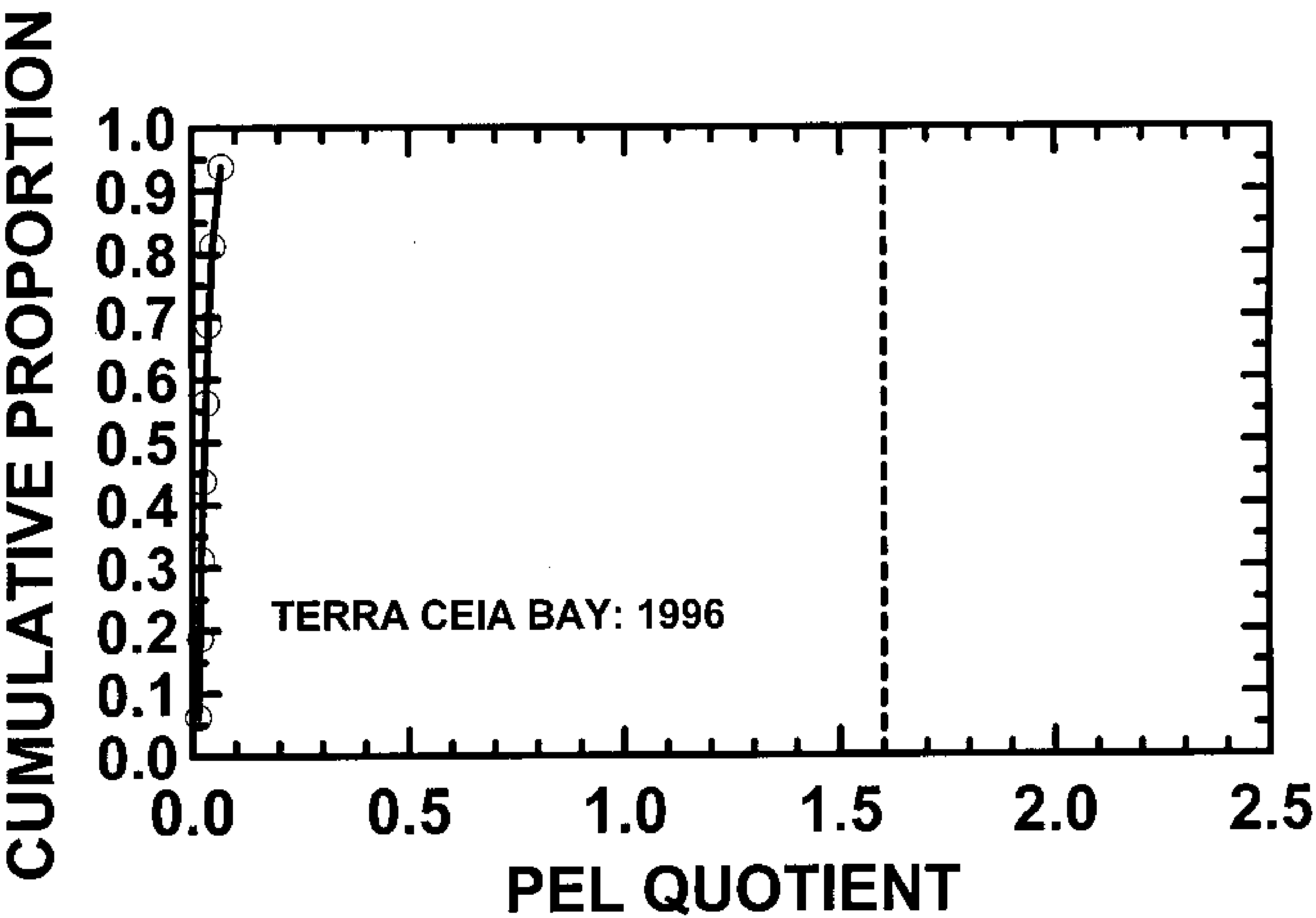


Figure 51. Cumulative proportion of the average PEL quotient for trace metals in the Terra Ceia Bay segment, 1996. Vertical line demarcates the threshold above which toxic effects are likely.

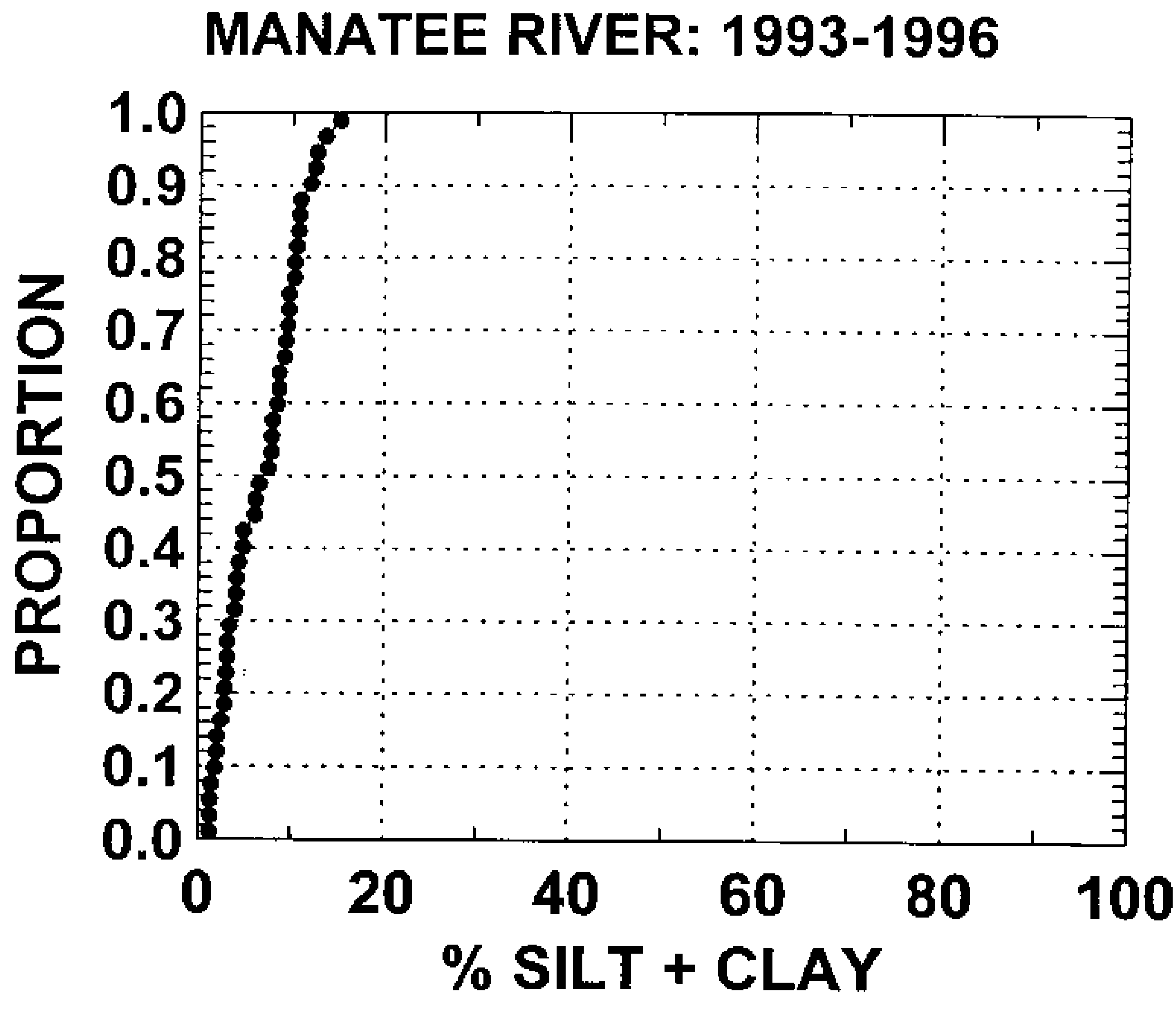


Figure 52. Cumulative proportion of the % Silt+Clay in Manatee River sediments, 1993-1996.

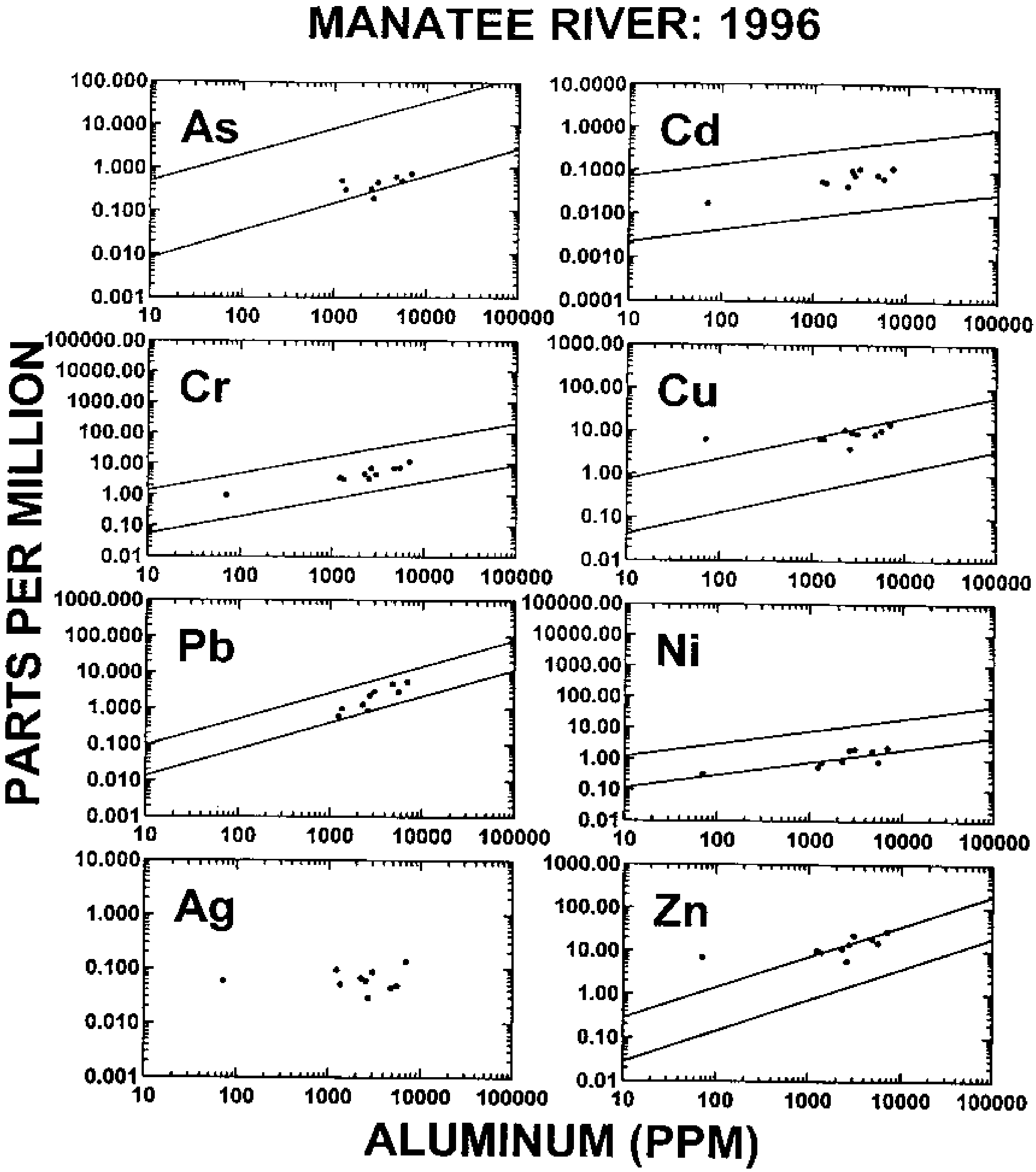


Figure 53. Trace metal concentrations vs. aluminum. Manatee River segment, 1996. Values falling within the parallel lines represent concentrations within normal background levels. Values falling above the upper line suggest anthropogenic enrichment; values falling below the lower line may indicate laboratory error.

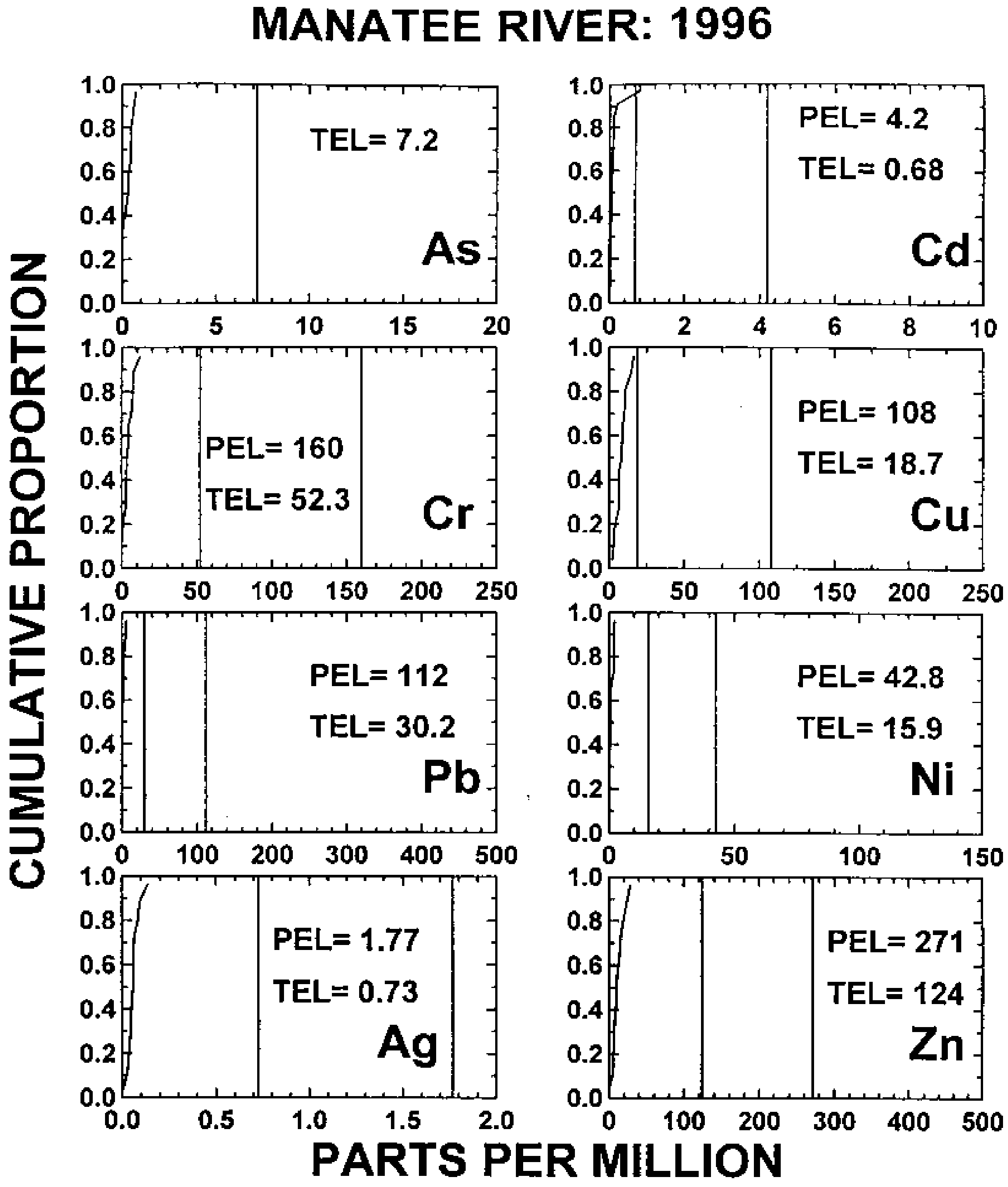


Figure 54. Cumulative proportions of trace metals in the Manatee River segment, 1996. Vertical lines demarcate the "Threshold Effects Level" [TEL], below which sediments are not considered to be contaminated, and the "Predicted Effects Level" [PEL], above which adverse ecological effects are likely.

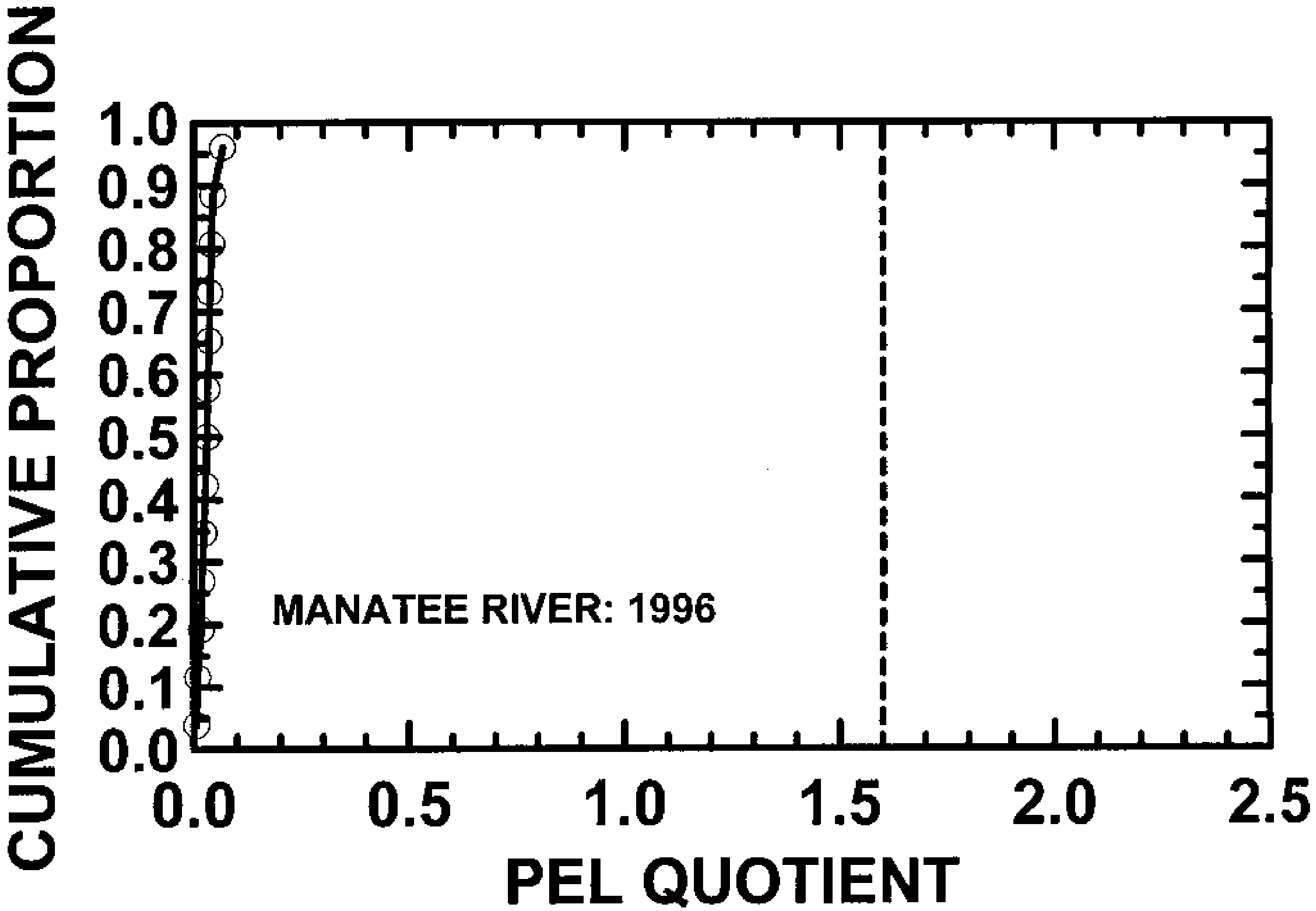


Figure 55. Cumulative proportion of the average PEL quotient for trace metals in the Manatee River segment, 1996. Vertical line demarcates the threshold above which toxic effects are likely.

SECTION IV
DISCUSSION

A spate of investigations conducted during the mid-1980s through early 1990s have shown that Tampa Bay has depositional areas with sediments contaminated by various trace metals (Doyle et al. 1985; Doyle et al. 1989; Long et al. 1991; Brooks & Doyle 1992; Daskalaskis & O'Connor 1994; Long et al. 1994 ; Seal et al. 1994; Long et al. 1995a; Carr *et* al. 1996), and where sediments may even be toxic (Carr et al. 1996). The management plan for Tampa Bay (TBNEP 1996) has summarized the sources, extents, and impacts of toxic contaminants, including trace metals, in the estuary. Objectives of this management plan include the identification of "hotspots" and sources of contaminants, improvements both stormwater treatment and source-control to ameliorate these "hotspots", and to continue to monitor the bay for changes in response to remediation (TBNEP 1996).

Generic sources of sediment contamination can include atmospheric deposition (Windom 1992; Golomb et al. 1997), point source discharges *(e.g.* ,industrial discharges and storm sewers: Shear et al. 1996; Iannuzzi et al. 1997), and non-point source runoff (USEPA 1992). The primary sources of metallic contaminants to Tampa Bay have been identified as urban runoff (chromium, copper, lead, mercury, zinc), atmospheric deposition (cadmium), and point sources (arsenic) (Frithsen et al. 1995).

Contaminated sediments are of environmental concern because they have been associated with reductions in faunal abundance and numbers of species (Somerfield et al. 1994; Hall & Frid 1995; Morrisey et al. 1995; Hansen et al. 1996), and the proliferation of "pollution tolerant" species (Ward & Hutchings 1996). Sediment contamination to the extent that biological community structure and function is altered can alter the trophic structure of the community and ultimately could be manifest as changes to higher trophic levels (e.g., fish, birds).

McConnell et al. (1996) addressed both ecological and human health risks associated with contaminated sediments in selected areas of the Tampa Bay estuary. Ecological risks were associated with several metals (e.g. ,chromium, copper, mercury, and nickel in upper Hillsborough Bay). Human health effects have not been indicated for any of the metals.

Anthropogenically enriched sediments were found throughout Tampa Bay. Highest incidences were in Hillsborough Bay (especially cadmium and zinc), the Hillsborough River (cadmium, copper, lead, and zinc), and the Palm River (cadmium, lead, and zinc). The frequency of enriched sediments was lowest in the Little Manatee River, Terra Ceia Bay, and the Manatee River-- all areas with few samples and limited spatial coverage.

Cadmium enrichment was the most widespread of any metal in Tampa Bay. Given that phosphoritic sediments are typically enriched with cadmium (Nathan 1984), that central Florida sediments are rich in phosphate, and that the phosphate fertilizer industry is the primary industry using the Port of Tampa (Tampa Bay Regional Planning Council 1986), this trend is not unexpected.

Approximately 6% (23.9 mi^2) of Tampa Bay sediments are estimated to be of "marginal" quality with respect to trace metal contamination. Hillsborough Bay, which is the most industrialized bay segment, showed the greatest incidence of enrichment and contamination. Approximately 8% (3.2 mi^2) of Hillsborough Bay sediments were sufficiently degraded to be classified as "subnominal"; as much as 34% (13.7 mi^2) of Hillsborough Bay segments were defined as "marginal" (for cadmium). Barely 1% (3.9 mi^2) of Tampa Bay sediments were found to be "subnominal" (for chromium and nickel). The trend is for metal concentrations in Tampa Bay to be higher where the percentage of fine-grained sediments are also higher (cf. Brooks & Doyle 1991), as is generally the case (De Gregori et al. 1996). The Manatee River segment appeared to be the least contaminated by trace metals, although only a single year of data are currently available.

The Hillsborough, Palm, and Alafia rivers, each of which discharge to Hillsborough Bay, show evidence of greater impairment than Hillsborough Bay proper. The databases for these rivers are, however, quite sparse and these trends need to be viewed cautiously.

The ecological impact of sediments defined as "enriched", "marginal" and "subnominal" using the SQAGs may actually be less than is implied by these data. Contaminants, such as trace metals, need to be "available" in order to impact resident biota. Bioavailability is not necessarily correlated with the environmental concentrations of a particular contaminant (Arjonilla et al. 1994). Abiotic factors which may determine bioavailability include acid-volatile sulfides, iron-oxides, redox potential/pH, and salinity

(Bryan & Langston 1992). Of these ancillary variables, salinity is the only one measured in this study.

The behavior and physiology of the benthic taxa will also determine the degree to which a species is impacted by contaminated sediments (Rainbow 1990). Sessile deposit feeders, such as the polychaetes which predominate in Tampa Bay *(e.g.Mediomastus* spp., various Spionidae; Grabe et al. 1996), are more likely to be affected by contaminated sediments than vagile fauna (e.g.,crabs, shrimps), which may be able to leave or avoid contaminated areas (Hebel et al. 1997). Additionally, some species are capable of physiologically regulating tissue concentrations of a particular metal(s) to the extent that body burdens do not correlate with environmental concentrations (Samant et al. 1990). Likewise, fish species which prey upon deposit feeders or which swallow quantities of sediments while feeding are also more likely to accumulate contaminants (Mac & Schmitt 1992).

The data collected during 1993-1996 to establish "baseline" conditions for Tampa Bay show a somewhat lower incidence of trace metal contamination than reported in other studies of Tampa Bay (Long et al. 1991; Coastal Environmental, Inc. 1996; Long et al. 1996). This is likely due, at least in part, to differences in study designs and objectives, as well as criteria for contamination. The present study is designed to provide unbiased estimates of variable means for each of the bay segments, as well as Tampa Bay as a whole. The NOAA studies (Long et al. 1991; Daskalaskis & O'Connor 1994; Long et al. 1994; Long et al. 1995a; Carr et al. 1996) targeted putative depositional areas known to be contaminated and therefore would be expected to depict a "worst-case" scenario. Additionally, there are differences in the criteria for contamination. The current program has adopted the guidelines developed for the State of Florida (MacDonald Environmental Sciences Ltd. 1994) whereas the NOAA studies employed Long & Morgan's (1990) criteria.

SECTION V
RECOMMENDATIONS

1. Contaminant data (including organics) still need to be assessed in concert with the biological data, particularly with the Benthic Index, as they become available. Such an analysis will facilitate interpretation of "cutoff"points to demarcate "healthy" from "subnominal" benthic habitat.
2. Outside funding should be sought to support bioassay analyses, as recommended in MacDonald (1997).
3. The Sediment Quality Triad (Chapman 1990) should be invoked as an interpretive tool should a bioassay database be developed (MacDonald 1997).
4. Consideration should also be given to securing outside funding to determine the status of organotins in Tampa Bay. Organotins have been used as a component of anti-fouling paints on ships (Langston 1990) and therefore are likely to be present in those parts of Hillsborough Bay where hull-stripping and repainting activities exist. Organotins are quite toxic at low concentrations (Langston 1990). Whether organotins provide an ecological risk to Tampa Bay is unknown.
5. Sampling is to be expanded to include the Hillsborough, Palm, Alafia, and Little Manatee Rivers for the years 1997-2000 to establish "baseline" conditions. Efforts should be made to secure funding to support and perhaps expand this river sampling. This recommendation is predicated on the possibility of freshwater withdrawals or additions to these rivers and their possible affects on the resident biota (*cf.* TBNEP 1996).

SECTION VI

LITERATURE CITED

ARJONILLA, M., J.M. FORJA, & A. GOMEZ-PARRA. 1994. Sediment analysis does not provide a good measure of metal bioavailability to *Cerastodenna glaucum* (Mollusca: Bivalvia) in confined coastal ecosystems. *Bull. Environ. Contam. Toxicol.* 52:810-817.

BROOKS, G.R. & L.J. DOYLE. 1991. Distribution of sediments and sedimentary contaminants. Pages 399-413. *In:* S.F. Treat & P.A. Clark. *Proc. Tampa Bay Area Scientific Information Symposium.* 27 Feb. - 1 Mar. 1991. Tampa, FL. TEXT, Tampa. 528p.

BROOKS, G.R.& L.J.DOYLE.1992. *A Characterization of Tampa Bay Sediments. Phase III. Distribution of Sediments and Sedimentary Contaminants.* Prep. for Southwest Florida Water Management District. Brooksville.

BRYAN, G.W. & W.J. LANGSTON. 1992. Bioavailability, accumulation and effects of heavy metals in sediments with special reference to UK estuaries: a review. *Environ. Pollut*. 76:89-131.

CARR,R.S.,E.R.LONG,H.L.WINDOM,D.C.CHAPMAN,G.THURSBY,G.M.SLOANE, & D.A. WOLFE. 1996. Sediment quality assessment studies of Tampa Bay, Florida. *Environ. Toxicol Chem.* 15:1218-1231.

CHAPMAN, P.N. 1990. The Sediment Quality Triad approach to determining pollution-induced degradation. *Sci. Tox. Environ.* 97-98:815-825.

COASTAL ENVIRONMENTAL,INC. 1996. *An Assessment of Sediment Contamination in Tampa Bay.* Prep. for Tampa Bay National Estuary Program. Coastal Environmental, Inc. St. Petersburg.

COASTAL ENVIRONMENTAL, INC. 1994. *Monitoring Program to Assess Environmental Changes in Tampa Bay, Florida.* Tampa Bay National Estuary Program Tech.Rep. #02-93. Coastal Environmental, Inc. St. Petersburg.

COURTNEY, C.M.,R. BROWN, & D. HEIMBUCH. 1993. *Environmental Monitoring and Assessment Program Estuaries- West Indian Province: Volume I. Introduction, Methods and Materials, and Quality Assurance. Field and Laboratory Operations Manual for a Synoptic Survey of Benthic Macroinvertebrates of the Tampa Bay Estuaries.*

COURTNEY,C.M.,S.A.GRABE,D. KARLEN,R.BROWN,& D. HEIMBUCH. 1995.1995 *Field Operations Manual for a Synoptic Survey of Benthic Macroinvertebrates of the Tampa Bay Estuaries.*

DASKALAKIS, K.D. & T.P. O'CONNOR. 1994. *Inventory of Chemical Concentrations in Coastal and Estuarine Sediments.* NOAA Tech. Mem. NOS ORCA 76. NOAA. Silver Spring, MD. 66 p.

DE GREGORI, I.H., H.C. PINOCHET, M.J. ARANCIBIA, & A.B. VIDAL. 1996. Grain size effect on trace metals distribution in sediments from two coastal areas of Chile. *Bull. Env. Contam. Toxicol.* 57: 163-170.

DOYLE, L.J.,E.S. VAN VLEET, W.M. SACKETT,N.J.BLAKE, & G.R. BROOKS. 1985. *Hydrocarbon Levels in Tampa Bay*. Final report to Florida Dept. Nat. Res. Univ. S. Florida. St. Petersburg. 192 p.

DOYLE, L.J., G.R. BROOKS, K.A. FANNING, E.S. VAN VLEET, R.H. BYRNE, & N.J. BLAKE. 1989. *A Characterization of Tampa Bay Sediments.* Univ. S. Florida. St. Petersburg. 99 p.

FRITHSEN, J.B., S.P. SCHREINER, D.E. STREBEL, R.M. LALJANI, D.T. LOGAN, & H.W. ZARBOCK. 1995. *Chemical Contaminants in the Tampa Bay Estuary: A Summary of distributions and Inputs.* TBNEP Tech. Publ. #01-95.

GOLOMB, D., D. RYAN,N. EBY, J. UNDERHILL, & S. ZEMBA. 1997. Atmospheric deposition of toxics onto Massachusetts Bay--1. Metals. *Atmospheric Environ.* 31 :1349-1359.

GRABE, S.A., C.M. COURTNEY, Z. LIN, D. ALBERDI, H.T. WILSON, JR., & G. BLANCHARD. 1996. *Environmental Monitoring and Assessment Program- Estuaries. West Indian Province 1993 Sampling. Volume III. Technical Report: A Synoptic Survey of the Benthic Macroinvertebrates and Demersal Fishes of the Tampa Bay Estuarine System.* Tampa Bay National Estuary Program Tech. Publ. #95-12.

HALL, J.A. & C.L.J. FRID. 1995. Responses of estuarine benthic macrofauna in copper-contaminated sediments to remediation of sediment quality. *Mar. Pollut.* Bull. 30:694-700.

HANSEN, D.J., J.D. MAHONY, W.J. BERRY, S.J. BENYI, J.M. CORBIN, S.D. PRATT, D.M. DI TORO, & M.B. ABEL. 1996. Chronic effect of cadmium in sediments on colonization by benthic marine organisms: an evaluation of the role of interstitial cadmium and acid-volatile sulfide in biological availability. *Environ. Toxicol. Chem.* 15 :2 126-2137.

HEBEL, D.K., M.B. JONES, & M.H. DEPLEDGE. 1997. Responses of crustaceans to contaminant exposure: a holistic approach. *Est. Coastal Shelf Sci*. 44: 177-184.

IANNUZZI, T.J., S.L. HUNTLEY, C.W. SCHMIDT, B.L. FINLEY, R.P. McNUTT, & S.J. BURTON. 1997. Combined sewer overflows (CSOs) as sources of sediment contamination in the lower Passaic River, New jersey. I. Priority pollutants and inorganic chemicals. *Chemosphere.* 34:213-231.

LANGSTON, W.J. 1990. Toxic effects of metals and the incidence of metal pollution in marine ecosystems. Pages 101-122. In: R.W. Furness & P.S. Rainbow (Eds.). *Heavy Metals in the Marine Environment.* CRC Press. Boca Raton.

LEWIS, R.R., III & R.L. WHITMAN, JR. 1985. A new geographic description of the boundaries and subdivisions of Tampa Bay. Pages 10-18. In: S.F. Treat, J.C. Simon, R.R. Lewis, & R.L. Whitman (Eds.). *Proceedings: Tampa Bay Area Scientific Information Symposium* . May 1982. Univ. South Florida.

LONG, E.R., A. ROBERTSON, D.A. WOLFE, J. HAMEEDI, & G.M. SLOANE. 1996. Estimates of the spatial extent of sediment toxicity in major U.S. estuaries. *Environ. Sci. Technol*. 30:3585-3592.

LONG, E.R., R.S. CARR, G.A. THURSBY, & D.A. WOLFE. 1995a. Sediment toxicity in Tampa Bay: Incidence, severity, and spatial extent. *Fla. Sci*. 58:163-178.

LONG, E.R., D.D. MacDONALD, S.L. SMITH, & F.D. CALDER. 1995b. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environ. Manage.* 19:81-97.

LONG, E.R., D.A. WOLFE, R.S. CARR, K.J. SCOTT, G.A. THURSBY, H.L. WINDOM, R. LEE, F.D. CALDER, G.M. SLOANE, & T. SEAL. 1994. *Magnitude and Extent of Sediment Toxicity in Tampa Bay, Florida* NOAA Tech. Mem. NOS ORCA 78. NOAA. Silver Spring, MD. 138 pp.

LONG, E.R., D. MacDONALD, & C. CAIRNCROSS. 1991. *Status and Trends in Toxicants and the Potential for Their Biological Effects in Tampa Bay, Florida.* NOAA Tech. Mem. NOS OMA 58. NOAA. Seattle, WA. 77p.

LONG, E.R. & L.G. MORGAN. 1990. *The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program.* NOAA Tech. Mem. NOS OMA 52. NOAA. Seattle. 175p + Appendices.

MAC, M.J. & C.J. SCHMITT. 1992. Sediment bioaccumulation testing with fish. Pages 295-312. In: G.A. Burton, Jr. (Ed.). *Sediment Toxicity Assessment.* Lewis Publ. Boca Raton.

MacDONALD, D.D. 1997. *Tampa Bay Sediment Quality, Workshop: Setting Targets and Defining Management Strategies.* Prep. for Tampa Bay National Estuary Program. MacDonald Environmental Sciences Ltd. Ladysmith, B.C., Canada. DRAFT.

MacDONALD, D.D. 1995. *Sediment Assessment Group Workshop on Sediment Assessment in Tampa Bay*. Prep. for Tampa Bay National Estuary Program. MacDonald Environmental Sciences Ltd. Ladysmith, B.C., Canada. 44p.

MacDONALD ENVIRONMENTAL SCIENCES LTD. 1994. *Approach to the Assessment of Sediment Quality in Florida Coastal Waters. Volume I. Development and Evaluation of Sediment Quality Assessment Guidelines.* Prep. for FDEP. MacDonald Environmental Sciences Ltd. Ladysmith, B.C., Canada. 126 p.

McCONNELL, R., R. DeMOTT, & J. SCHULTEN. 1996. *Toxic Contamination Sources Assessment: Task I - Risk Assessment for Chemicals of Potential Concern and Methods for Identification of Specific Sources.* TBNEP Tech. Publ. #09-96.

MORRISEY, D.J., A.J. UNDERWOOD, & L. HOWITT. 1995. Development of sediment-quality criteria-- a proposal from experimental field-studies of the effects of copper on benthic organisms. *Mar. Pollut. Bull.* 31:372-377.

NATHAN, Y. 1984. The minerology and geochemistry of phosphorites. Pages 275-291. *In:* J.O. Nriagu & P.B. Moore (Eds.). *Phosphate Minerals.* Springer-Verlag. Berlin. 442p.

NETER, J., W. WASSERMAN, & M.H. KUTNER. 1985. *Applied Linear Statistical Models.* 2nd Ed. Irwin. Homewood, Ill. 1127p.

NOAA. 1993. *Sampling and Analytical Methods of the National Status and Trends Program-- National Benthic Surveillance and Mussel Watch Projects--1984-1992. Volume III. Comprehensive Descriptions of Analytical Methods.* NOAA Tech. Mem. NOS ORCA 71. Silver Spring, MD.

RAINBOW, P.S. 1990. Heavy metal levels in marine invertebrates. Pages 67-79. *In:* R.W. Furness & P.S. Rainbow (Eds.). *Heavy Metals in the Marine Environment.* CRC Press. Boca Raton.

SAMANT, H.S., K.G. DOE, & O.C. VIYADA. 1990. An integrated chemical and biological study of the bioavailability of metals in sediments from two contaminated harbours in New Brunswick, Canada. *Sci. Total* Environ. 96:253-268.

SCHROPP, S.J., F.J. LEWIS, H.L. WINDOM, J.D. RYAN, F.D. CALDER, & L.C. BURNEY. 1990. Interpretation of metal concentrations in estuarine sediments of Florida using aluminum as a reference element. *Estuaries.* 13:227-235.

SEAL, T.L., F.D. CALDER, G.M. SLOANE, S.J. SCHROPP, & H.L. WINDOM. 1994. *Florida Coastal Sediment Contaminants Atlas. A Summary of Coastal Sediment Quality Surveys.* FDEP. Tallahassee. 112p.

LITERATURE CITED (continued)

SHEAR, N.M., C.W. SCHMIDT, S.L. HUNTLEY, D.W. CRAWFORD, & B.L. FINLEY. 1996. Evaluation of the factors relating combined sewer overflows with sediment contamination of the lower Passaic River. *Mar. Pollut. Bull.* 32:288-304.

SOMERFIELD, P.J., J.M. GEE, & R.M. WARWICK. 1994. Soft sediment meiofaunal community structure in relation to long-term heavy metal gradient in the Fa1 estuary. *Mar. Ecol. Progr. Ser.* 105:79-88.

TAMPA BAY NATIONAL ESTUARY PROGRAM. 1996. *Charting the Course: The Comprehensive Conservation and Management Plan for Tampa Bay.* St. Petersburg.

TAMPA BAY REGIONAL PLANNING COUNCIL. 1986. *Documenting the Importance of Tampa Bay.* St. Petersburg.

USEPA. 1990. *Near-Coastal Program Plan for 1990: Estuaries.* USEPA. ORD. Narragansett, RI. EPA 600/4-90/033.

USEPA. 1992. *Proceedings of the EPA 's Contaminated Sediment Management Strategy Forums.* USEPA. Office of Water. Washington, DC. EPA 823-R-92-007. 215 p.

USEPA. 1993. *Environmental Monitoring and Assessment Program--Laboratory Methods Manual--Estuaries.* USEPA. Cincinnati, OH. [Draft]

WARD, T.J. & P.A. HUTCHINGS. 1996. Effects of trace metals on infaunal species composition in polluted intertidal and subtidal marine sediments near a lead smelter, Spencer Gulf, South Australia. *Mar. Ecol. Progr. Ser.* 135:123-135.

WINDOM, H.L. 1992. Contamination of the marine environment from land-based sources. *Mar. Pollut. Bull.* 25:32-36.