MORRO BAY

– LIST FOR ARSENIC

S/B BASED ON INORGANIC NOT TOTAL ARSENIC

1.95ppm 3.43ppm (TOTAL)

OEHHA SCREENING VALUE FOR I.O. As IS 1.0 ppm
USEPA SCREENING VALUE FOR I.O. As IS 1.2 ppm

$$\left.\begin{array}{l} 1.95 \times .10 = 0.0195\ (0.02) \\ 3.43 \times .10 = 0.0343\ (0.03) \end{array}\right\}$$ these are below USEPA S.V.

Change

Do not List

– 4 samples collected bet. 1983 - 2002

Ø EXCEEDING THE OEHHA 1.0 STD FOR INORGANIC As
Ø " " USEPA 1.2 STD " " "

4 80

California Environmental Protection Agency
CENTRAL COAST REGIONAL WATER QUALITY CONTROL BOARD

303(d) INVESTIGATIONS AND TMDL PROJECTS*

(Not all projects need to be approved at every level)

US Environmental Protection Agency approved TMI

Clear Creek TMDL for Mercury, *approved June 21, 2004 by USEPA, which is the effective date.*	Regional Board Resolution Technical Support Document MB**)
Morro Bay TMDL and Implementation Plan for Pathogens, Including Chorro and Los Osos Creeks, *approved January 20, 2004 (OAL approved November 19, 2003, which is the effective date)*	State Board and Regional Bo Resolution and Amendment Technical Support Document MB**)
Morro Bay TMDL and Implementation Plan for Sediment Including Chorro Creek, Los Osos Creek and the Morro Bay Estuary, *approved January 20, 2004 (OAL approved December 3, 2003, which is the effective date)*	State Board Resolution Regional Board Resolut Amendment Technical Support Docum MB**)
San Lorenzo River Nitrate TMDL, *approved January 14, 2003*	Technical Support Document MB**) Regional Board Resolution ar Amendment
San Lorenzo River TMDL for Sediment Including Carbonera Creek, Lompico Creek, and Shingle Mill Creek, *approved February 19, 2004 (OAL approved December 18, 2003, which is*	State Board Resolution Regional Board Resolution ar Amendment Regional Board Staff Report I 2003

Original submittal

✓

the effective date)	Regional Board Staff Report September 20, 2002 Supplemental Sheet for Sept[e] 2002 Technical Support Document MB**)
California Office of Administrative Law approved TM	
None at this time.	
State Water Resources Control Board approved TM	
None at this time.	
Regional Water Quality Control Board approved TM	
Dairy Creek Dissolved Oxygen TMDL	Staff Report Final Project Report Resolution
Los Osos Creek Nutrient TMDL	Staff Report Final Project Report (1.6 MB* Resolution
San Luis Obispo Creek Pathogen TMDL	Final Project Report (2.7 MB* Resolution
TMDLs currently in progress	
Aptos/Valencia Creek Sediment TMDL	Preliminary Project Report Appendices A & C Appendix B Report Appendix B Figures Appendix B Tables Appendix D Figure 1-1 Figure 2-1
Aptos/Valencia Creek Pathogen TMDL	Project Plan Progress Report
Carbonera Creek Pathogen TMDL	Project Plan
Chorro Creek Nutrient TMDL	Final Project Report

Chumash Creek Dissolved Oxygen TMDL	Final Project Report
Corralitos Creek Pathogen TMDL	Project Plan
Las Tablas Creek Mercury TMDL	Progress Report, October 20(2002 Project Report
Lompico Creek Pathogen TMDL	Project Plan
Los Osos Creek and Warden Creek Dissolved Oxygen TMDL	Final Project Report
Morro Bay Metals	Project Report Recommenda Delist Appendix 1 - State Mussel W. Appendix 2 - Monitored Asse: Data Appendix 3 - Tissue Data Appendix 4 - Coring Data
Pajaro River Nutrient TMDL (including Llagas Creek)	Draft Preliminary Project Rep MB**)
Pajaro River Sediment TMDL (including San Benito River, Llagas Creek and Rider Creek)	Preliminary Project Report (3. Special Studies related to the River Sediment TMDL
Salinas River Fecal Coliform TMDL	Project Plan
Salinas River Nutrient TMDL	Project Plan
Salinas River Pesticides	Project Report, *anticipated cc* *date, December 2004* Decision Document
San Lorenzo River Pathogens TMDL	Project Plan
San Lorenzo River Estuary Pathogens TMDL	Project Plan Progress Report

San Luis Obispo Creek Nutrient TMDL	Project Report
Santa Maria and Oso Flaco Fecal Coliform TMDL	Project Plan
Santa Maria and Oso Flaco Nitrate TMDL	Project Plan
Schwan Lake Pathogens TMDL	Project Plan
Soquel Lagoon Pathogens TMDL	Project Plan Progress Report
Waddell Creek Nutrient TMDL	Project Report: Recommenda Delist
Watsonville Slough Pathogen TMDL	Project Report: Pending Appendix A - Problems and S Report Appendix B - Source Identific Report
Watsonville Slough Pesticides TMDL	Project Plan
303(d) Investigations currently in progress	
Monterey Harbor Lead	Progress Report
Regional Sediment Assessment	Regional Sediment Assessm Project Report Appendices ABCE Appendix B McNeil Appendix D

*This page is updated monthly (last updated March 7, 2005)
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CCRWQCB

(450)

Project Report:

Keeling, Delist Morro Bay for Metals

[redacted] [redacted]

www.swrcb.ca.gov/rwqcb3/TMDL/documents/FinalDelistPROJECTReport

#450

Project Report:
Recommendation to Delist
Morro Bay, San Luis Obispo County, California
For Metals
From the 303(d) list

State of California
Central Coast Regional Water Quality Control Board
December 2003

Staff contact information:
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Proposal to Delist Morro Bay for Metals

1. Introduction

Morro Bay (Bay) was added to California's 303(d) list for metals in 1996, because levels of certain metals in the tissue of shellfish exceeded Median International Standards[1] (MIS) and were greater than Elevated Data Levels[2] (EDLs) as reported by the State Mussel Watch program along with anecdotal evidence that cannot be verified. This document reviews the 303(d) listing of Morro Bay, describes several monitored assessments or studies performed in the area after the initial listing, and recommends that Morro Bay be removed from the 303(d) list of impaired waters for metals.

1.1. What was the *basis* for listing Morro Bay as impaired for metals?

Morro Bay was placed on the 303(d) list in 1996 based on exceedences of MIS values and EDL numbers reported by State Mussel Watch Program. According to Region 3 files, the listing appeared to be based entirely on **tissue** data. The tissue was from resident and transplanted California mussels.

There were four sample sites that State Mussel Watch had used between 1980 and 1993. According to Regional Board files, only **two** sites were used to list Morro Bay. They were sites 429.0 and 429.2 (see Figure 1). Site 429.0 is outside the mouth of the Bay and site 429.2 is just inside the Bay. Site 429.0 was sampled on 6/28/1982, 1/21/1983 and 5/3/1983. Site 429.2 was sampled on 1/26/1987, 3/14/1988, 12/19/1988, 2/2/1990 and 1/20/1993. Sites sampled followed State Mussel Watch Program sampling protocol. Data for sampling locations (including two additional sites not used for listing purposes) are shown in Appendix 1.

The metals in the initial listing were Aluminum (Al), Arsenic (As), Cadmium (Cd), Chromium (Cr), and Mercury (Hg). The rationale for why Morro Bay was listed is described below. Other metals that did not exceed literature values, and therefore were not part of the reason the Bay was listed, will not be mentioned here.

Al – Site 429.2, on 1/20/1993, had an exceedence of an EDL 85 with a value of 180 ppm wet weight. One out of eight analyzed samples exceeded the EDL 85 of 138.43 ppm.

As – Site 429.0, on 1/21/1983 and 5/3/1983, had levels of 1.95 ppm and 3.43 ppm weight wet. These levels were cited as exceeding MIS (1.5 ppm wet weight is the MIS for shellfish). Two out of two samples exceeded the MIS.

Cd – Site 429.2, on 1/26/1987, 3/14/1988, 12/19/1988, 2/2/1990 and 1/20/1993 had levels over the MIS values (levels ranged from 1.01 – 1.23 ppm wet weight). Five out of five samples at site 429.2 were over MIS. One out of three samples were above MIS values at site 429.0 (6/28/1982, 1.17 ppm wet weight).

[1] Median International Standards are values compiled by the State Water Resources Control Board as in-house guidance provided to the Regional Boards. They are based on criterion developed from a United Nations Food and Agriculture Organization publication of a survey of health protection criteria used by member nations (Nauen 1983). They are guidance values only.
[2] Introduced by State Water Resources Control Board staff in 1983 as an internal comparative measure (2000).

Cr – Site 429.2, on 1/20/1993, had a value that was 0.5 ppm over the MIS standard of 1.0 ppm (1.5 ppm wet weight). No samples at site 429.0 were above the EDL or MIS values. Therefore, one out of five samples was above the MIS for site 429.2 and zero out of three samples were above either a MIS or EDL for site 429.0.

Hg – Two samples out of eight were above the EDL 85 values (0.06 ppm) with concentrations of 0.136 ppm and 0.061 ppm wet weight on 1/26/1987 and 1/20/1993 respectively. Both samples were taken at site 429.2.

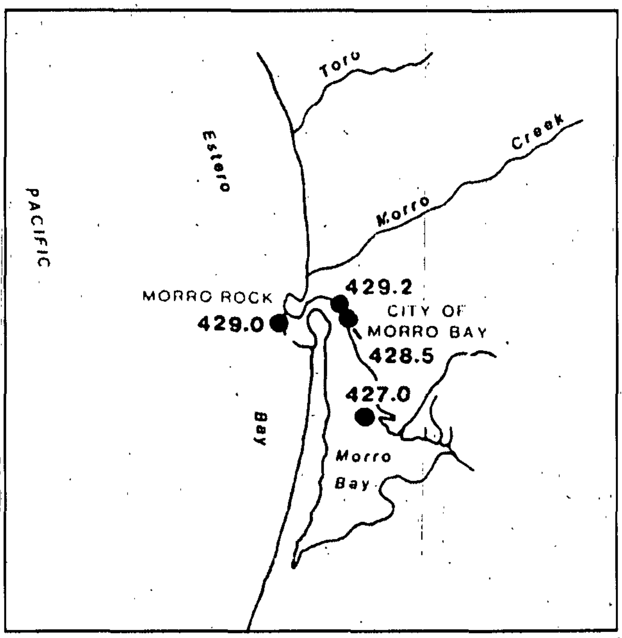

Figure 1: State Mussel Watch Program's sampling sites, Morro Bay, CA

1.2. Assessment Studies

There were three studies conducted since the 1996 listing to determine if impairment existed in Morro Bay due to metals. First, Regional Board staff took a broad sampling of sediment and water samples in the Bay and contributing watershed. This study will be referred to as the "assessment study." Second, California Polytechnic, San Luis Obispo (Cal Poly) took native clam samples in various areas of the Bay and analyzed their tissue for the concentration of certain metals. This study will be referred to as the "tissue sampling study." And finally, a University of California at Berkeley (UC Berkeley) PhD candidate student conducted a study that consisted of taking sediment cores at four different sites in the Morro Bay estuary. This study will be referred to as the "coring study." All three of these studies contributed vital information towards the conclusion that Morro Bay be removed from the 303(d) list.

1.3. Background

1.3.1. <u>General site background</u>

Morro Bay is a natural embayment located on the central coast of California, about 60 miles north of Point Conception and about 100 miles south of Monterey Bay (Figure 2). The contributing watershed area for Morro Bay is estimated to be 48,450 acres (USDA-SCS, 1989). Chorro Creek drains about 65 percent of the watershed and Los Osos Creek drains the remaining 35 percent. The watershed's highest elevation is 2,763 feet above sea level and its farthest point from the Bay is approximately 10 miles. The primary land uses are agriculture, urban lands, and multi-use public lands (MBNEP, 2000). The geology of the watershed is a mix of igneous, metamorphic and sedimentary rock less than 200 million years old. Debris landslides, soil creep, and large slumps occur within this terrain, usually triggered by intense rainstorms (USDA-SCS, 1989).

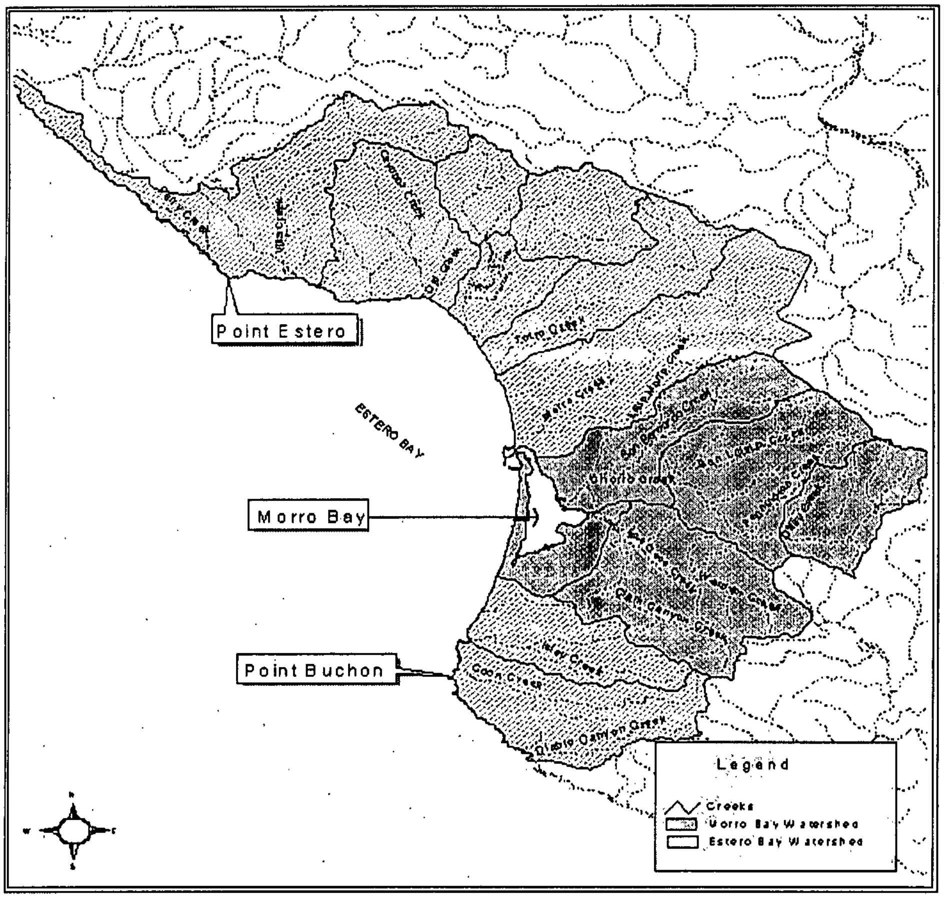

Figure 2: Morro Bay/location

The Bay originally had a larger opening to the ocean that was closed in 1911. This closure, which connected the "Morro Rock" to the mainland, may have had an effect on the natural flushing of the Bay. However, the details of the hydrology and the social implications of what would happen should the man made connection be removed are beyond the scope of this report.

1.3.2. Metals background

The Jurassic-Cretaceous Franciscan Formation underlies 80% of the watershed. The Franciscan Formation is a mixture, consisting of sandstone (greywacke), claystone, shale, chert, conglomerate and a variety of metamorphic rocks including serpentine. It is well known that these types of mafic rocks contain high levels of magnesium, iron, vanadium, nickel, chromium and manganese. In fact, natural levels were sufficiently high that chromium had been mined in portions of the watershed. Therefore, based on this type of geology, high levels of metals in the sediment would be expected.

Studies conducted by Marine Research Specialists as part of the City of Morro Bay/Cayucos Sanitary District Offshore Monitoring and Reporting Program (2002) show that the concentration of metals in the sediment are increasing over time, *outside* the Bay, in the area just north of Morro Rock. Dredged material from inside the Bay is often deposited in this area. Since the Bay and estuary have high levels of metals in the sediment, removing sediment from an area of high concentration and releasing it in an area of low concentration, would likely increase the overall concentration in the area just north of Morro Rock.

Although there are high levels of metals in the sediment, it does not appear that these metals are in the water column at elevated levels (Regional Board sample collection March 2001[3]). It was unclear if these high levels in the sediment should be considered as pollution or if they should be considered natural due to the geologic nature of this area. It was also unclear if metals at these levels pose a threat to aquatic organisms, or if the organisms have adapted to the metals in the sediment. Other than naturally occurring metals in the contributing watershed, possible sources included urban runoff, boat hull paints, and historic mining operations. There is no heavy industry discharging to Morro Bay that would contribute additional metals.

With this background information, Regional Board staff set out to determine if impairment due to metals existed. Before the studies are addressed, a quick review on the standards relating to metals is provided below.

2. Metal Objectives

2.1. Basin Plan Objectives

According to Region 3's Water Quality Control Plan (Basin Plan) (Regional Water Quality Control Board, 1994), there should not be any constituents present in water bodies at levels which compromise beneficial uses. Numeric objectives exist for water; however, no numeric objectives exist for either sediment or tissue. Beneficial uses for Morro Bay include: industrial service supply, water contact recreation, non-contact recreation, wildlife habitat, cold freshwater habitat, fish migration, fish spawning, preservation of biological habitats of special significance, preservation of rare and endangered species, estuarine habitat, commercial and sport fishing, aquaculture, and shellfish harvesting.

Water

The Basin Plan contains both narrative (Table 1) and numeric (Table 2) water quality objectives for specific metals and beneficial uses. The narrative objective is interpreted to mean that concentrations of metals, in this situation, should not exist in a suspended or settleable form in the water column. Water quality objectives in the Basin Plan are expressed as concentrations of *total*

[3] Five (5) water samples were taken in the Bay during a heavy storm. No samples exceeded California Toxics Rule standards. See section 3 for discussion of results.

metals in the water column. In addition to the Basin Plan, the California Toxics Rule (Federal Register, 2000) provides water quality objectives expressed as *dissolved* metals concentrations. Where the California Toxics Rule is more stringent than the Basin Plan, California Toxics Rule supersedes the Basin Plan (Federal Register, 2000, pp 31687). Similarly, if the Basin Plan is more stringent than the California Toxics Rule, Basin Plan numbers shall be used.

Table 1: Basin Plan's Narrative Objective Description

Suspended Material	Waters shall not contain suspended material in concentrations that cause nuisance or adversely affect beneficial uses.
Settleable Material	Waters shall not contain settleable material in concentrations that result in deposition of material that causes nuisance or adversely affects beneficial uses.

Table 2: Basin Plan's Water Quality Objectives for metals in marine environments

Metal	Total Concentration (μg/L)
Cadmium	0.2
Chromium	50
Copper	10
Lead	10
Mercury	0.1
Nickel	2
Zinc	20

2.2. California Toxics Rule

Water

It is now the State Water Resources Control Board's policy to use dissolved metals measurements to evaluate compliance with aquatic life water quality standards because dissolved metal more closely approximates the bioavailable fraction of the metal in the water column than does total recoverable metal (40 CFR Part 131, 2000, pp 31690). Therefore, based on this policy and based on the rationale that dissolved metals more closely approximate the bioavailable fraction of metal in the water column, results from the water column will be tested for dissolved metals (Table 3) instead of total metals measurements as this is considered the most protective measurement for protection of aquatic life.

Table 3: California Toxics Rule[4] Water Quality Standards for metals in marine environments

	Saltwater	
Metal	Criterion Maximum Concentration, dissolved (µg/L)	Criterion Continuous Concentration, dissolved (µg/L)
Arsenic	69	36
Cadmium	42	9.3
Chromium (total)	1100	50
Copper	4.8	3.1
Lead	210	8.1
Nickel	74	8.2
Selenium	290	71
Silver	1.9	no value given
Zinc	90	81

2.3. Other guidance (sediment and tissue)

Sediment
One set of *guidance* values used to evaluate sediment concentrations are the NOAA SQuiRT values (Screening Quick Reference Tables). SQuiRT presents screening concentrations for inorganic and organic contaminants in various environmental media. These screening concentrations were derived initially using a database compiled from studies performed in both saltwater and freshwater in all different areas in North America and published in NOAA Technical Memorandum NOS OMA 52. The tables are intended for preliminary screening purposes only; they do not represent official NOAA policy and do not constitute criteria or clean-up levels. Users of SQuiRT values are strongly encouraged to review supporting documentation to determine appropriateness for their specific use. In other words, in certain situations use of these values may not be appropriate. The Morro Bay watershed, with it's naturally occurring mafic formations, may not be a good place to use the SQuiRT values because concentrations of metals in this area are not typical when compared with the general average of North American values.

Tissue
Most metals do not have a standard tissue objective established by United States Environmental Protection Agency (USEPA), California Office of Environmental Health Hazard Assessment (OEHHA), United States Food and Drug Administration, Department of Health Services (DHS) or US Fish and Wildlife. The few metals that do have standards include: arsenic with a USEPA standard of 1.2 ppm (wet weight) for inorganic arsenic, an OEHHA objective of 1.0 ppm (wet weight) for total arsenic, cadmium with a USEPA standard of 4.0 ppm (wet weight) and OEHHA standard of 3.0 ppm (wet weight) and copper with a U.S. Fish and Wildlife Biological Effects level set at 15 ppm (wet weight). All the other metals that were tested in tissue do not have approved standards to compare against.

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[4] Taken from Federal Register. Volume 65, No. 97. Part III. Environmental Protection Agency, 40 CFR Part 131. Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California; Rule. Thursday, May 18, 2000.

Additionally, the US Food and Drug Administration's (USFDA) (1993) cites a chromium level of concern for shellfish tissue at 13 ppm (FDA 1993). Because of the lack of tissue standards surrounding Cr, staff will use this value as a guidance value.

Although there are no approved United States standards to compare all tissue values against, there are values called median international standards (MIS). MIS is a "literature value" criterion developed from a United Nations Food and Agriculture Organization publication of a survey of health protection criteria used by member nations (Table 4). Though the standards do not apply within the United States, they provide an indication of what other nations consider to be an elevated concentration of trace elements in shellfish (State Mussel Watch Program, 2000). These MIS values will be used as "literature" values to evaluate the tissue data collected in the Tissue Sampling Study.

Table 4: Median International Standards for Trace Elements, (values in table are for the edible portion, ppm, wet weight), (Nauen 1983)

Element	Freshwater fish	Shellfish	Range	Number of Countries with Standards
Arsenic	1.5	1.4	0.1 to 5.0	11
Cadmium	0.3	1.0	0.05 to 2.0	10
Chromium	1.0	1.0	1.0	1
Copper	20.0	20.0	10 to 100	8
Lead	2.0	2.0	0.5 to 10.0	19
Mercury	0.5	0.5	0.1 to 1.0	28
Selenium	2.0	0.3	0.3 to 2.0	3
Zinc	45.0	70.0	40 to 100	6

3. Listing "Guidelines" for California, 1997

Regional Board staff considered factors identified in the 1998 Clean Water Act Section 303(d) Listing Guidelines for California (Ad Hoc Workgroup, 1997) for removing waterbodies from the 303(d) list. While these guidelines were never formally reviewed and approved as policy or official criteria, they were developed by staff with relevant expertise from the Regional Water Quality Control Boards, the State Water Resources Control Board, and the US Environmental Protection Agency. Therefore, Region 3 staff believes they provide a reasonable basis for considering whether to delist a waterbody. As of the date of writing this document, California still does not have an established listing or delisting policy.

The six Factors recommended in 1997 for delisting a waterbody were:

1. Objectives are revised, and the exceedence is thereby eliminated.
2. A beneficial use is de-designated after US EPA approval of a Use Attainability Analysis, and the non-support issue is thereby eliminated.
3. Faulty data led to the initial listing. Faulty data include, but are not limited to typographical errors, improper quality assurance/quality control (QA/QC) procedures, or Toxic Substances Monitoring/**State Mussel Watch EDLs which are not confirmed by risk assessment for human consumption.**
4. It has been documented that the objectives are being met and beneficial uses are not impaired based on "Monitored Assessment" criteria.
5. A TMDL has been approved by the US EPA.
6. There are control measures in place which will result in protection of beneficial uses. Control measures include permits, cleanup and abatement orders, and watershed management plans which are enforceable and include a time schedule.

As can be seen in bullet number three, State Mussel Watch EDLs are not considered to be a reason for listing. Al and Hg were listed as metals of concern based on EDL levels. Therefore, staff recommends that Morro Bay be delisted as impaired by Al and Hg because EDLs should not have been considered for listing purposes; therefore, we will not be discussing these metals further. Additionally, MIS values are no longer used as a value to indicate impairment of tissue. Because the recommendations above are guidelines, and not a policy, staff decided to go forward with a Monitored Assessment, in order to better ascertain that beneficial uses are being met and the waterbody is not impaired. Monitored Assessment data follow.

4. Assessment Study

Regional Water Quality Control Board (Regional Board) staff conducted a monitored assessment on March 7 and 8, 2001. The sample collection on March 7 and 8 was after a period of very heavy rain. Sampling after a period of very heavy rain was meant to mimic worst-case scenarios with regard to water quality in the Bay because metals are carried via suspended sediment. The assessment was designed to be consistent with recommendations as mentioned above.

4.1. Methods

4.1.1. <u>Water</u>

Water was sampled from five (5) separate locations throughout the Bay on March 8, 2001. The separate locations were meant to represent the back, middle and front of the Bay and were also meant to represent the flow from the two creeks that feed the Bay (sites were Front Bay, Middle Bay, Back Bay, Mouth Chorro and Mouth Los Osos – see Figure 3). Battelle Laboratory, a National Environmental Laboratory Accreditation Program Certified Lab, which specializes in getting low detection limits in salt water, analyzed samples for dissolved metals (aluminum, arsenic, barium, cadmium, chromium, copper, lead, mercury, nickel, vanadium and zinc).

4.1.2. <u>Sediment</u>

Sediment was sampled from 16 separate locations (see Figure 3). Specific locations were chosen for multiple reasons. For example, some were chosen to represent historical sites that had been used as sampling sites for other studies. Others were chosen to represent separate land uses (e.g. representative of where a storm drain exits into the Bay or where boat use is heavy). And finally, some were chosen to represent influences from the two separate creeks, Chorro and Los Osos, which feed the estuary and the Bay. BC Labs analyzed sediment by using EPA method SW-6010 which tested for aluminum, arsenic, barium, cadmium, chromium, copper, iron, lead, nickel, vanadium and zinc. Results were reported as total metals on a dry weight basis. Mercury was analyzed using EPA method SW-7471.

In addition to sampling the sediment for the presence of metals, five of the samples were also put through an 18-hour Synthetic Precipitation Leaching Procedure test (SPLP) (EPA method number 1312) in deionized water to determine if the sediment released metals into an aqueous environment. A deionized water leaching process was chosen instead of the standard acid leaching process in order to better mimic natural conditions.

The SPLP test was designed to mimic rainfall events, hence the name synthetic precipitation. Standard procedures indicate that a SPLP test run on samples west of the Mississippi should be analyzed using deionized water with a pH of 5.0 and a minute amount of a sulfuric nitric solution. This solution is created by taking a gallon of deionized water, dipping a rod into a mixture of 60/40% sulfuric nitric acid and stirring the gallon of water with this rod. Next, a rod is dipped into this newly created mixture, removed and placed into another new gallon of deionized water. As described, very little acid is present in the deionized water mixture. In retrospect, using the standard "acid" leaching test would have been the more appropriate test to run, however, based on the extremely small amount of acid used in the test, the results obtained in this study should be fairly similar to what would have been obtained using the standard acid SPLP test (Penner, pers. comm. 2003).

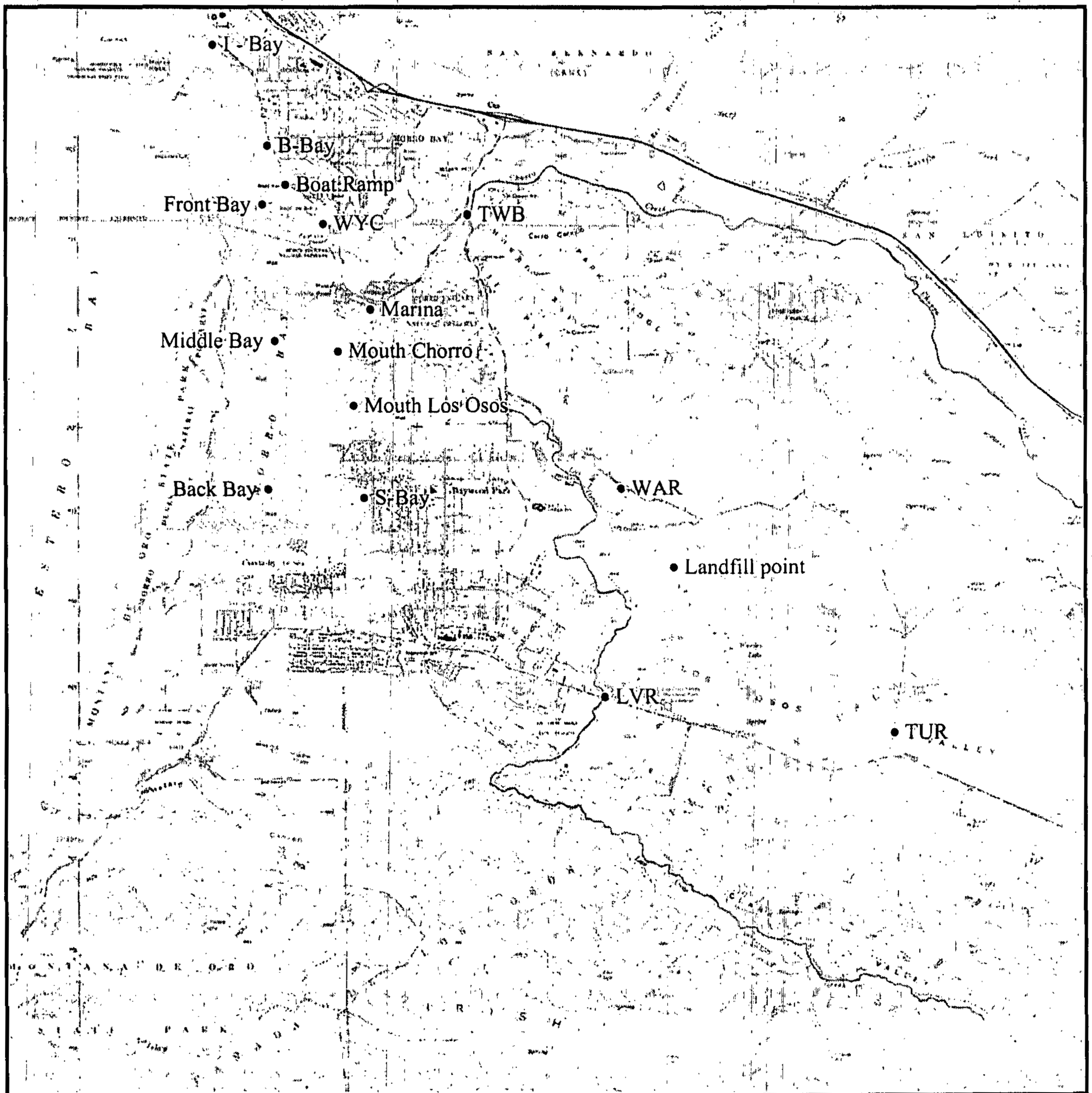


Figure 3: Sampling locations for monitored assessment (both water and sediment samples taken).

4.2. Results of the Monitored Assessment

4.2.1. Water

Of the five samples taken in the Bay, there were no violations of any kind for dissolved metals in the water column. The California Toxics Rule states that grab samples shall be compared against Criterion Maximum Concentration and that samples taken over a 4-day period shall be compared against the Criterion Continuous Concentration. Because samples were taken on one day, they were compared against the Criterion Maximum Concentration. Even when the metals were compared against the Criterion Continuous Concentration, the metals were far below the standard with the exception of two samples (Mouth of Los Osos Creek and Mouth of Chorro Creek) that were slightly above the Criterion Continuous Concentration for Ni at 8.450 and 11.300 µg/L respectively (the standard is 8.2 µg/L). These samples were taken on a day that the Bay was extremely turbid due to an intense rainstorm and a significant amount of sediment had washed down from the watershed. Therefore, this day represented a worst-case scenario. The majority of the time the turbidity in the Bay is much lower and it is expected that this condition would not persist even when compared to the 4-day time period of the Criterion Continuous Concentration.

4.2.2. Sediment

Levels of metals in the sediment were fairly high when compared with NOAA SQuiRT values. Metal concentrations of sediment samples indicated that on the whole, concentrations were highest in the middle and back-Bay, moderate in the creeks and lowest near the areas that were selected to represent boat use and storm drain outlet areas. Graphs of data for chromium and nickel are shown in Figure 4 and 5. All metals exhibited similar patterns. Graphs of all metals tested for are included in Appendix 2.

Results from the SPLP analysis, that is, the *water* tested after being in contact with the sediment sampled for 18 hours, yielded virtual nondetects in all five samples (no values were greater than 0.012 µg/L – total metals).

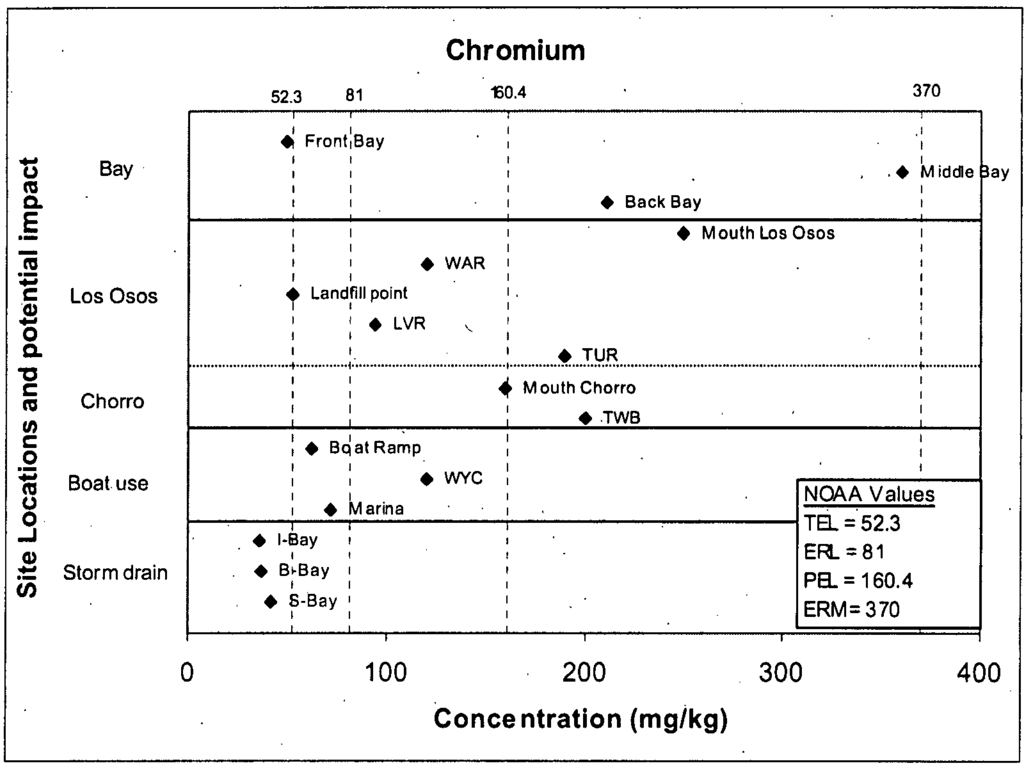


Figure 4: Graph of chromium concentrations in various locations throughout the Morro Bay Watershed.

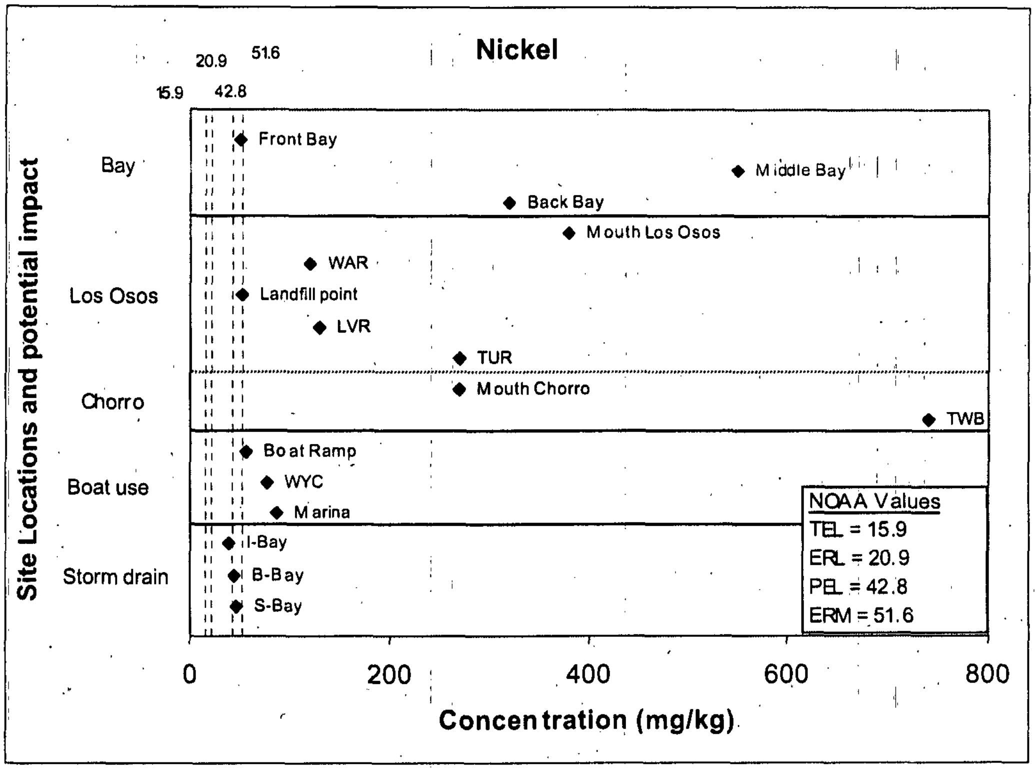


Figure 5: Graph of nickel concentrations in various locations throughout the Morro Bay Watershed.

4.3. Discussion/conclusions

4.3.1. Water

Levels of metals in the water column are not above any of the standards and are not considered to be problematic.

4.3.2. Sediment

Based on the sediment samples, boats and storm drain runoff land use areas did not seem to be significant metal sources. It appeared the metals were coming from the creeks and settling in the Bay; specifically hanging up where the creeks emptied into the Bay. Concentrations of metals are the highest in the middle of the Bay. It appears that the sediment bound metals travel down the creeks and into the Bay. The area in the middle of the Bay is most likely a depositional area where sediment accumulates and is spread-out as the tide comes in and out. Towards the mouth of the Bay the levels of metals decrease. This is most likely due to mixing with littoral sand, flushing from the tides and the increased distance from the creek mouths.

Levels of metals in the sediment are clearly elevated as compared to NOAA SQuiRT values, however based on the above study; they do not appear to be elevated due to stormwater or boating operations. They appear to be coming from the distal parts of the watershed.

In this particular situation, NOAA SQuiRT values were initially used to evaluate the results of the sediment collected from the assessment study. On closer inspection, it became apparent that the concentration of the sediment far exceeded most of the guidelines set up by the SQuiRT tables even in areas that would have been taken to represent "background" samples. After completing the final study, staff decided that in this case, SQuiRT tables were not appropriate in this area due to the high levels of natural background in the soil.

It should be noted that leaching of metals from the sediment into the water is not expected to happen based on the results from the SPLP analysis. This is because virtually nondetectable levels of metals were found in the water analyzed. As mentioned in the methods section, the SPLP analysis was designed to mimic the leaching of elements from substrate into water during rainfall events. Please see Appendix 2 for details.

5. Tissue Sampling Study

Based on the water sampling results, staff concluded that levels of metals in the water were not problematic. However, levels of metals in the sediment may pose a problem to aquatic organisms living in the sediment and other organisms that feed on them. Therefore, a study was done to determine if these aquatic organisms were absorbing these metals into their tissue.

5.1. Methods

A Cal Poly student (Jennifer Pehaim) under the supervision of professor Dr. Yarrow Nelson, took native clams (*Macoma secta* and *Macoma suda)* from five separate areas in the Bay, homogenized their tissue and analyzed them for the concentration of metals. Sampling protocols followed State Mussel Watch guidelines. Sediment samples were also analyzed to compare values between tissue and sediment. Locations of the five sampling areas are similar to the assessment study and are shown in Figure 6. Samples were taken on April 29 and May 4-5, 2002. These days were chosen to take advantage of the negative tides occurring during the daylight hours. For some metals, only two sites were chosen to analyze tissue and sediment due to budgetary reasons.

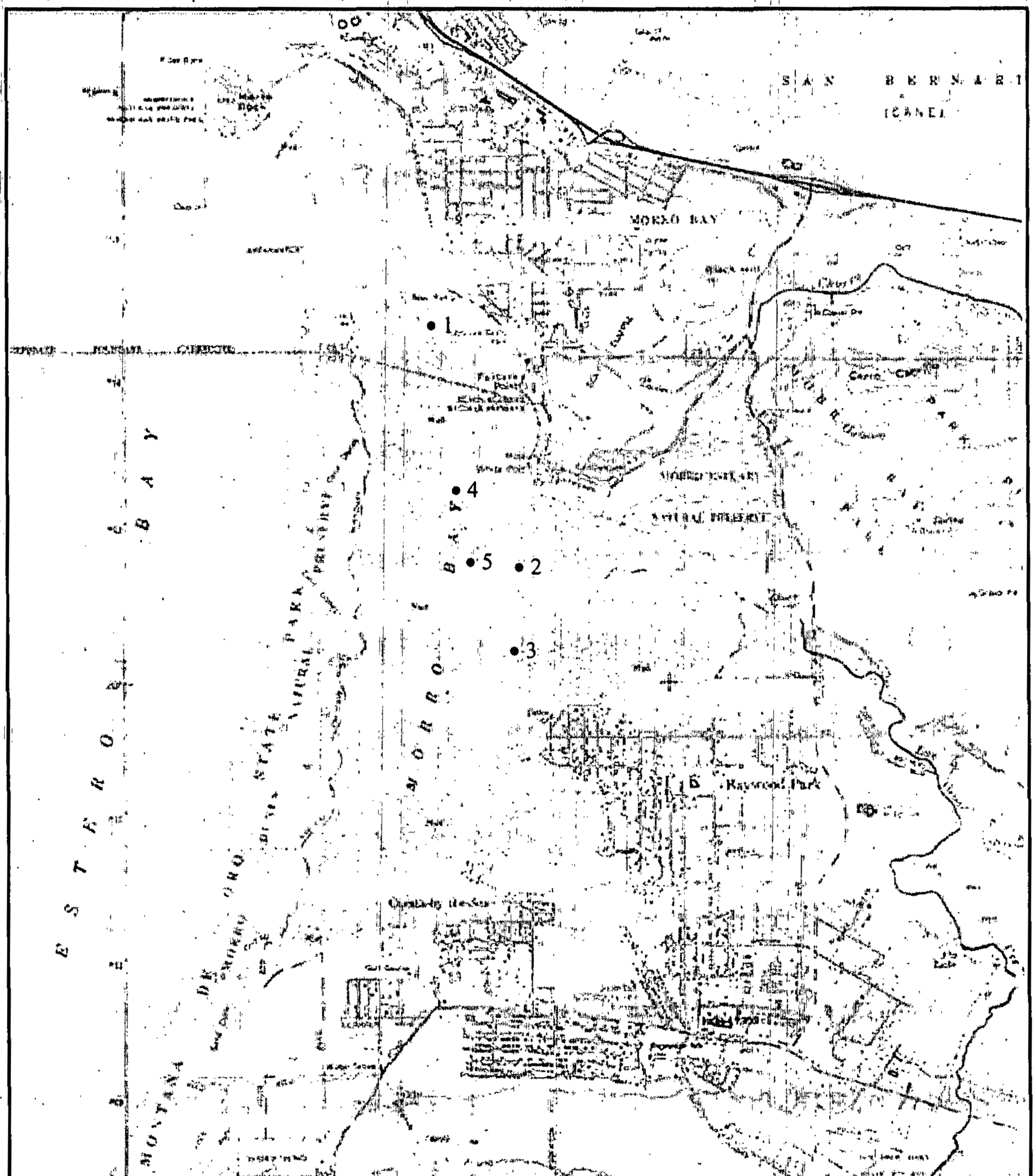


Figure 6: Tissue Study sample locations
Site 1 =Front Bay, 2= Chorro Mouth, 3= Osos Mouth, 4= North Middle Bay and 5= South Middle Bay

5.2. Results

Metal concentrations for sediment and clam tissues, averaged over all sites are shown in Figures 7 and 8.

Evaluating each site individually, no tissue was over an established limit. Chromium, lead, zinc, iron, nickel and vanadium do not have any standards to measure the data against. Please see Appendix 3 for data details.

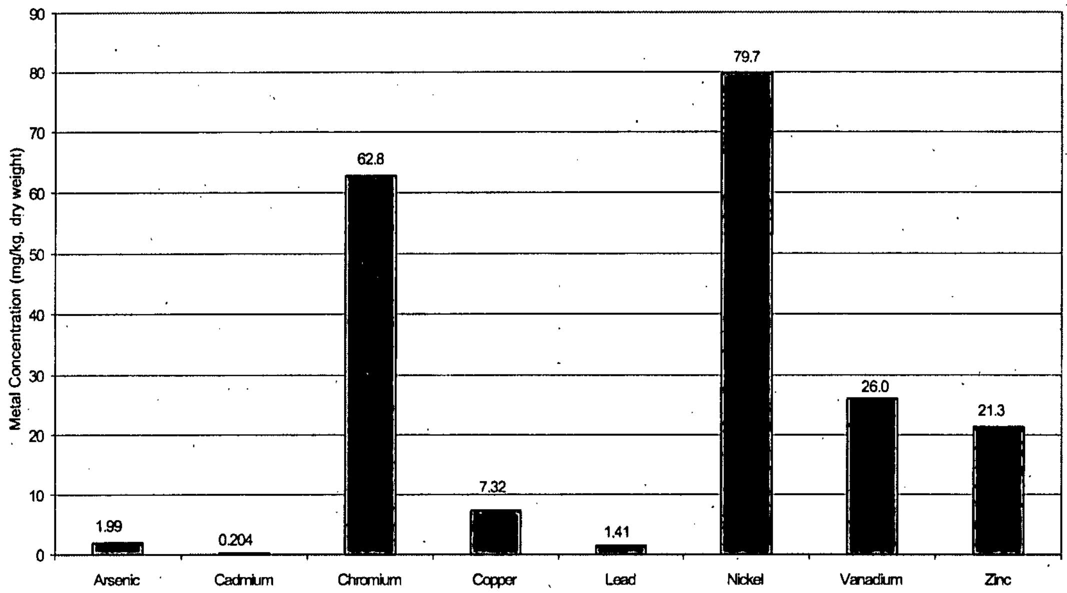


Figure 7: Metal concentrations averaged by metal over all sites, for sediment.

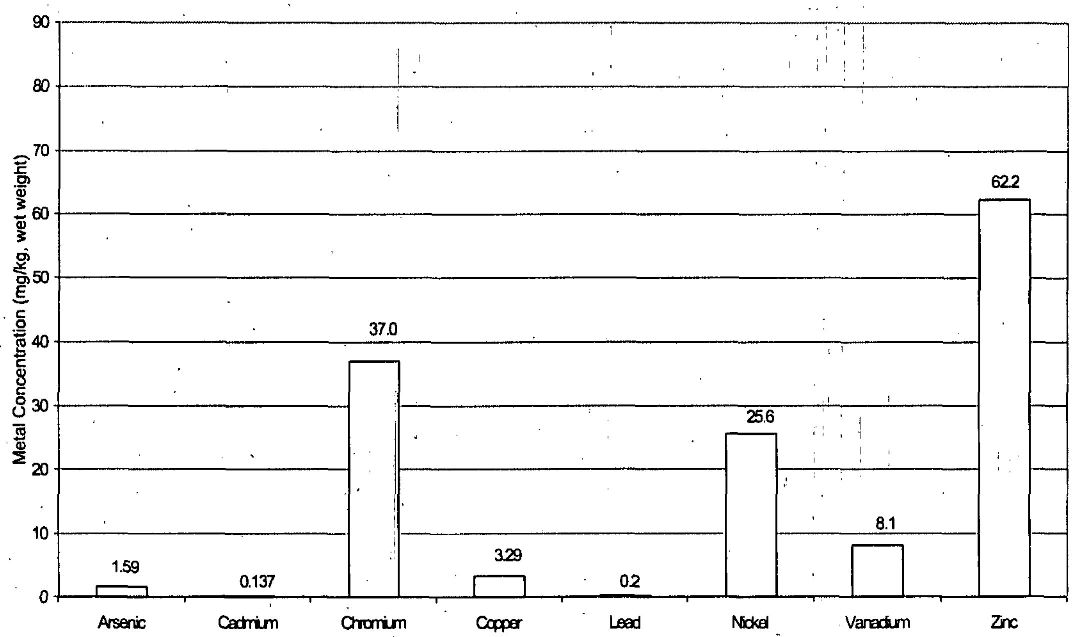


Figure 8: Metal concentrations averaged by metal over all sites, for tissue.

5.3. Discussion/conclusions

Although these preliminary results are based on only a small amount of data, some general conclusions can be made. The following discussion is sorted by metal.

- Arsenic - Clam tissue concentrations in the two sites were below the USEPA screening value (1.2 ppm for inorganic arsenic) and were slightly above the OEHHA screening value (1.0 ppm for total arsenic). Tissue measured at 1.45 and 1.74 ppm measured as total arsenic. The inorganic portion of arsenic is the form of arsenic that is a human health concern. Typically, 10%, or less than 10% in marine environments, is the most likely amount of inorganic arsenic when compared with the total arsenic reading. Taking the highest value obtained of 1.74 ppm and multiplying it by 10% gives us 0.174 ppm, which is below the USEPA value.
- Cadmium – No exceedences of standards (EPA and OEHHA values of 4.0 and 3.0 ppm weight wet). Tissue values measured ranged between 0.0373 and 0.490 ppm.
- Chromium – Fairly high levels of chromium were evident from all five sampling locations. Although the levels in the tissue are high, it is probable that levels of chromium in clam tissue has been high for over a century based on the natural geology of the area. The MIS value is 1.0 ppm, based on only one country (Hong Kong, 1983). US Food and Drug Administration cites a level of concern of 13 ppm (FDA 1993). Tissue values measured ranged between 5.96 and 104 ppm.
- Copper – US Fish and Wildlife Biological Effects value for copper is 15 ppm. There were no exceedances for copper. Tissue measured at 2.85 and 3.73 ppm.
- Iron – No standards exist.
- Lead – No standards exist. When compared with MIS values, there was one slight exceedence of "literature" values (MIS value is 2.0 ppm). Tissue values were 0.348 and 2.16 ppm respectively.

- Nickel - no standards exist. Tissue values ranged from 6.41 to 68.0 ppm.
- Vanadium - no standards exist. Tissue values ranged from 0.799 to 22.3 ppm.
- Zinc - Significantly higher zinc concentrations were observed in the clam tissues compared to the zinc concentrations in the sediments, indicating that zinc might bioaccumulate in these two species of clams. Information regarding the characteristics of shellfish meat indicates that these organisms are well known for being a good source of zinc in one's diet. Therefore, it may be due to a certain metabolic process that zinc is higher in these clams. MIS value for zinc is 70 ppm and the tissue samples were 32.8 and 91.7 ppm.

Some clams have slightly elevated levels of Cr and Zn in their tissue when compared against the few guidance values and "literature" values that exist. However, this brings us to the question of where are these metals coming from? Have the clams always had higher levels of metals in their tissue based on natural conditions of the area? If so, does having a slightly higher level of metal in its tissue mean it is harmful for the organism? An attempt to answer these questions is in the next section.

6. Coring Study

Based on the two studies above and background information, staff was fairly confident that the levels of metals in the sediment were coming from the geologic formations in the watershed. It did not appear that the levels of metals were problematic in the water. Although Cr and Zn appeared elevated in the clam tissue, the question still remained...was this high concentration of metals natural or not? And, for how long have concentrations been as they are now? A coring study was developed to answer these questions.

6.1. Methods

UC Berkeley students (Liam Reidy and David Wahl) recovered several sediment cores from the salt marshes surrounding Morro Bay for stratigraphic and sedimentological analyses (Figure 9). Sediment cores were collected on July 25-26, 2002. A hand operated Livingston piston corer was used to recover the cores. The cores (Chorro, Morro and Los Osos) measured 143 cm, 320 cm, and 307 cm, respectively. In addition to the marsh cores, Reidy and Wahl also recovered one short core, which measured 80 cm, from a tidal mudflat within the Bay, for heavy metal analysis. Cores were encased in plastic core liners and/or plastic wrap, and transported to the UC Berkeley Pollen Laboratory for sub-sampling and analysis. Some cores were shorter than others due to the inability to penetrate a sand layer.

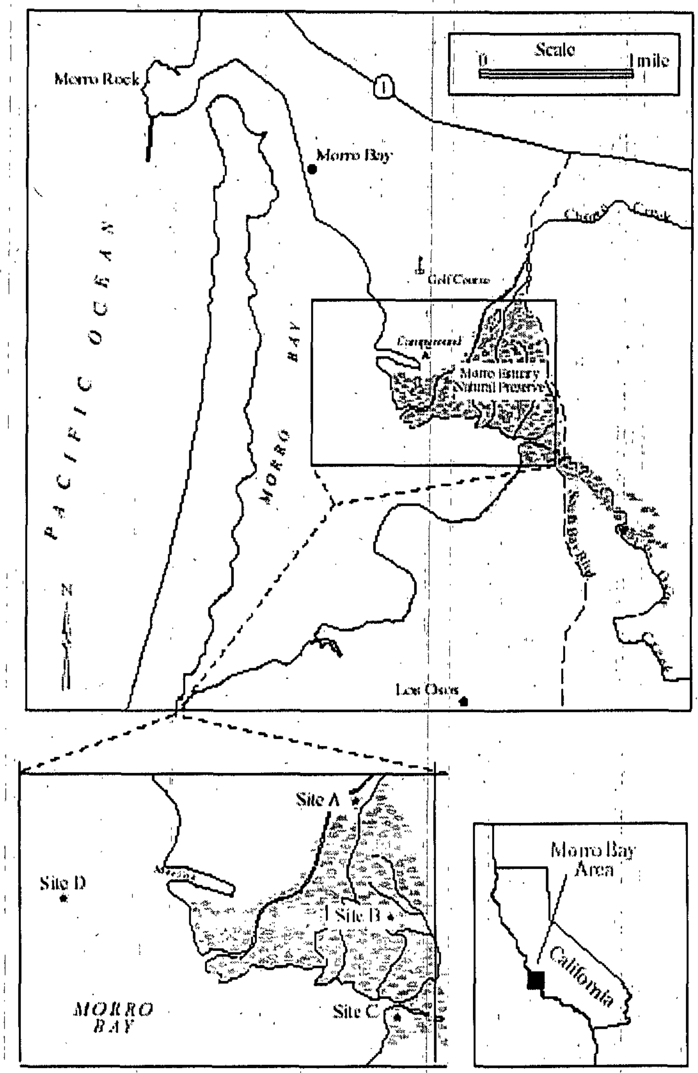


Figure 9: Map of the Morro Bay Estuary showing the coring locations
Site A = Chorro site, Site B = Morro Site, Site C = Los Osos site, and Site D = Mudflat site.

Cores recovered from the Morro Bay Estuary were correlated to each other using a combination of the first appearance of non-native pollen types, radiocarbon dating (Gallagher, 1996), the peak in anthropogenic lead, and magnetic susceptibility (Reidy and Byrne, unpublished data). A discussion of these methods provided by Liam Reidy follows below.

Non-Native Pollen

Fortunately, in California it is possible to date recent (i.e. < 300 year old) sediment cores by the first appearance of non-native pollen types (Mudie and Byrne, 1980; Cole and Liu, 1994; Mensing and Byrne, 1998; Cole and Wahl, 1999; Reidy, 2001). Many plant species not indigenous to California have been introduced into the Morro Bay area in historic times, and in some cases their pollen can be readily identified to the species or genus level. These non-native pollen types are therefore useful chronological markers, especially if the history of introduction is well known. Two important non-native pollen types in the Morro Bay marsh cores are: Red-stem filaree (*Erodium cicutarium*) and Blue gum (*Eucalyptus globulus*).

In the Morro marsh core, *Erodium cicutarium* pollen first appears at the 210 cm level. This probably reflects the arrival of the Spanish in the Morro Bay area during the second half of the 18th Century. There is a possibility that this species arrived in California just prior to Spanish settlement (Mensing and Byrne, 1998). *Erodium* pollen has been found in a core from the Santa Barbara channel at levels dating to A.D. 1750-1765 which predate the establishment of the mission at San Diego in A.D. 1769. Mission San Luis Obispo de Tolusa, located 12 km to the south-east of Morro Bay was established in A.D.1772. We therefore assume that first appearance *Erodium* in the Morro marsh core represents a date of A. D. 1770 ±10yrs. Preliminary results from the Los Osos core indicate that the first appearance of *Erodium* occurs at the 120 cm level.

Eucalyptus pollen first appears in the Morro marsh core at 60 cm. We interpret this to represent A.D. 1920 ±10 yrs. This estimate is based on the known date of *Eucalyptus* plantings as windbreaks in the area close to the marsh in ca. A.D. 1915, and the founding of the Morro Bay golf course in A.D. 1928 (Gates and Bailey, 1982). *Eucalyptus* was first planted in the city of Morro Bay as early as A.D. 1865 (Gallagher, 1996), but these trees are too far from the core site to have provided pollen that would have shown up in the Morro marsh core.

The first introduction of *Eucalyptus* into California in A.D. 1853 is well documented (Weir, 1957). By A.D. 1870 *Eucalyptus* had had been widely planted in California, especially in urban areas. The date of local introduction of *Eucalyptus* rather than date of initial introduction to California provides the maximum age for the first appearance of *Eucalyptus* pollen in a sediment core. *Eucalyptus* flowers are insect pollinated, and therefore do not produce large volumes of wind-dispersed pollen. Thus, *Eucalyptus* trees must be close to a given core site for *Eucalyptus* pollen to be "visible" in the fossil record. *Eucalyptus* trees have rapid growth rates and characteristically flower early in their development (McClatchie, 1902). If the maturation time of the trees is 4 to 5 years, then A.D. 1920, is the likely date for the first appearance of *Eucalyptus* pollen in the Morro Bay cores.

Radiocarbon

Longer term (i.e. more than 500 year) changes in sedimentation rates are best reconstructed by radiocarbon dating of organic material such as shell or wood. Gallagher (1996) as part of her dissertation research at Morro Bay obtained seven radiocarbon dates from marsh cores taken within the Morro Estuary Natural Preserve. Six of these dates were from the central part of the marsh and one from the marsh in the Los Osos valley. These dates cover the period 3975 before present (B.P.) to 760 B.P. and indicate sediment accretion rates of between 1.60 mm/yr and 2.40 mm/yr (Gallagher, 1996).

The sedimentation rate for the upper section of Core F5 (Gallagher, 1996) which was taken close to the Morro marsh core analyzed as part of this project (Site B in Figure 1) is circa 2.00 mm/yr. We therefore assume a sedimentation rate for the pre-European section of our core to be 2.00 mm/yr. Gallagher's 1996 Los Osos valley core has a near surface sedimentation rate of 1.64 mm/yr. We also used this rate for the pre-European section of our Los Osos core, analyzed as part of this study (Site C in Figure 1).

Anthropogenic Lead

Numerous studies have shown that the marine and lacustrine sediments can provide a record of the human use of lead (Pb), especially since A.D. 1940 (Chow et al., 1973; Reidy, 2001). Lead concentration profiles for the Morro Bay marsh sediments analyzed as part of this study provide chronological control for the past 30 years.

In the upper sections of all three cores there is a prominent spike in lead concentrations: at 25 cm in the Morro, 20 cm in the Chorro, and 5 cm in the Los Osos core. We interpret these spikes to represent an increase in lead deposition at the core sites following the construction of South Bay Boulevard in A.D. 1967 (Gates and Bailey, 1982). These spikes are attributable to combustion of leaded gasoline. Lead from automobile exhaust would have been accumulating at the core sites from A.D. 1967 until circa A.D. 1975 when the use of leaded gasoline was made illegal.

Lead concentrations in the near surface samples decline to background levels, which reflects the phasing out of leaded gasoline since A.D. 1973 and its ban in A.D. 1995. The lead profile is in general agreement with Callender and Van Metre (1997) who found decreasing lead concentrations in recently deposited lake and reservoir sediments in the US.

Magnetic susceptibility

Magnetic susceptibility does not provide a chronological marker but allows cores with similar magnetic profiles to be correlated with each other, and thus provide information on the spatial pattern of sediment accumulation. Standard whole core K measurements of the magnetic susceptibility of all cores were made with a Bartington Magnetic Susceptibility Sensor MS2C. K is an unitless value which represents the magnetic mineral properties of the sediment. Changes in magnetic properties throughout a core can provide an important index of environmental change.

In addition to dating procedures described above, each core was sampled at 5 cm intervals for the presence of metals including aluminum, arsenic, cadmium, chromium, copper, iron, magnesium, nickel, lead, silicon, vanadium and zinc.

6.2. Results

The methods described above were used to place an estimated date on certain sections of the core. The results can be seen in Figure 10. Different depths represent different dates in each of the cores. This is reasonable as sediment is expected to accumulate at different rates in different portions of the Bay and estuary system.

Core correlation representing dates at certain depths was graphed against metals concentration at depths. Although only values from the metal chromium are presented, all metals followed similar behavior throughout the core (Figures 11-14). Please see Appendix 4 for the graphs for all metals.

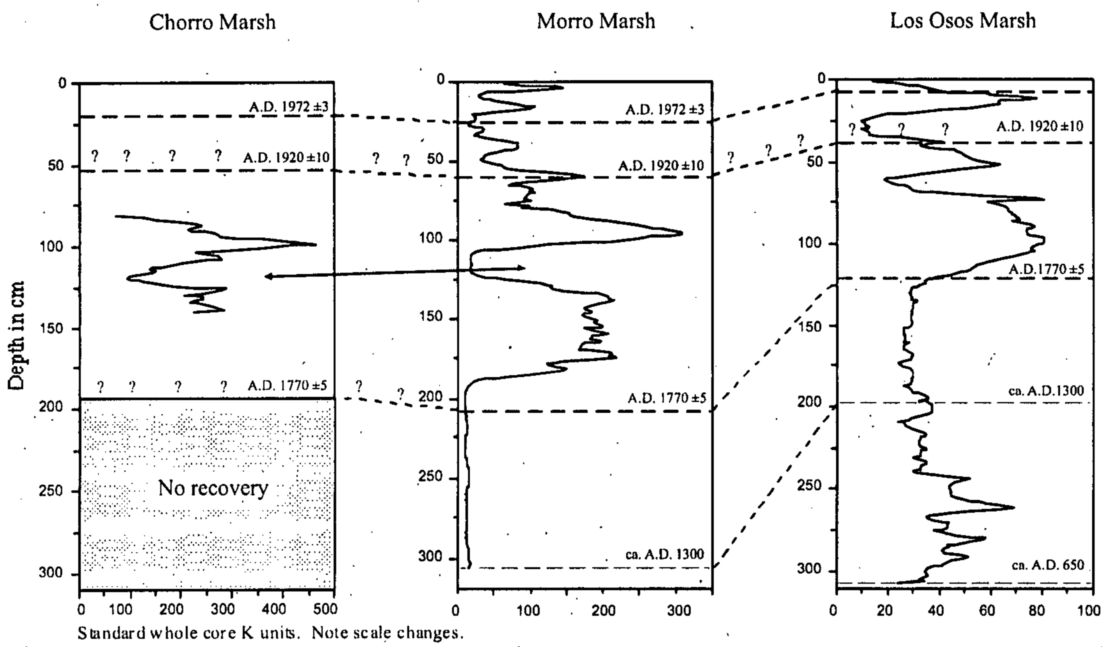


Figure 10: Morro Chorro and Los Osos marsh sediment cores cross-correlated using magnetic susceptibility radiocarbon dates (Gallegher, 1996), first appearance of non-native pollen types, and anthropogenic lead peaks.

Note: The dashed lines with "????" between cores are approximate and were not confirmed by pollen analysis as part of this study.

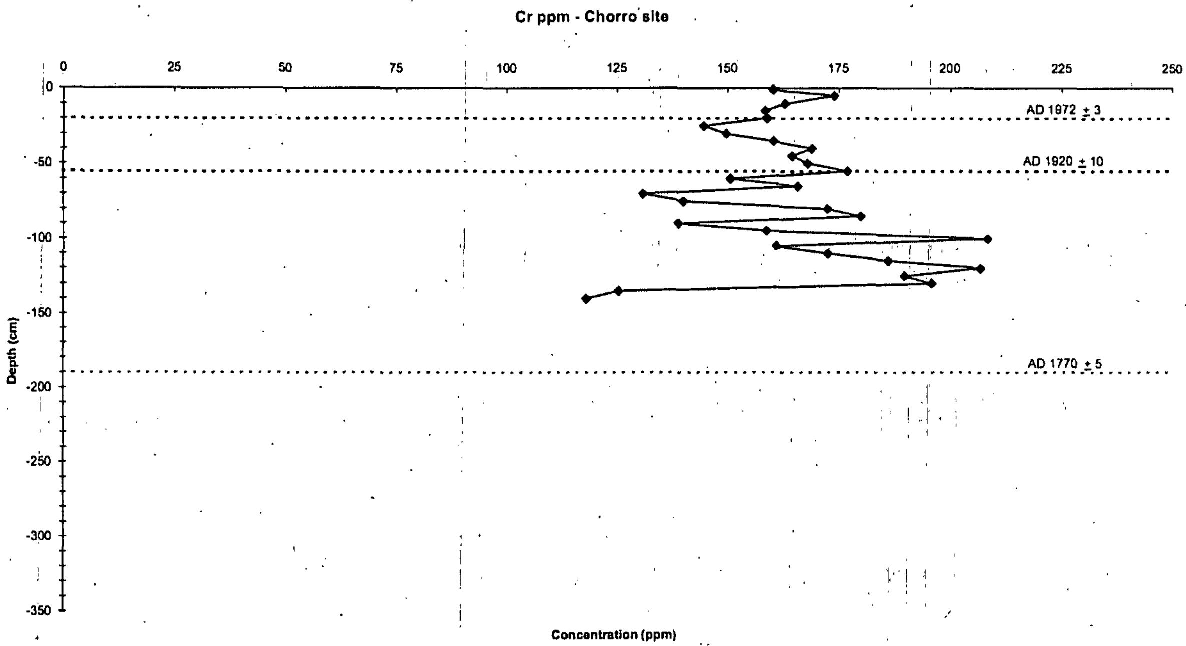


Figure 11: Sediment core of Chorro site (site A) indicating chromium concentration plotted against depth[5].

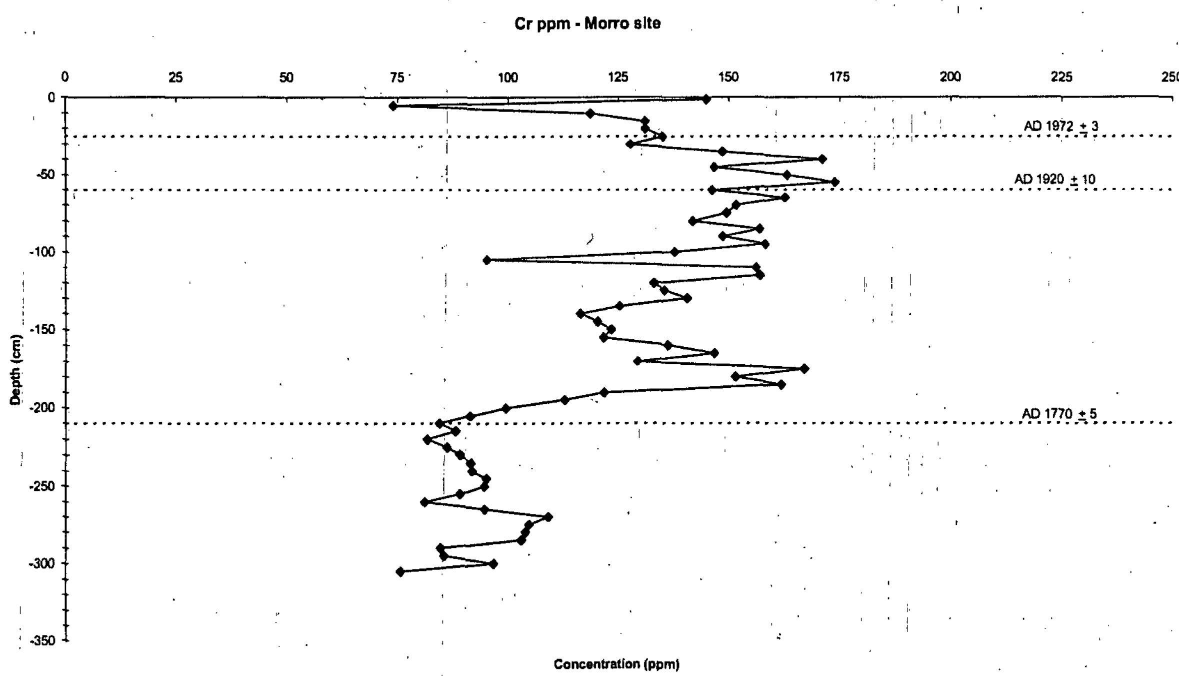


Figure 12: Sediment core of Morro site (site B) indicating chromium concentration plotted against depth.

[5] Less recovery than Morro and Los Osos site due to an impenetrable sand layer just short of 1.5 meters.

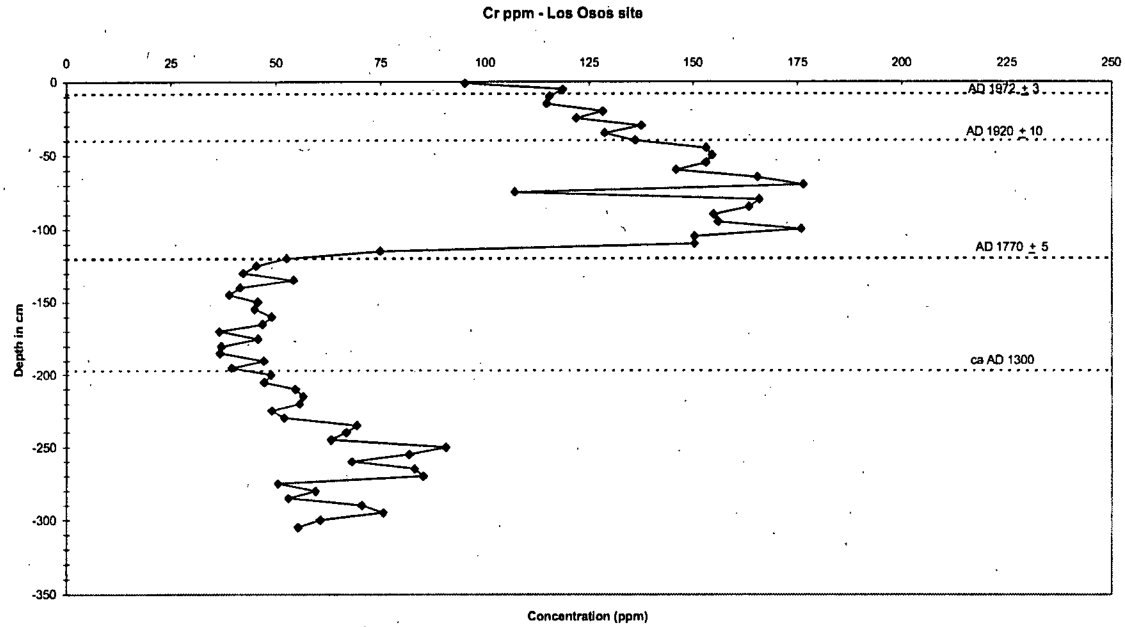


Figure 13: Sediment core of Los Osos site (site C) indicating chromium concentration plotted against depth.

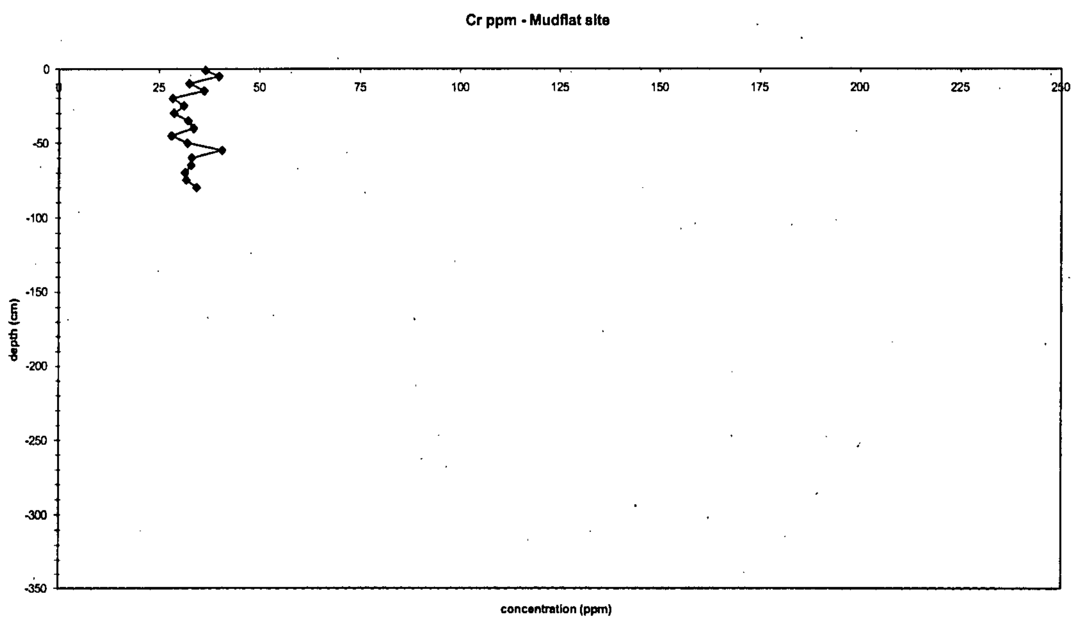


Figure 14: Sediment core of Mudflat site (site D) indicating chromium concentration plotted against depth[6].

[6] Dating this type of mudflat area is not possible due to the constant movement of the soil. Therefore, no dating information was presented.

6.3. Discussion/conclusions

As can be seen from the above graphs, levels of metals in the sediment remained fairly constant until about 1770. At that time, there was an increase of the metals concentration. This most likely correlates to exploration and occupation of Morro Bay by settlers. Around this time period, settlers came into the Morro Bay area and began farming, grazing animals, building roads/structures, and other activities that increased land disturbances. It is most likely due to these types of land disturbances that the levels of metals increase above the 1770 marker.

After approximately 1920, the levels of metals become fairly stable and even appear to decrease in concentration slightly. This may be due to the watershed reaching some sort of equilibrium. For the Chorro, Morro and Los Osos sites, the concentrations continue to decline or remain the same from the 1920's on. For the Mudflat site, levels of metals are considerably less than in the estuary. This provides further evidence that metals are coming from the watershed.

Historically, a common explanation for the presence of metals in the sediment has been the erosion of metals from mining operations within the watershed. Based on the above data, it appears that levels of metals in the sediment remained fairly constant during the periods of mining (1870-1941 (Regional Board, 1999)) and even nearly 100 years later. Also, most of the known mining was in the Chorro Creek watershed and the cores from both Los Osos Creek area and Chorro Creek area look essentially the same. This type of data is fairly strong evidence that the high concentration of metals in the sediment is most likely not due to mining.

The high concentration of metals in the sediment, based on the above study, is most likely due to natural and accelerated erosion that occurred mostly in the 1800s. It does not appear that the levels are increasing, nor does it appear that the levels are due to any recent pollution (save the lead spike in the 1970s). From the above data, it seems as though the watershed has naturally occurring levels of certain metals and when the land is disturbed, the metals find their way down to the estuary sediment. The method for preventing future inputs of high levels of metal concentrated sediment into the Bay would be to prevent anthropogenic sedimentation from occurring in the watershed. The Morro Bay Siltation TMDL is the mechanism to address any excess sediment that enters the Bay.

7. EMAP study

Just before completion of this document, staff learned that EMAP (Environmental Monitoring and Assessment Program – US EPA) sampled 30 different locations within Morro Bay the week of 9/8/03. EMAP sampling included 30 randomly selected sites in Morro Bay, and measured for sediment chemistry, benthic infauna, fish tissue, fish populations, water column chemistry, and sediment toxicity. The data should be available approximately September 2004, maybe later, depending on when EMAP gets all their data together. Department of Fish and Game is the agency that actually collected the samples so the Regional Board may have access to the data earlier through Fish and Game. While this sampling program in Morro Bay was proposed late in 2002), Regional Board staff were not certain that it was going to happen until June 2003. Regional Board staff will evaluate the data as it becomes available for future watershed assessment. Staff anticipates that the results of this sampling program will support the results of the studies evaluated in this report.

8. Overall Conclusions

Based on the above information, the existing data indicates that Morro Bay is an area with soils that are rich in metals. The concentration of metals has remained fairly constant over the last hundred years. Levels of metals may exceed NOAA SQuiRT values, but these values are only for guidance, and local tissue samples generally do not display any impairment with respect to these metals (except for Cr).

Although there do not appear to be "standards" to which shellfish tissue can be compared, concentrations of Cr are considerably above the level of concern cited by the US Food and Drug Administration (USFDA, 1993). This may or may not be problematic for the commercial shellfish farm located in Morro Bay. The clams that were collected as part of this study were removed directly from the sediment in which higher concentrations of naturally occurring metals were observed. The shellfish that is harvested in Morro Bay is suspended in bags that are in the water column. Cr did not appear to be problematic in the water column and elevated levels of metals in the tissue of the harvested oysters is not expected. However, without money to do another study to confirm or deny this theory, it is difficult to know for certain. Staff recommends that commercially produced oysters be tested for the presence of metals in their tissue at some point in the future.

Based on the above-mentioned analyses, staff believes water quality objectives are being met. **Therefore, Regional Board staff recommends delisting Morro Bay for metals** based on the fact that objectives are being met and beneficial uses are not impaired based on "Monitored Assessment" criteria. Based on the data collected in all three studies:

- Water quality objectives are currently being met in the water column,
- The metals present in sediment appear to be the natural result of local geology and do not represent "pollution,"
- Levels of metals in the tissue appear to be at reasonable levels considering the natural geology of the area, and
- There appears to be no correlation between the concentration of metals in the sediment and the water above it.

9. Works Cited

Buchman, M.F. "NOAA Screening Quick Reference Tables." NOAA HAZMAT Report 99-1, Seattle WA, Coastal Protection and Restoration Division, National Oceanic and Atmospheric Administration, 12 pages, 1999.

California Code of Regulation. Title 23, Subchapter 15, Statement of Reason. 1984.

California State Mussel Watch. "Ten Year Data Summary 1977-1987. Water Quality Monitoring Report No. 87-3." May 1988.

California State Water Resources Control Board. Division of Water Quality. Bay Protection and Toxic Cleanup Program, et. al. Chemical and Biological Measures of Sediment quality in the Central Coast Region. Final Report. New Series No. 5. October 1998

Callender, E. and Van Metre, P.C. (1997). Reservoir Sediment Cores Show U.S. Lead Declines. *Environmental Science and Technology News* 9: 424A-428A.

Chow, T. J., Bruland, K. W., Bertine, K., Soutar, A., Koide, M., Goldberg, E.D. (1973). Lead Pollution: Records in Southern California Coastal Sediments. *Science* Vol. 181, No. 4099, pp. 551-552.

Clean Water Act. Section 303(d). Listing Guidelines for California, August 11, 1997.

Cole, K and Liu, G. (1994). Holocene Paleoecology of an Esturay on Santa Rosa Island, California. *Quaternary Research* 41, 326-335.

Cole, K and Wahl, E. (2000) A late Holocene Paleoecological Record from Torrey Pines State Preserve, California. *Quaternary Research* 53, 341-351.

Federal Register. Volume 65, No. 97. Part III. Environmental Protection Agency, 40 CFR Part 131. Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California; Rule. Thursday, May 18, 2000.

Gallagher, J. (1996) Late Holocene evolution of the Chorro delta, Morro Bay, California. Unpublished Ph.D dissertation University of California, Los Angeles.

Gates, D. L. and Bailey, J. H. (1982). *Morro Bay's Yesterdays. Vignettes of Our City's Lives and Times*. El Moro Publications.

Marine Research Specialists. City of Morro Bay/Cayucos Sanitary District Offshore Monitoring and Reporting Program. 2002 Annual Report.

McClatchie, A.J. (1902). *Eucalyptus Cultivated in the United States*. U.S.D.A. Bureau of Forestry Bulletin No. 35. Washington, D.C. Government Printing Office.

Mensing, S. and Byrne, R. (1998). Pre-mission invasion of *Erodium cicutarium* in California. *Journal of Biogeography* 25: 757-762.

Morro Bay National Estuary Program, Turning the Tide for Morro Bay: Comprehensive Conservation Management Plan for Morro Bay. Chapter 2. 2000.

Mudie, P.J. and Byrne, R. (1980). Pollen evidence for historic sedimentation rates in California Coastal Marshes. *Estuarine and Coastal Marine Science* 10: 305-316.

Nauen, C.E. Compilation of Legal Limits for Hazardous Substances in Fish and Fishery Products, Circular No. 764. FIRI/C764, Food and Agricultural Organization of the United Nations. 1983.

Regional Water Quality Control Board, Shanta Duffield. Monitored Assessment Study sampling for metals in Morro Bay and the surrounding watershed. March 2001

Regional Water Quality Control Board, Katie McNeill. Siltation TMDL for Chorro Creek, Los Osos Creek and the Morro Bay Estuary. 2001.

Regional Water Quality Control Board. Water Quality Control Plan (Basin Plan). September 1994.

Regional Water Quality Control Board. Inactive Metal Mines In Four San Luis Obispo County Watersheds. Surface Water Quality Impacts and Remedial Options. June 1999.

Reidy, L. and Byrne, R., University of California at Berkeley, unpublished data.

Reidy, L.M. 2001. Evidence of Environmental Change Over the last 2000 years at Mountain Lake in the northern San Francisco Peninsula, California. Unpublished MA Thesis, Geography Department, University of California, Berkeley.

Penner, Rick. BC Laboratories. Personal communication May 16, 2003. (661)-327-4911.

State Water Resources Control Board. State Mussel Watch Program.1995-1997 data report. September 2000.

U.S. Department of Agriculture, Soil Conservation Service. Pages 2 & 4. 1989a. *Enhancement Plan Morro Bay Watershed.*

United States Food and Drug Administration. Guidance Document for Chromium in Shellfish. http://www.cfsan.fda.gov/~frf/guid-cr.html. 1993.

Weir, D. A. 1957. *That Fabulous Captain Waterman*. Comet Press Books, New York.

Appendix 1 – Data from State Mussel Watch

Table of data for all sampling locations.

Appendix 1

State Mussel Watch Data - Morro Bay, ppm, wet weight

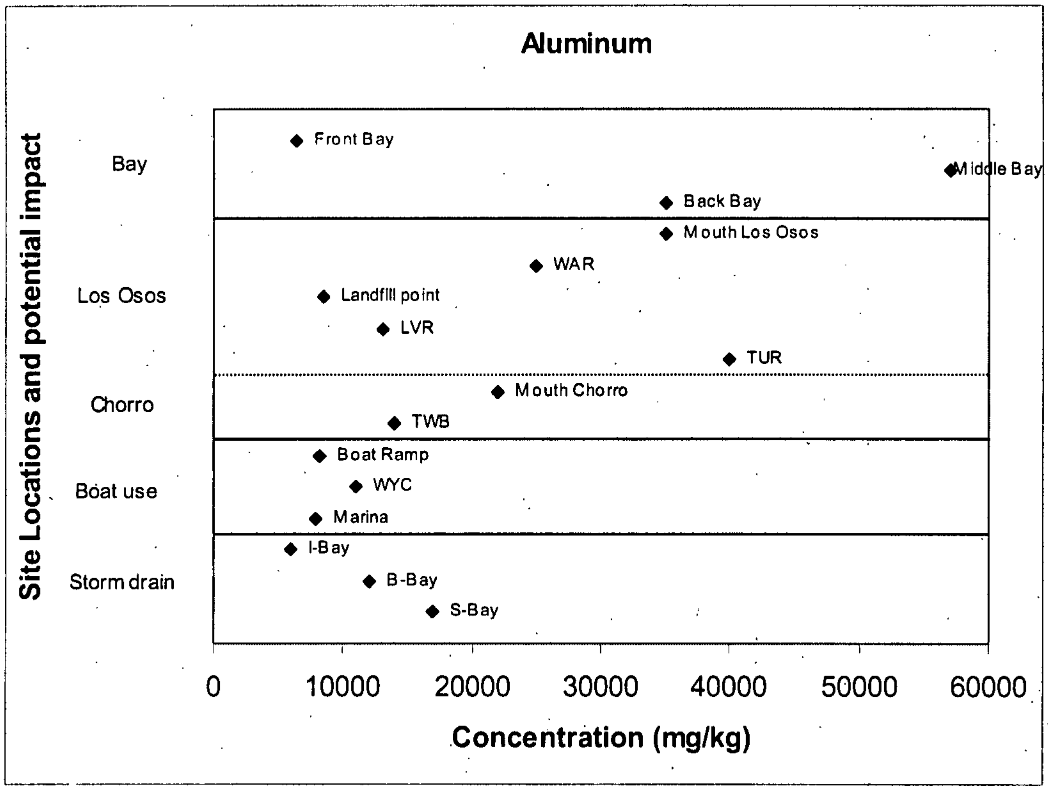
Station No.	Date	Sample Type*	Metal												
			Al	As	Cd	Cr	Cu	Pb	Mn	Hg	Ni	Se	Ag	Ti	Zn
427.0	5/30/1980	RBM	100.82	na	0.95	0.33	0.76	0.260	1.79	0.43	1.08	na	0.008	na	16.57
427.0	12/14/1980	TCM	55.42	na	1.23	0.38	1.32	0.280	1.51	0.31	na	na	0.017	na	21.88
428.5	5/30/1980	RBM	51.46	na	1.23	0.19	1.34	0.450	1.72	0.026	0.6	na	0.008	na	18.72
428.5	12/14/1980	TCM	55.43	na	1.03	0.27	1.53	0.160	1.68	0.033	na	na	0.016	na	22.26
429.0	6/28/1982	RCM	28.06	na	1.17	0.3	0.94	0.190	0	0.019	na	na	0.007	na	20.30
429.0	1/21/1983	RCM	31.78	1.95	0	0.35	0.8	0.210	0.91	0.027	na	na	0.078	na	25.61
429.0	5/3/1983	RCM	52.22	3.43	0.49	0.33	0.75	0.140	1.55	0.021	na	na	0.007	na	28.17
429.2	1/26/1987	TCM	55.96	na	1.09	0.62	3.13	0.320	1.51	0.136	na	0.49	0.007	na	27.72
429.2	3/14/1988	RBM	56	na	1.19	0.52	1.18	0.219	1.31	0.036	0.62	na	nd	6.78	22.03
429.2	12/19/1988	TCM	66.5	na	1.23	0.53	2.42	0.290	1.63	0.049	na	na	0.004	na	25.50
429.2	2/2/1990	TCM	85.9	na	1.01	0.51	1.9	0.333	1.41	0.024	na	na	0.002	na	26.28
429.2	1/20/1993	TCM	180.0	na	1.7	1.5	2.8	0.350	2.3	0.061	na	na	0.007	na	35.00

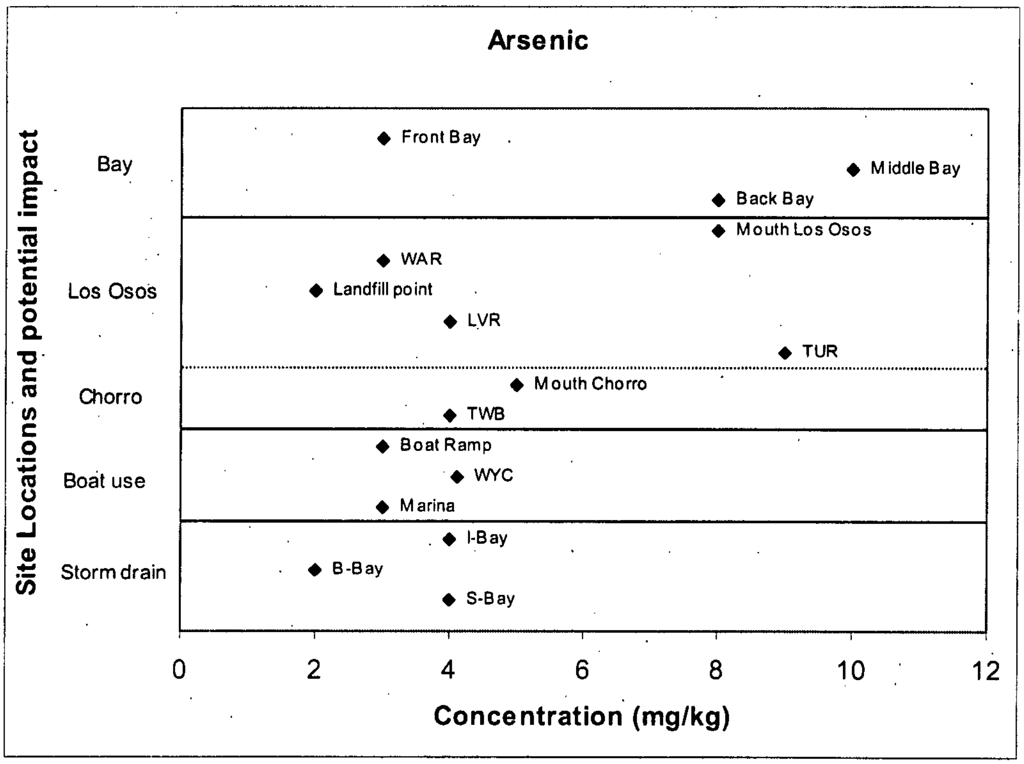
*RCM = Resident California Mussel
*RMB = Resident Bay Mussel
*TCM = Transplanted California Mussel

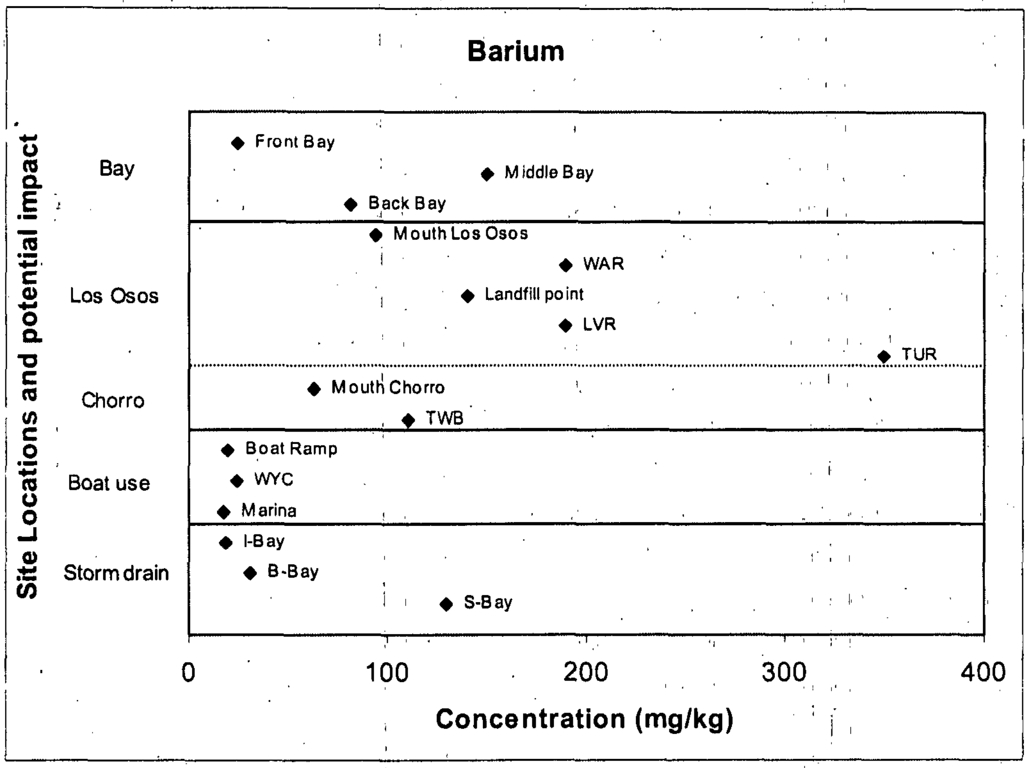
na = not analyzed
nd = not detected

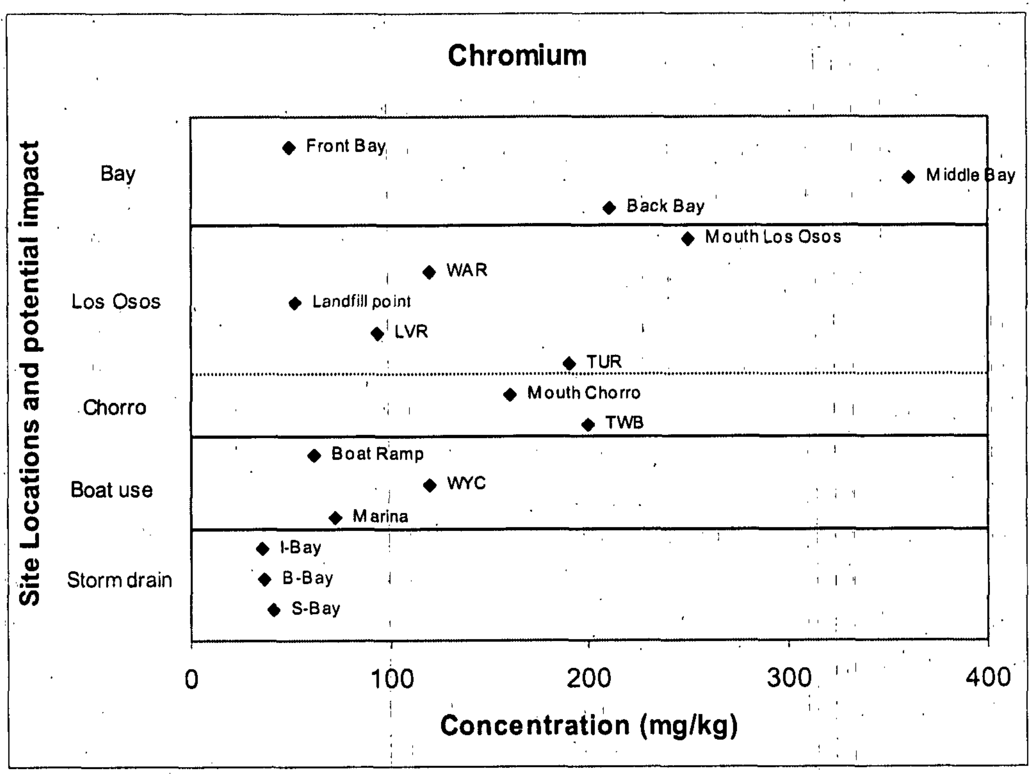
Appendix 2 - Assessment study

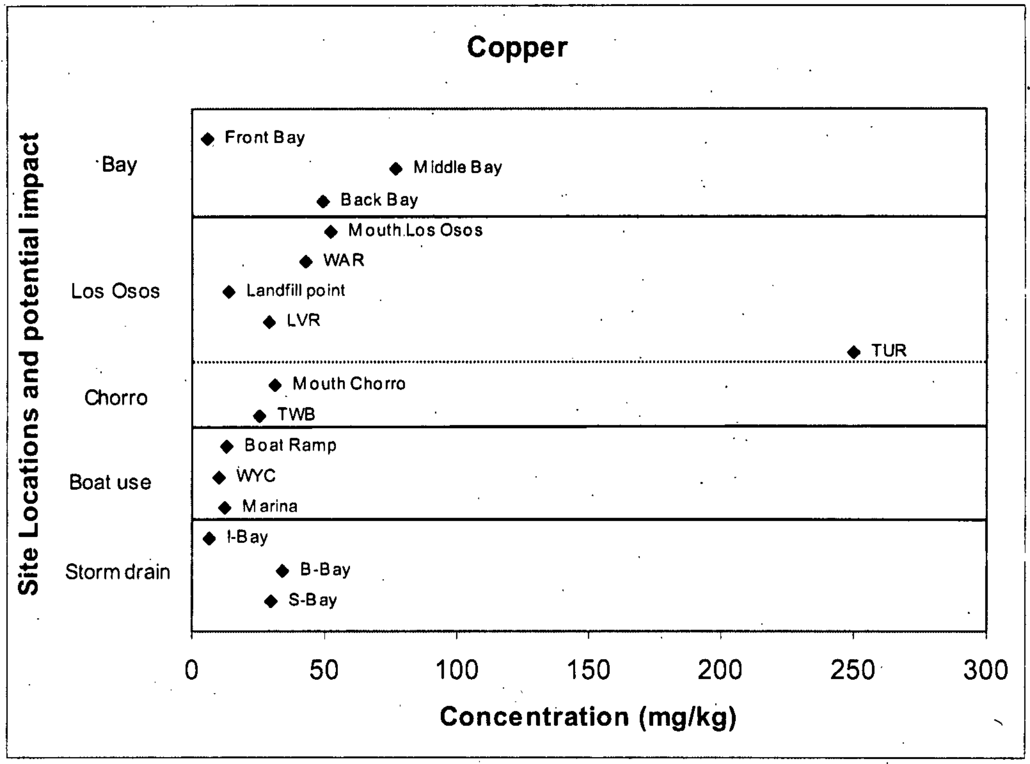
Graphs of all metals at all 16 sites for sediment
Table of dissolved water concentrations for 5 Bay sites
SPLP data for 5 Bay sites

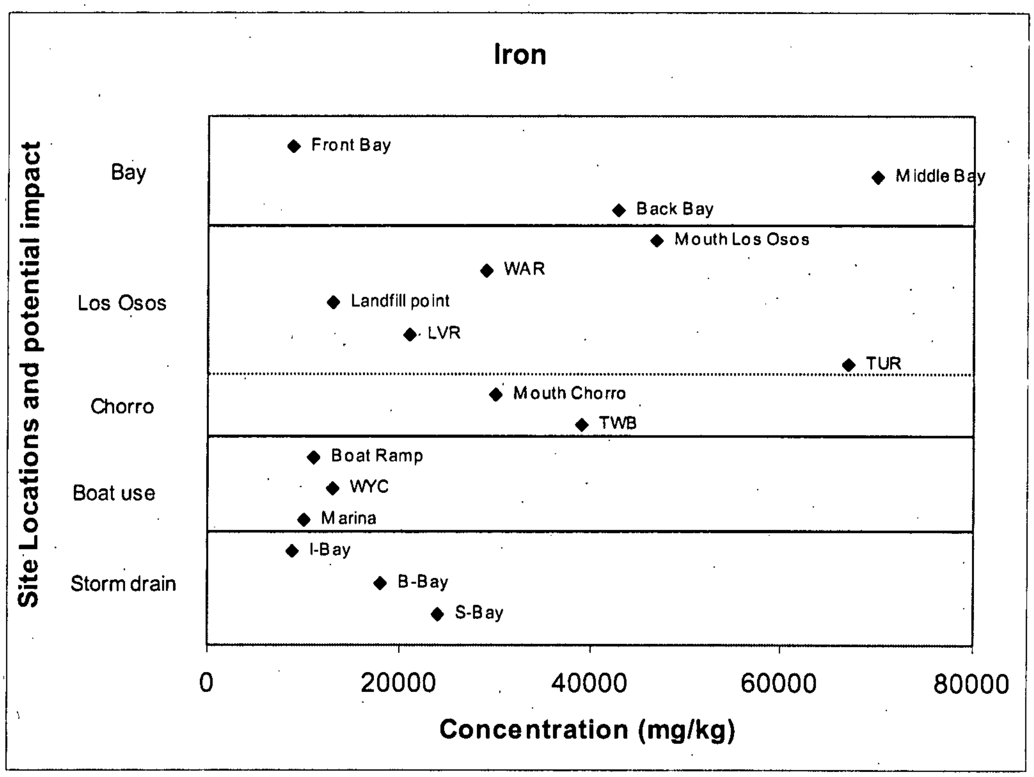

Aluminum
Site Locations and potential impact
Bay
Los Osos
Chorro
Boat use
Storm drain
Front Bay
Middle Bay
Back Bay
Mouth Los Osos
WAR
Landfill point
LVR
TUR
Mouth Chorro
TWB
Boat Ramp
WYC
Marina
I-Bay
B-Bay
S-Bay
0
10000
20000
30000
40000
50000
60000
Concentration (mg/kg)

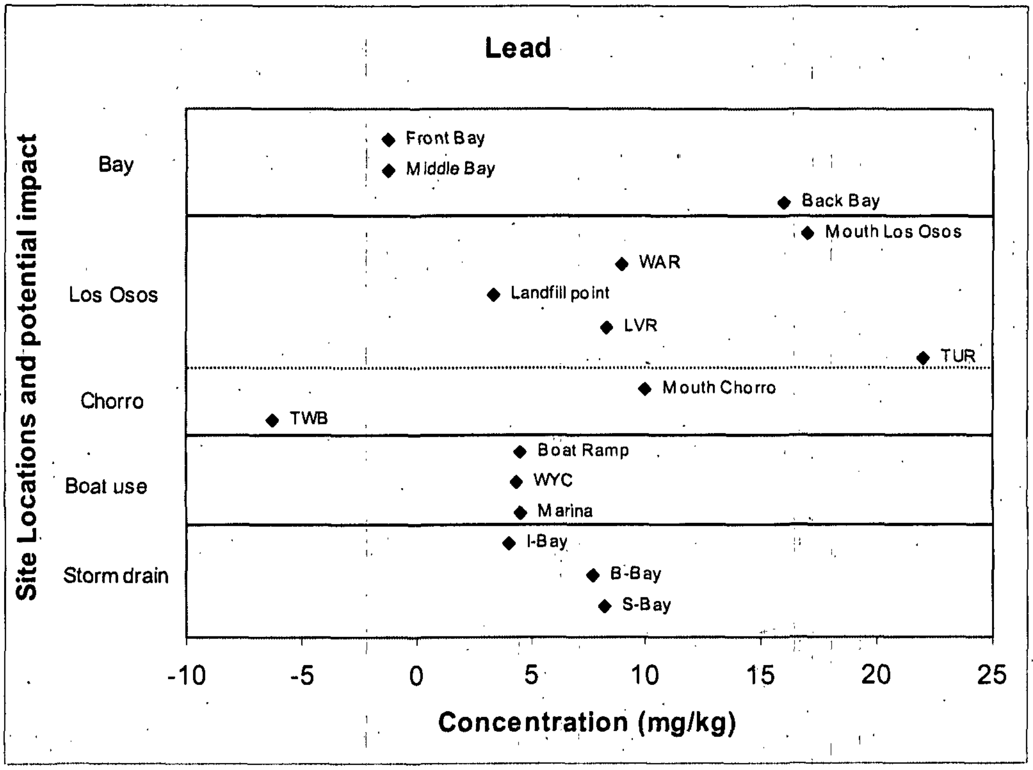

Arsenic
Site Locations and potential impact
Bay
Los Osos
Chorro
Boat use
Storm drain
Front Bay
Middle Bay
Back Bay
Mouth Los Osos
WAR
Landfill point
LVR
TUR
Mouth Chorro
TWB
Boat Ramp
WYC
Marina
I-Bay
B-Bay
S-Bay
0
2
4
6
8
10
12
Concentration (mg/kg)

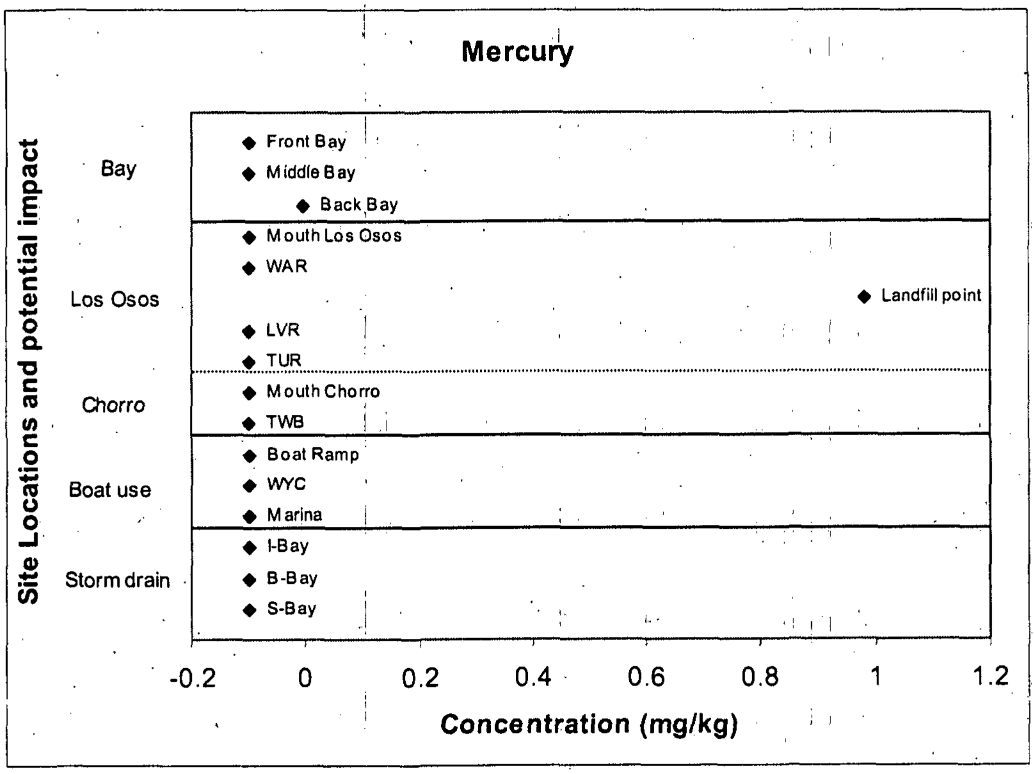

Barium
Site Locations and potential impact
Bay
Front Bay
Middle Bay
Back Bay
Los Osos
Mouth Los Osos
WAR
Landfill point
LVR
TUR
Chorro
Mouth Chorro
TWB
Boat use
Boat Ramp
WYC
Marina
Storm drain
I-Bay
B-Bay
S-Bay
0
100
200
300
400
Concentration (mg/kg)

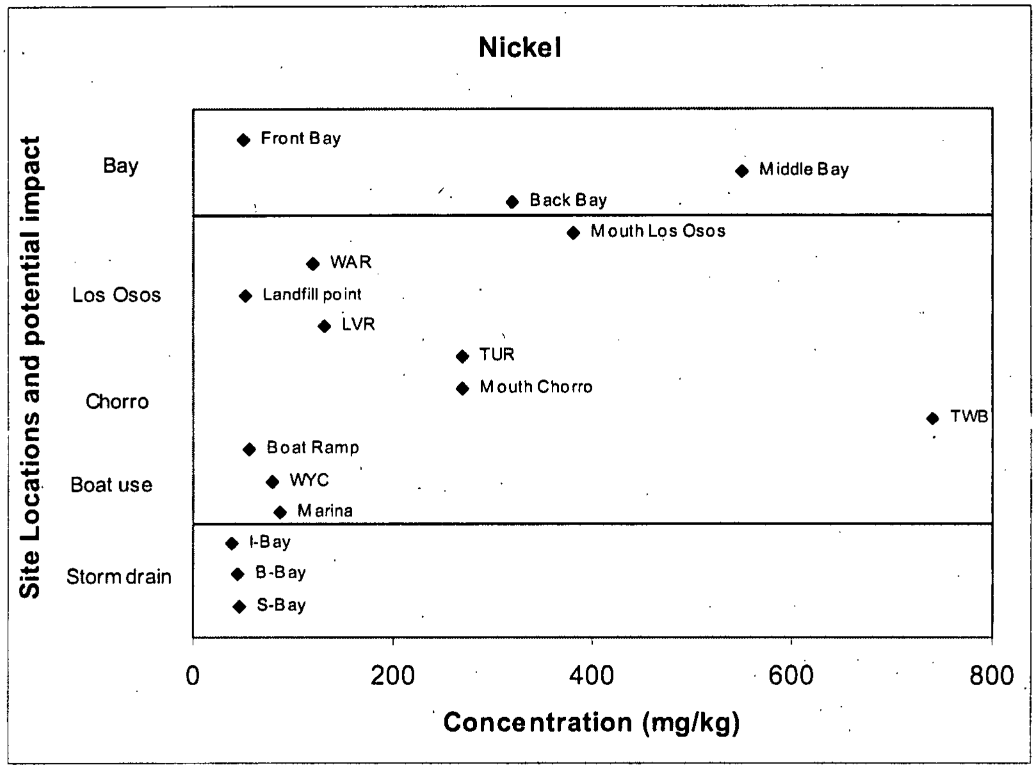

Chromium
Site Locations and potential impact
Bay
Front Bay
Middle Bay
Back Bay
Los Osos
Mouth Los Osos
WAR
Landfill point
LVR
TUR
Chorro
Mouth Chorro
TWB
Boat use
Boat Ramp
WYC
Marina
Storm drain
I-Bay
B-Bay
S-Bay
0
100
200
300
400
Concentration (mg/kg)

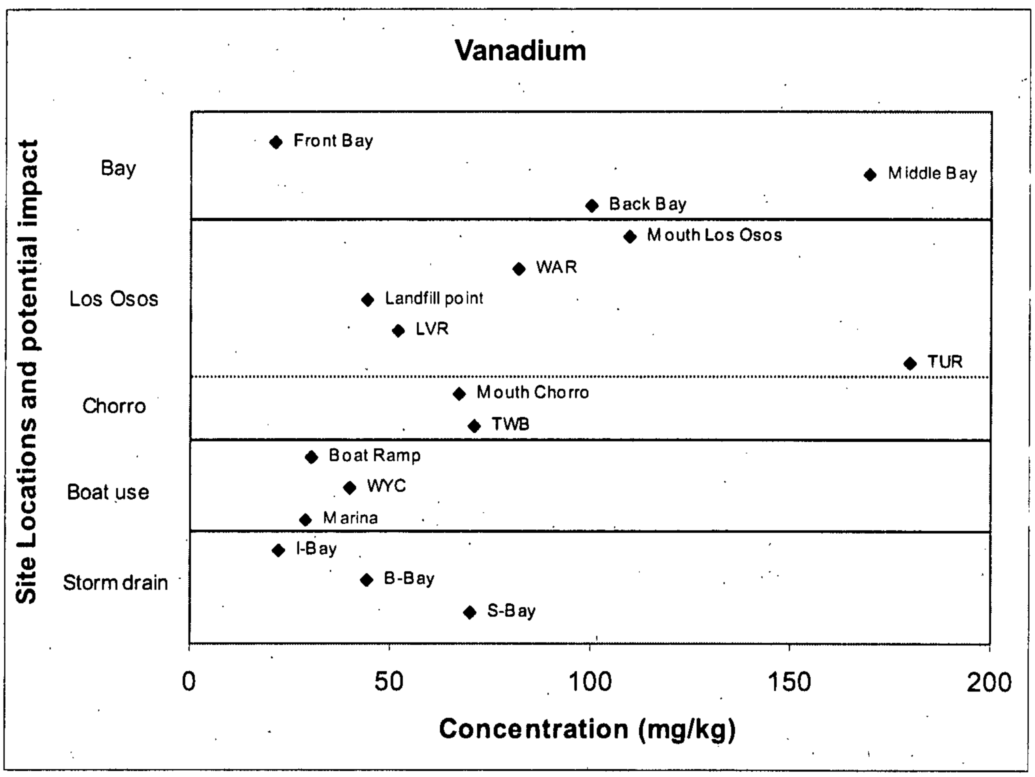

Copper
Site Locations and potential impact
Bay
Front Bay
Middle Bay
Back Bay
Los Osos
Mouth Los Osos
WAR
Landfill point
LVR
TUR
Chorro
Mouth Chorro
TWB
Boat use
Boat Ramp
WYC
Marina
Storm drain
I-Bay
B-Bay
S-Bay
0
50
100
150
200
250
300
Concentration (mg/kg)

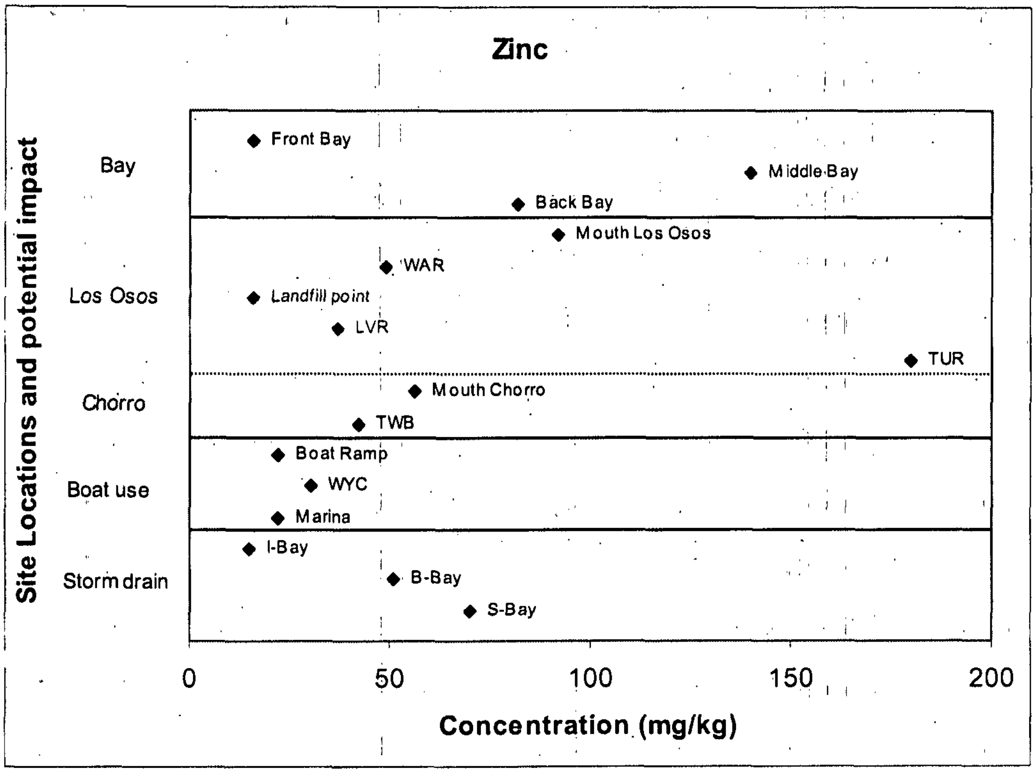

Iron
Site Locations and potential impact
Bay
Front Bay
Middle Bay
Back Bay
Los Osos
Mouth Los Osos
WAR
Landfill point
LVR
TUR
Chorro
Mouth Chorro
TWB
Boat use
Boat Ramp
WYC
Marina
Storm drain
I-Bay
B-Bay
S-Bay
0
20000
40000
60000
80000
Concentration (mg/kg)


Lead
Site Locations and potential impact
Bay
Los Osos
Chorro
Boat use
Storm drain
Front Bay
Middle Bay
Back Bay
Mouth Los Osos
WAR
Landfill point
LVR
TUR
Mouth Chorro
TWB
Boat Ramp
WYC
Marina
I-Bay
B-Bay
S-Bay
-10
-5
0
5
10
15
20
25
Concentration (mg/kg)


Mercury
Site Locations and potential impact
Bay
Los Osos
Chorro
Boat use
Storm drain
Front Bay
Middle Bay
Back Bay
Mouth Los Osos
WAR
Landfill point
LVR
TUR
Mouth Chorro
TWB
Boat Ramp
WYC
Marina
I-Bay
B-Bay
S-Bay
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
Concentration (mg/kg)


Nickel
Site Locations and potential impact
Bay
Los Osos
Chorro
Boat use
Storm drain
Front Bay
Middle Bay
Back Bay
Mouth Los Osos
WAR
Landfill point
LVR
TUR
Mouth Chorro
TWB
Boat Ramp
WYC
Marina
I-Bay
B-Bay
S-Bay
0
200
400
600
800
Concentration (mg/kg)


Vanadium
Site Locations and potential impact
Bay
Los Osos
Chorro
Boat use
Storm drain
Front Bay
Middle Bay
Back Bay
Mouth Los Osos
WAR
Landfill point
LVR
TUR
Mouth Chorro
TWB
Boat Ramp
WYC
Marina
I-Bay
B-Bay
S-Bay
0
50
100
150
200
Concentration (mg/kg)



All sediment samples were measured in mg/kg dry weight.

Appendix 2 **Water**

Dissolved metals in water
Reported in µg/L

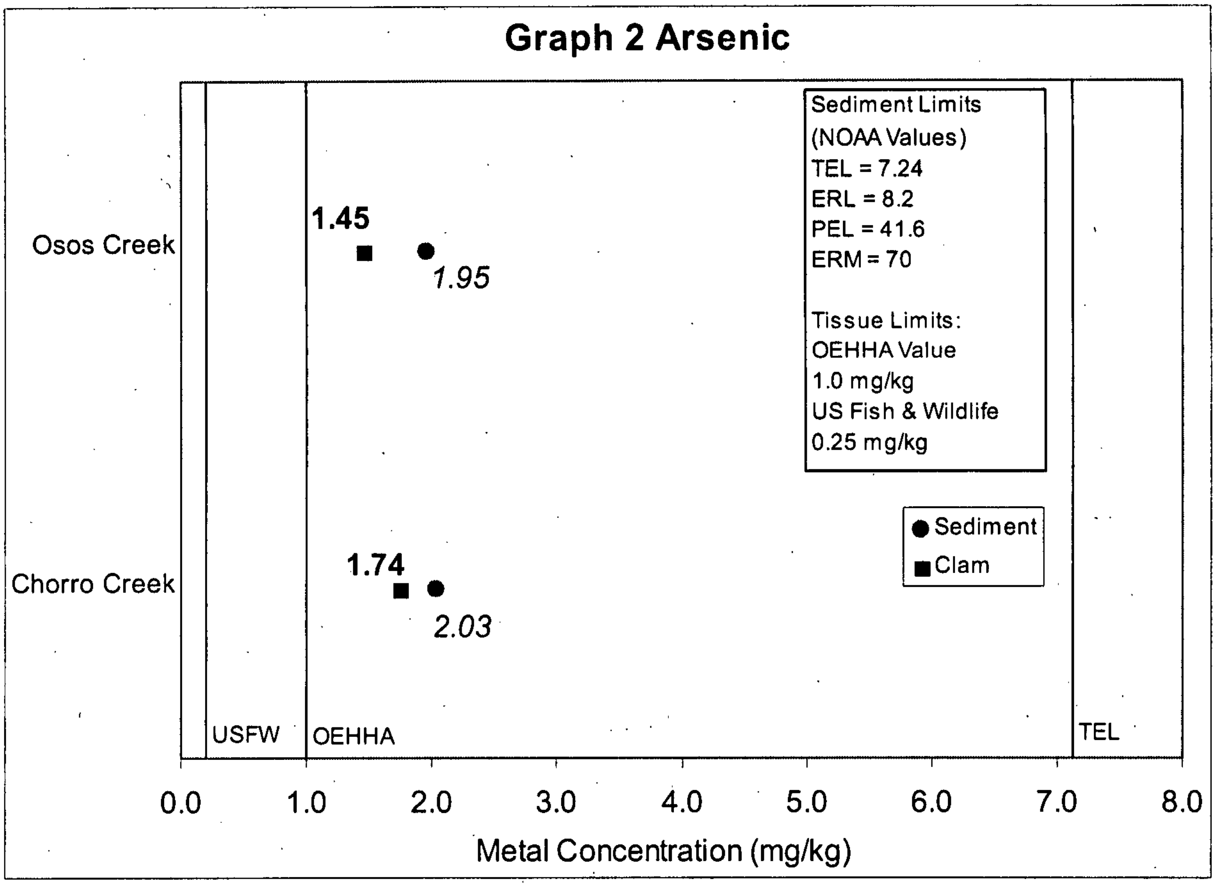
Sites	Al	As	Ba	Cd	Cr	Cu	Pb	Hg	Ni	V	Zn
					Metals						
Back Bay	2.05	0.739	37	0.0582	0.287	0.703	0.0308	0.000549	4.26	2.29	9.83
Mouth Los Osos	2.000	0.398	74.600	0.0349	0.932	1.340	0.0061	0.001520	8.450	4.170	5.860
Mouth Chorro	2.000	0.691	71.300	0.0686	0.290	0.815	0.0051	0.000733	11.300	2.790	9.410
Middle Bay	2.000	0.785	24.900	0.0467	0.216	0.419	0.0038	0.000517	3.270	2.120	10.500
Front Bay	2.000	0.899	17.600	0.0377	0.166	0.262	0.0039	0.000362	1.730	2.460	8.330

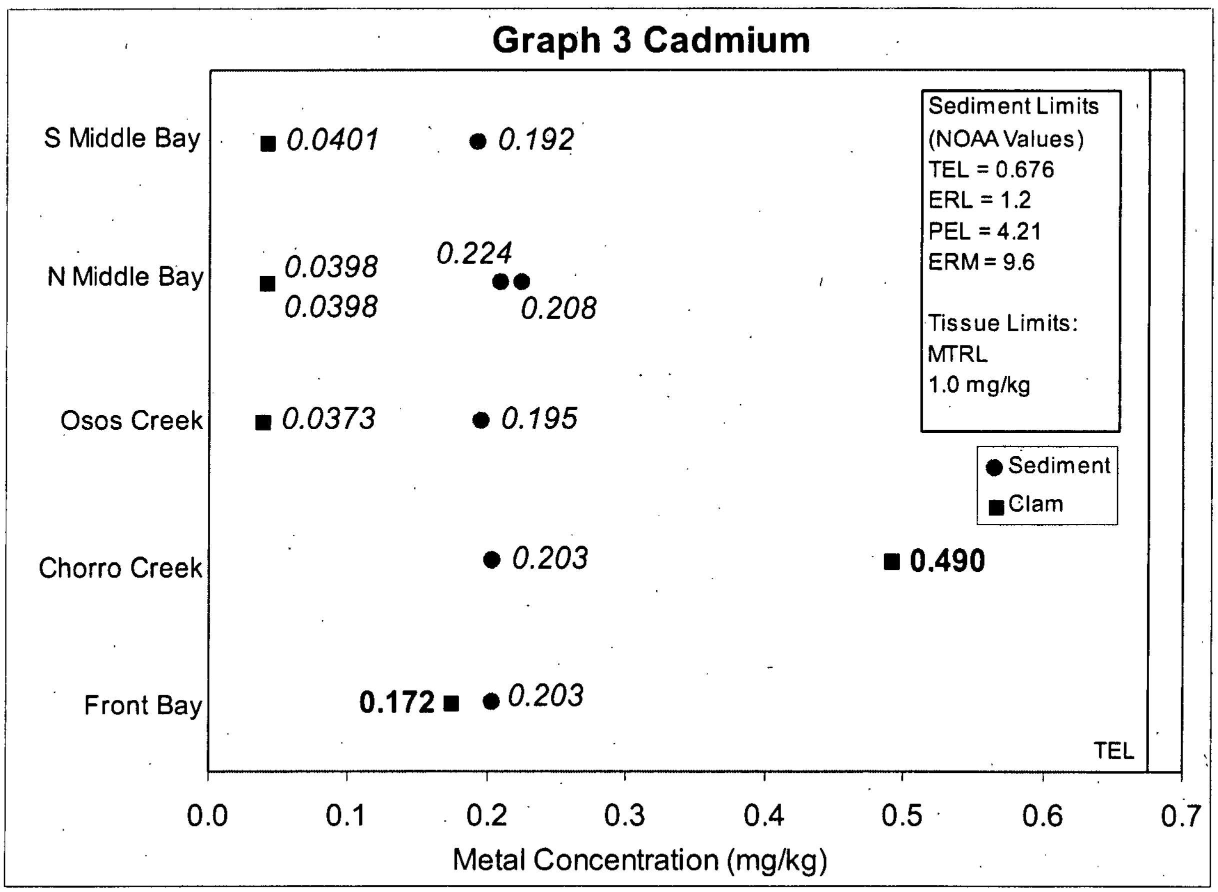
Total metals per a SPLP leaching process of the sediment
Reported in mg/L

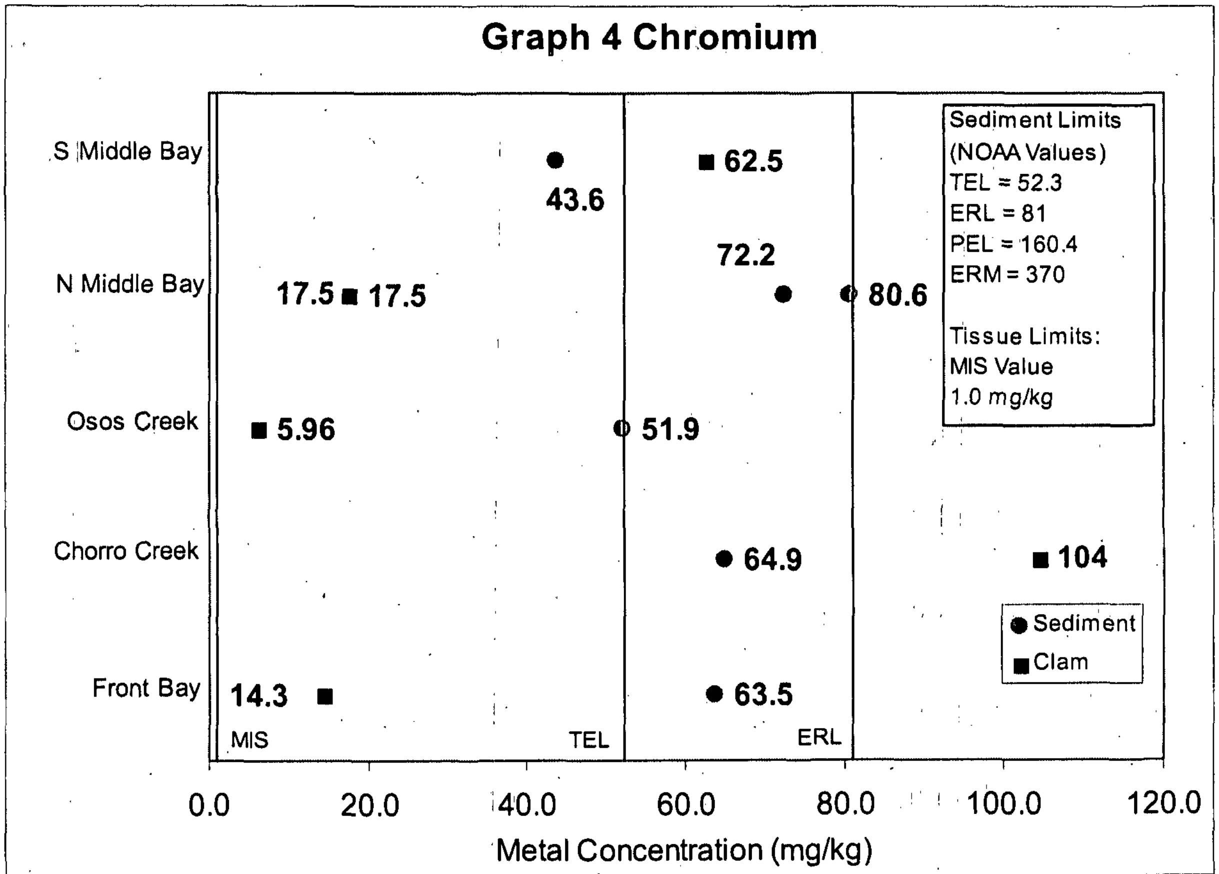
Sites	Al	As	Ba	Cd	Cr	Cu	Pb	Hg	Ni	V	Zn
						Metals					
Back Bay	35000	8	81	-0.25	211	49	16	-0.005	320	100	82
Mouth Los Osos	35000	8	94	-0.25	250	52	17	-0.1	380	110	92
Mouth Chorro	22000	5	63	-0.25	160	31	10	-0.1	270	67	56
Middle Bay	57000	10	150	-0.25	360	77	-1.25	-0.1	550	170	140
Front Bay	6400	3	24	-0.25	49	5.5	-1.25	-0.1	50	21	16

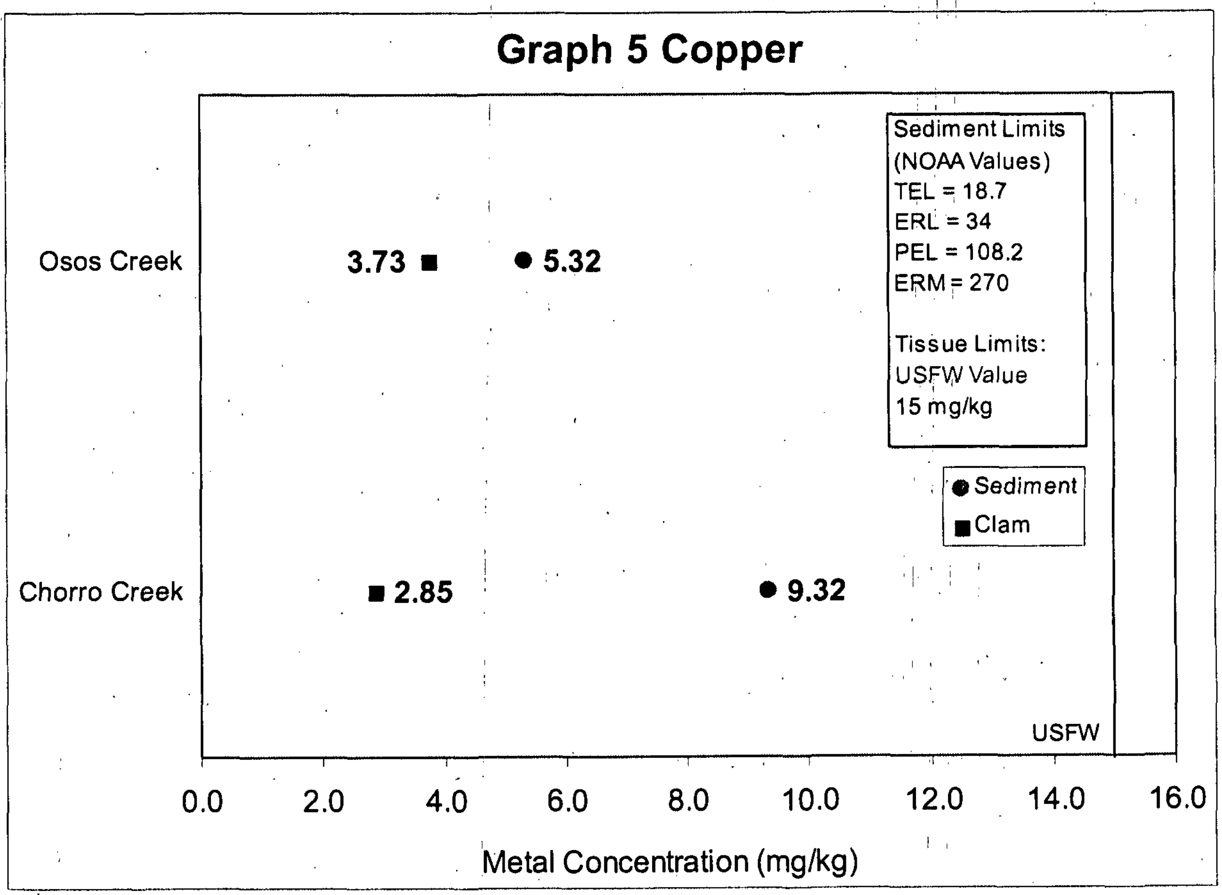
Appendix 3 – Tissue study

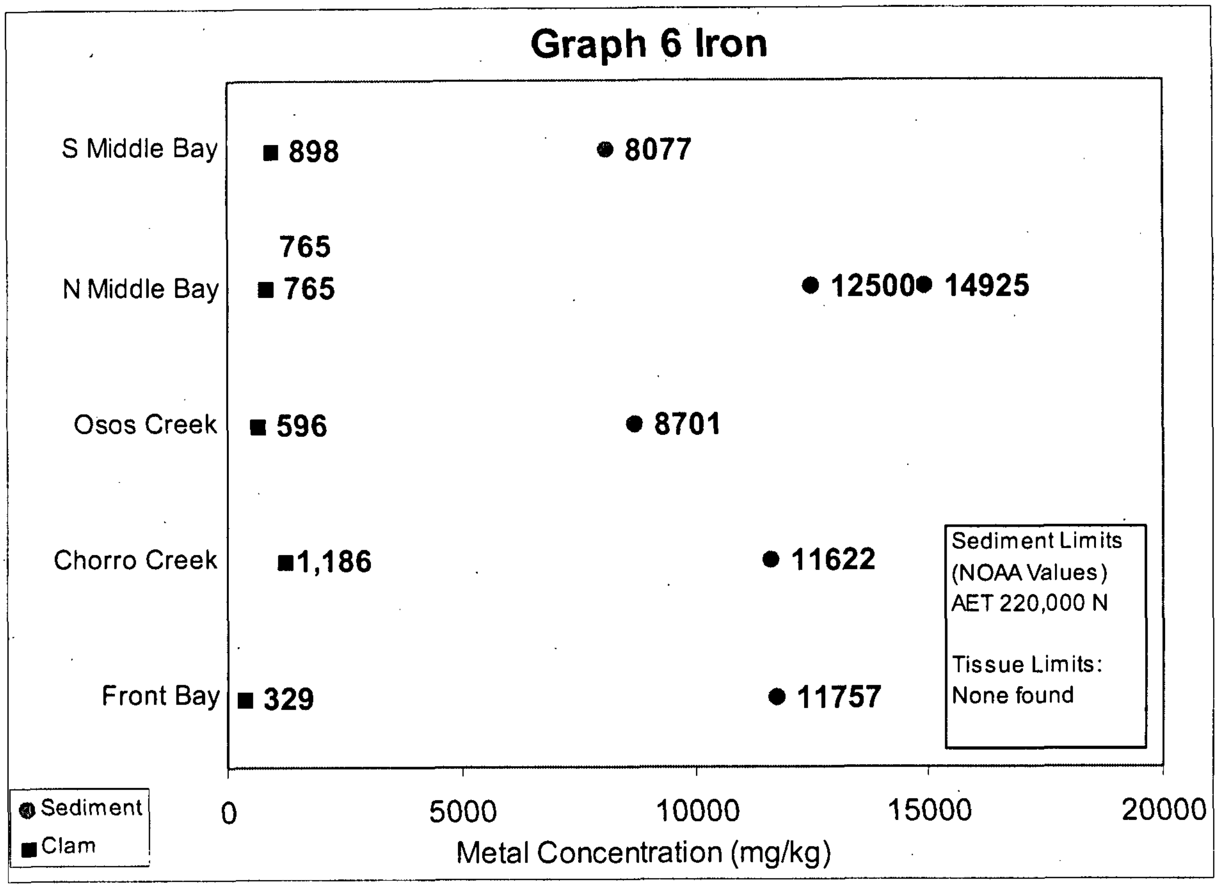
Graphs of all metals at five sampling sites

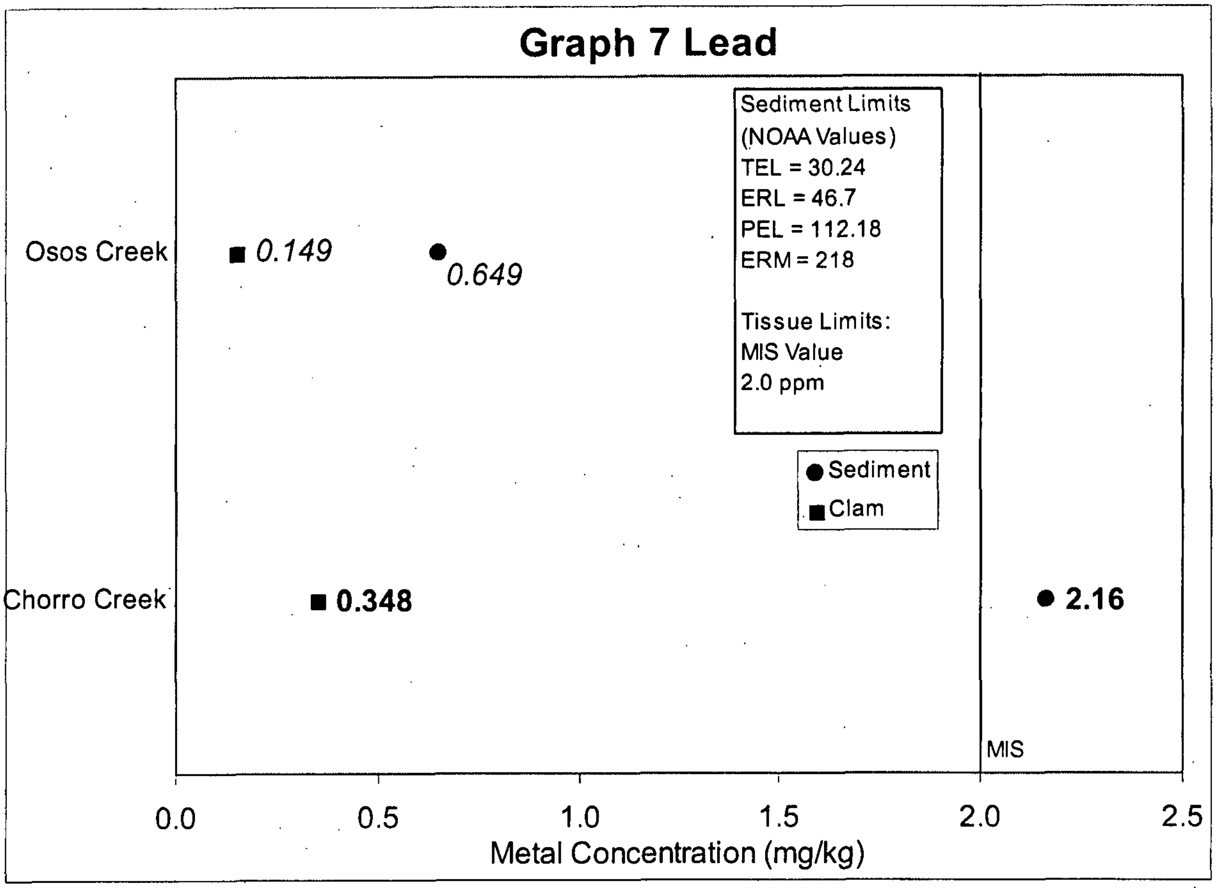

Graph 2 Arsenic
Sediment Limits
(NOAA Values)
TEL = 7.24
ERL = 8.2
PEL = 41.6
ERM = 70
Tissue Limits:
OEHHA Value
1.0 mg/kg
US Fish & Wildlife
0.25 mg/kg
Sediment
Clam
Osos Creek
1.45
1.95
Chorro Creek
1.74
2.03
USFW
OEHHA
TEL
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
Metal Concentration (mg/kg)

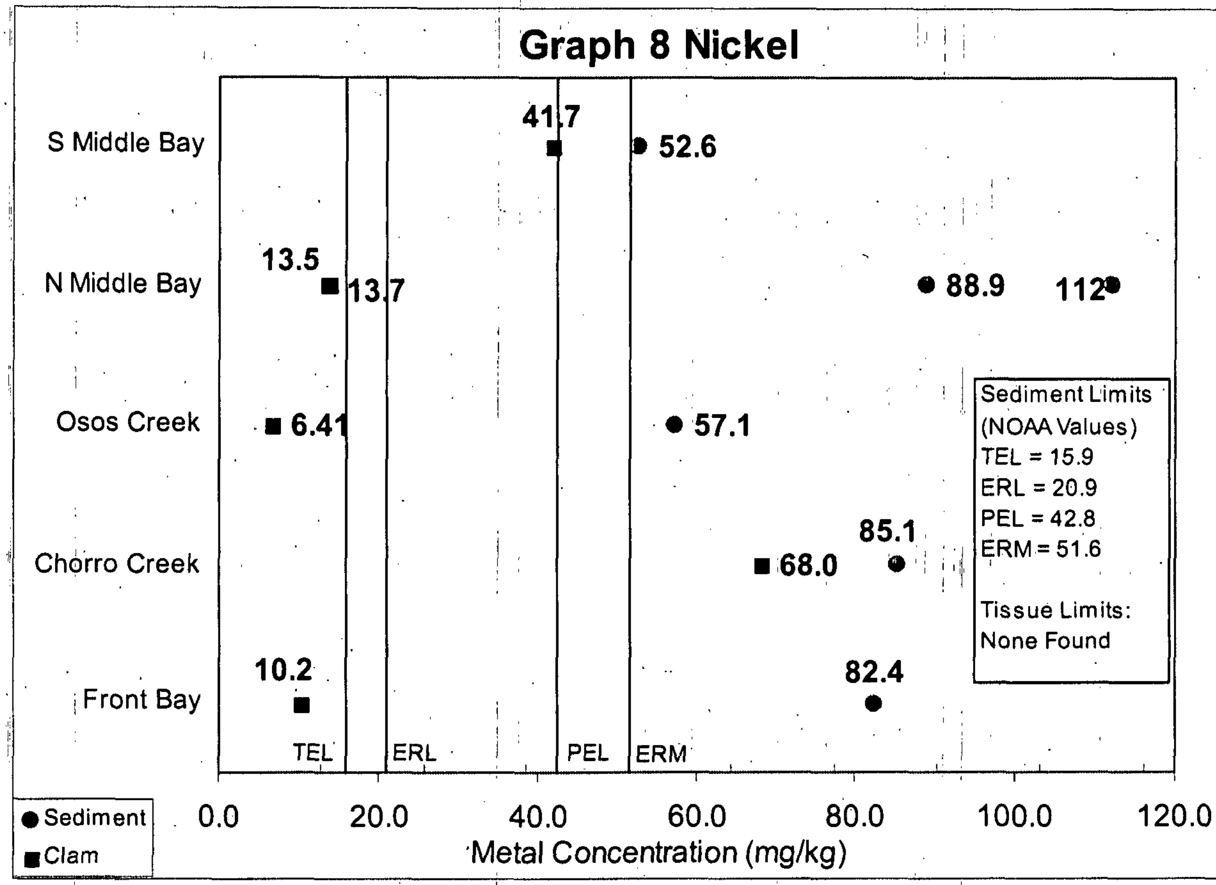

Graph 3 Cadmium
Sediment Limits
(NOAA Values)
TEL = 0.676
ERL = 1.2
PEL = 4.21
ERM = 9.6
Tissue Limits:
MTRL
1.0 mg/kg
Sediment
Clam
S Middle Bay
0.0401
0.192
N Middle Bay
0.0398
0.0398
0.224
0.208
Osos Creek
0.0373
0.195
Chorro Creek
0.203
0.490
Front Bay
0.172
0.203
TEL
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Metal Concentration (mg/kg)

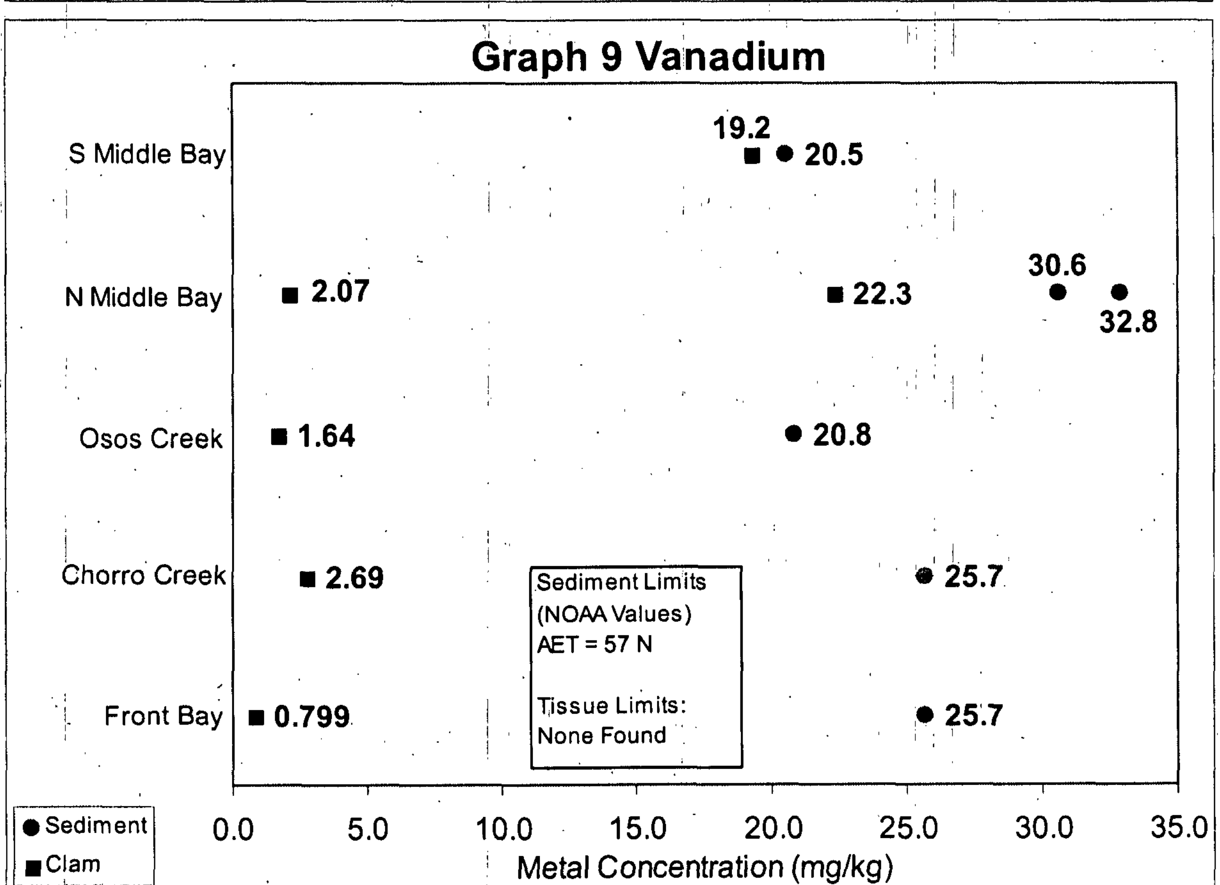

Graph 4 Chromium
S Middle Bay
N Middle Bay
Osos Creek
Chorro Creek
Front Bay
43.6
62.5
72.2
17.5
17.5
80.6
5.96
51.9
64.9
104
14.3
63.5
MIS
TEL
ERL
Sediment Limits
(NOAA Values)
TEL = 52.3
ERL = 81
PEL = 160.4
ERM = 370
Tissue Limits:
MIS Value
1.0 mg/kg
Sediment
Clam
0.0
20.0
40.0
60.0
80.0
100.0
120.0
Metal Concentration (mg/kg)

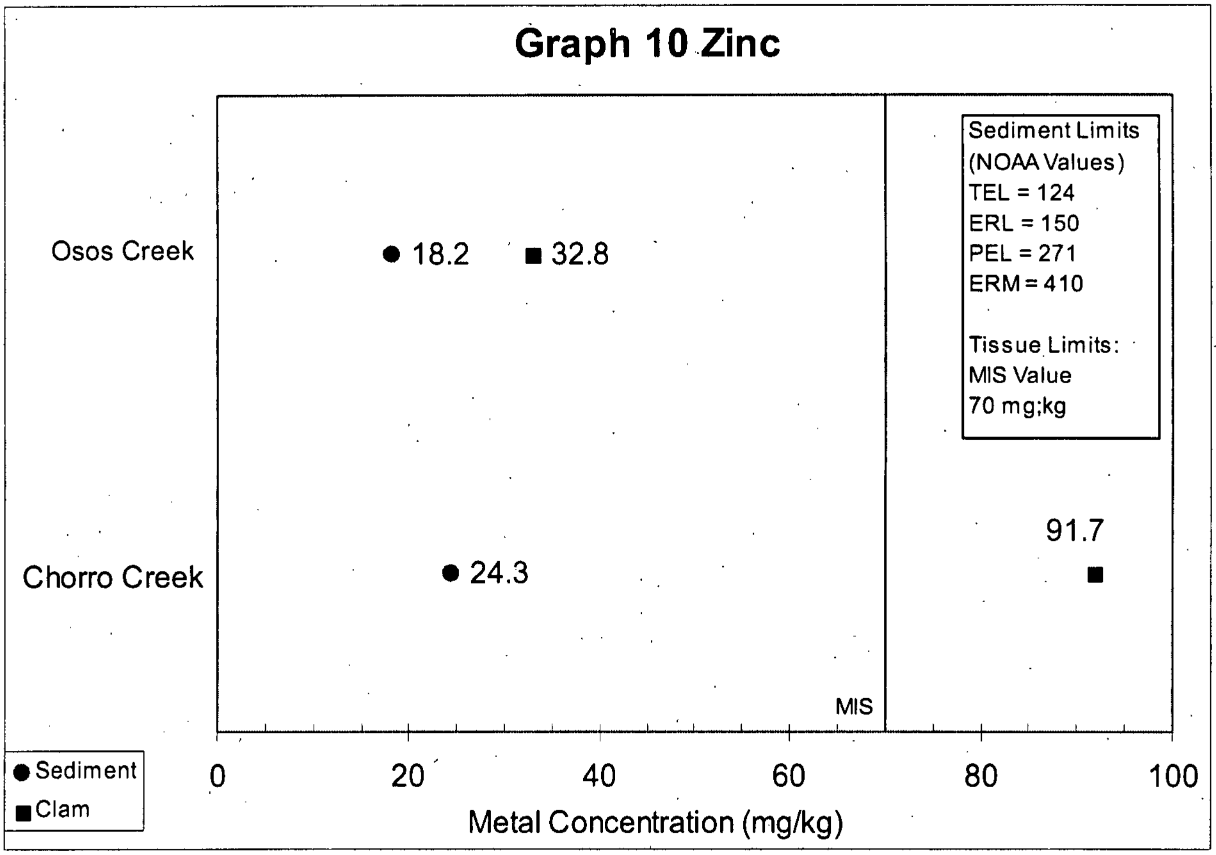

Graph 5 Copper
Osos Creek
Chorro Creek
3.73
5.32
2.85
9.32
Sediment Limits
(NOAA Values)
TEL = 18.7
ERL = 34
PEL = 108.2
ERM = 270
Tissue Limits:
USFW Value
15 mg/kg
Sediment
Clam
USFW
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
Metal Concentration (mg/kg)


Graph 6 Iron
S Middle Bay
N Middle Bay
Osos Creek
Chorro Creek
Front Bay
898
8077
765
765
12500
14925
596
8701
1,186
11622
329
11757
Sediment Limits
(NOAA Values)
AET 220,000 N
Tissue Limits:
None found
Sediment
Clam
0
5000
10000
15000
20000
Metal Concentration (mg/kg)


Graph 7 Lead
Osos Creek
Chorro Creek
0.149
0.649
0.348
2.16
Sediment Limits
(NOAA Values)
TEL = 30.24
ERL = 46.7
PEL = 112.18
ERM = 218
Tissue Limits:
MIS Value
2.0 ppm
Sediment
Clam
MIS
0.0
0.5
1.0
1.5
2.0
2.5
Metal Concentration (mg/kg)

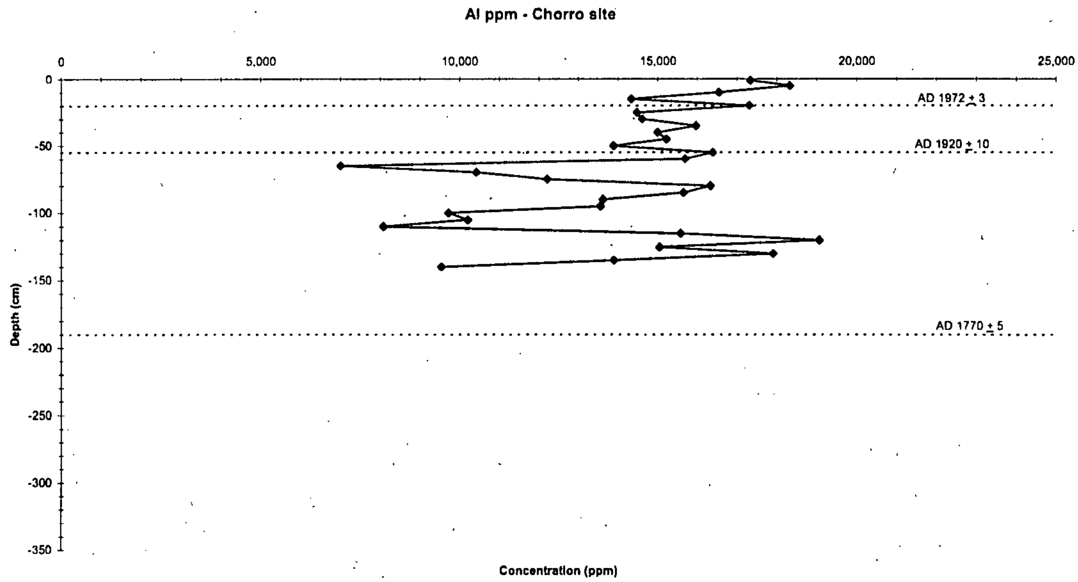

Graph 8 Nickel
S Middle Bay
N Middle Bay
Osos Creek
Chorro Creek
Front Bay
41.7
52.6
13.5
13.7
88.9
112
6.41
57.1
85.1
68.0
10.2
82.4
TEL
ERL
PEL
ERM
Sediment Limits
(NOAA Values)
TEL = 15.9
ERL = 20.9
PEL = 42.8
ERM = 51.6
Tissue Limits:
None Found
Sediment
Clam
0.0
20.0
40.0
60.0
80.0
100.0
120.0
Metal Concentration (mg/kg)

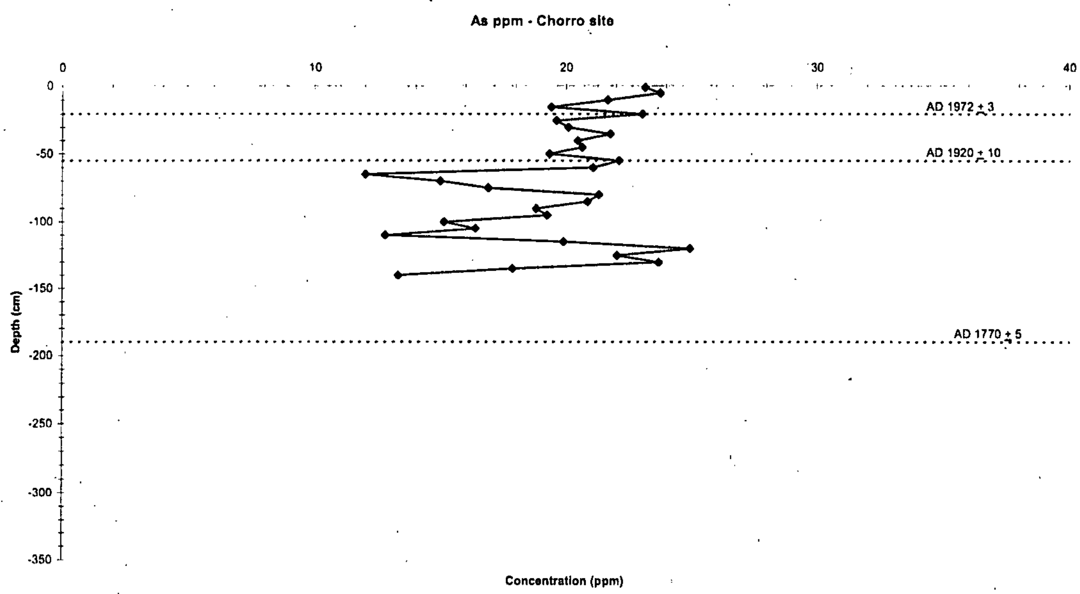

Graph 9 Vanadium
S Middle Bay
N Middle Bay
Osos Creek
Chorro Creek
Front Bay
19.2
20.5
2.07
22.3
30.6
32.8
1.64
20.8
2.69
25.7
0.799
25.7
Sediment Limits
(NOAA Values)
AET = 57 N
Tissue Limits:
None Found
Sediment
Clam
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
Metal Concentration (mg/kg)

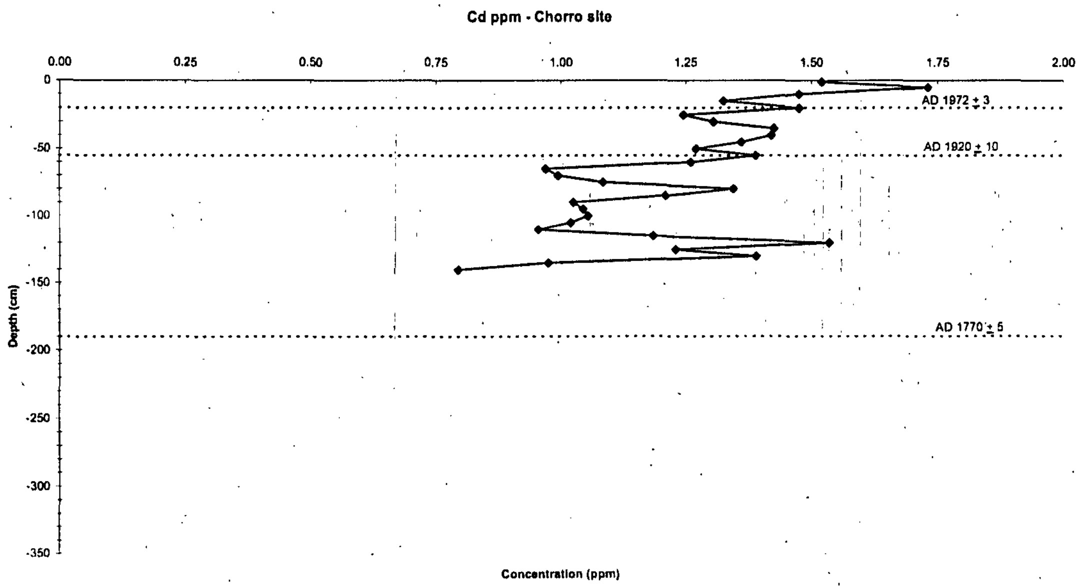

Graph 10 Zinc
Sediment Limits
(NOAA Values)
TEL = 124
ERL = 150
PEL = 271
ERM = 410
Tissue Limits:
MIS Value
70 mg;kg
Osos Creek
18.2
32.8
Chorro Creek
24.3
91.7
MIS
0
20
40
60
80
100
Metal Concentration (mg/kg)
Sediment
Clam

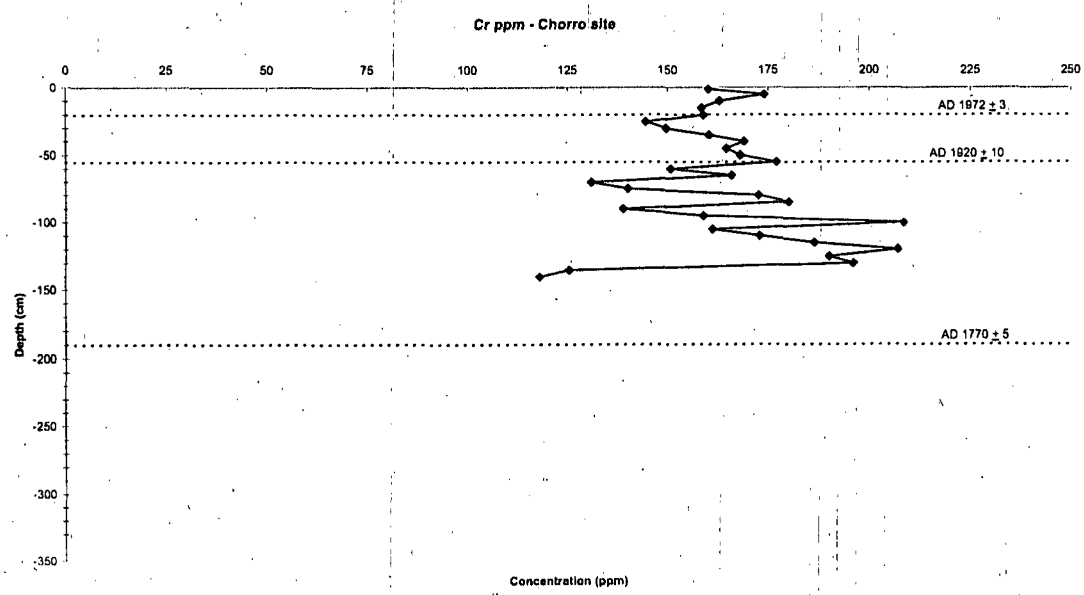
Appendix 4 - Coring study

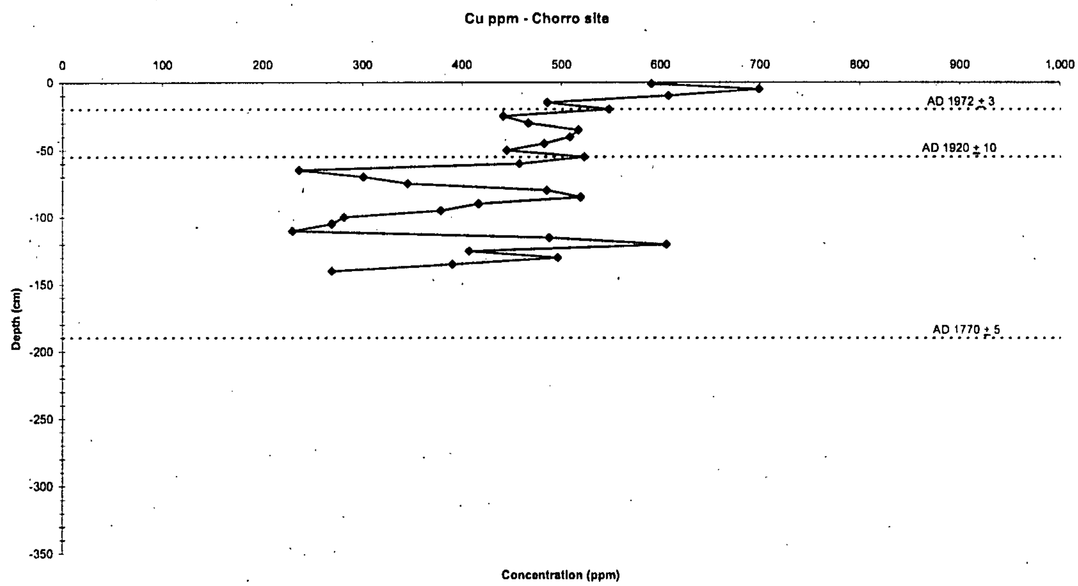
Graphs of all metals at four coring sites

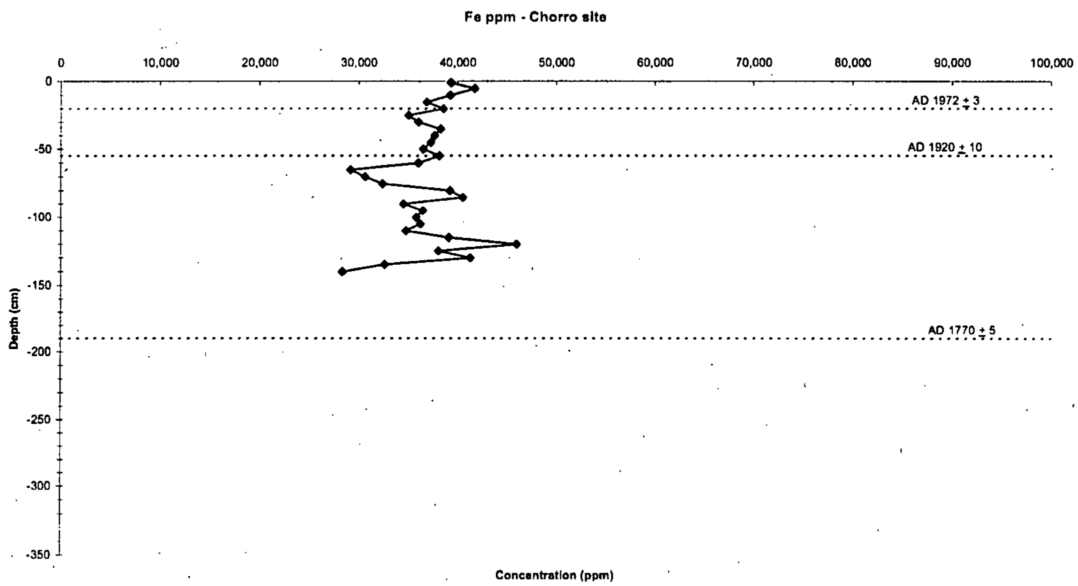

Al ppm - Chorro site
0
5,000
10,000
15,000
20,000
25,000
0
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Concentration (ppm)

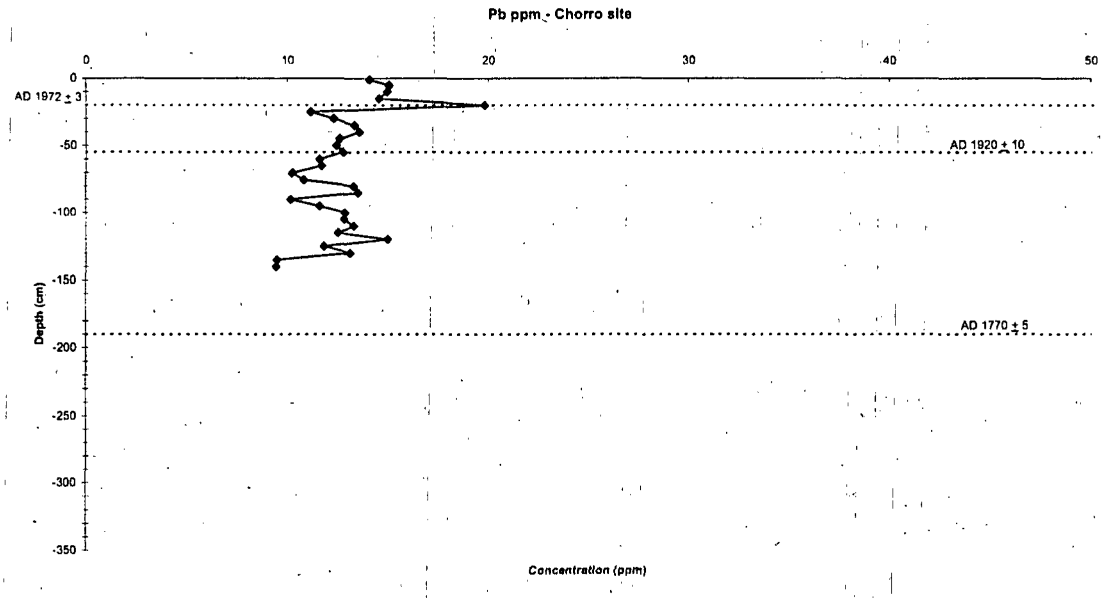

As ppm - Chorro site
0
10
20
30
40
0
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Concentration (ppm)

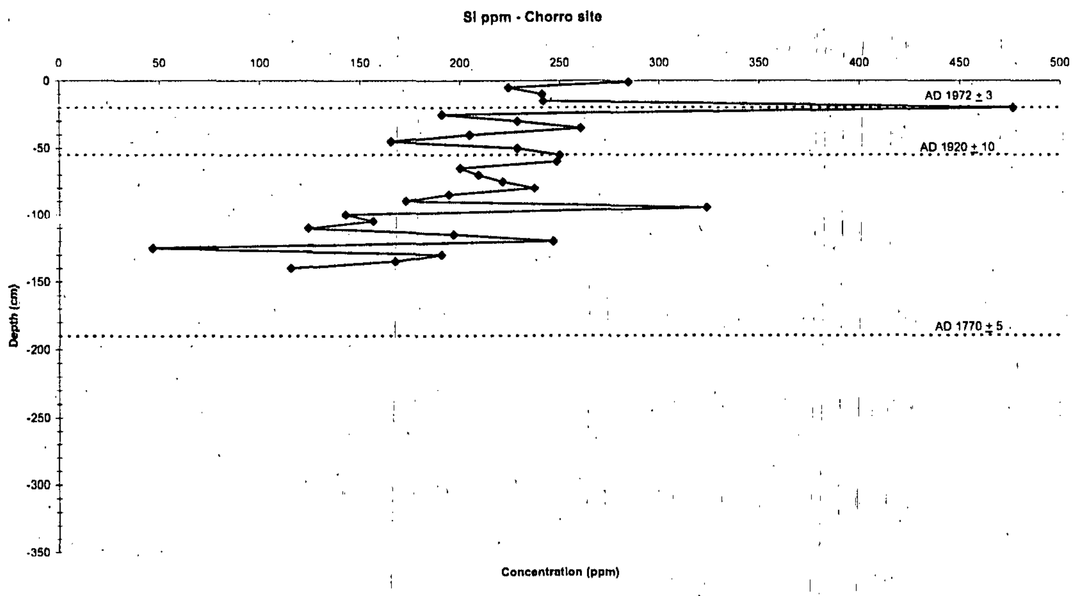

Cd ppm - Chorro site
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
0
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Concentration (ppm)

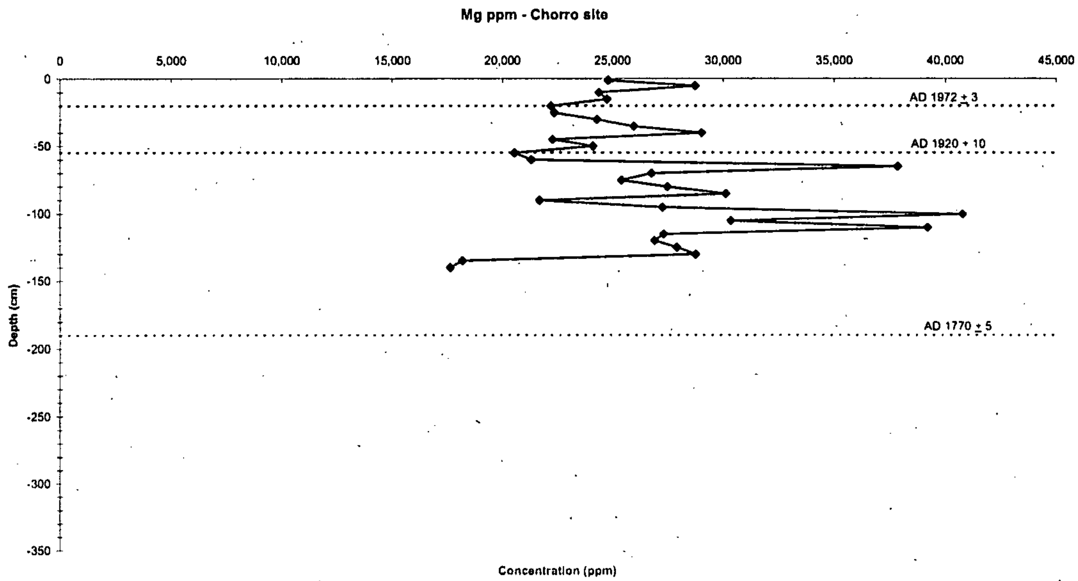

Cr ppm - Chorro site
0
25
50
75
100
125
150
175
200
225
250
0
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Concentration (ppm)

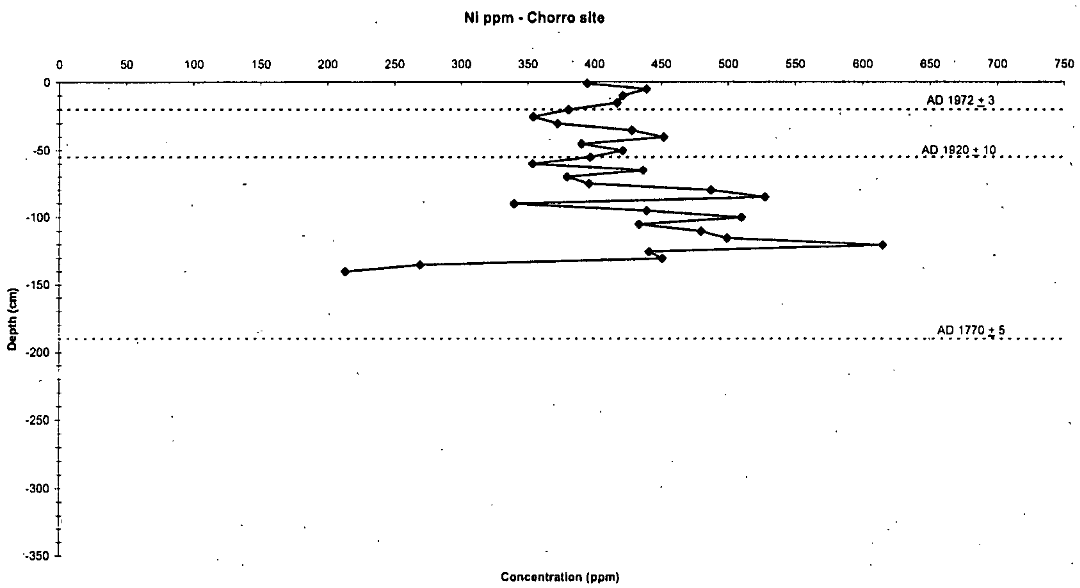

Cu ppm - Chorro site
0
100
200
300
400
500
600
700
800
900
1,000
0
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Concentration (ppm)

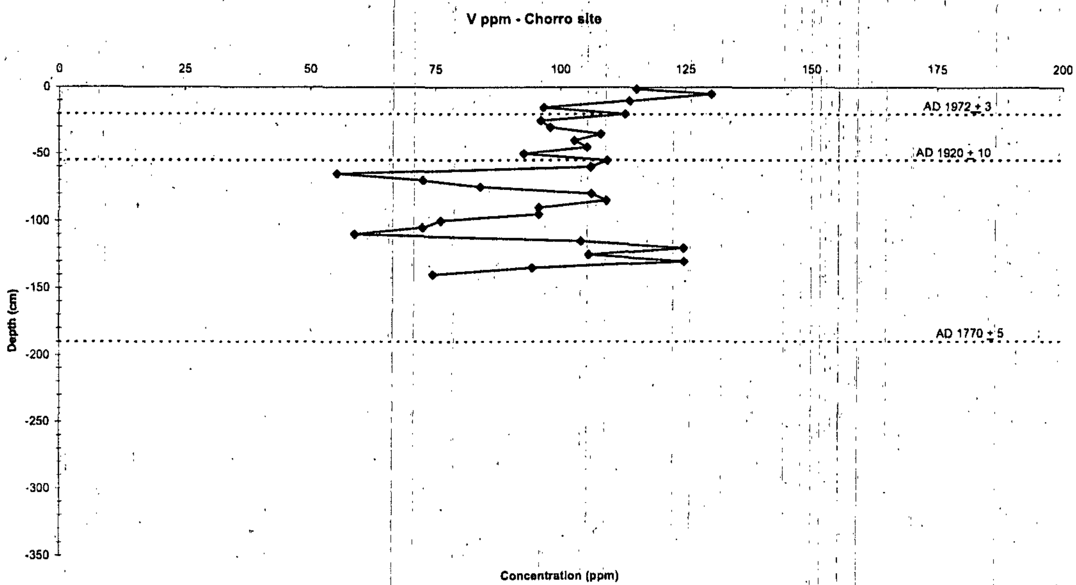

Fe ppm - Chorro site
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
0
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Concentration (ppm)

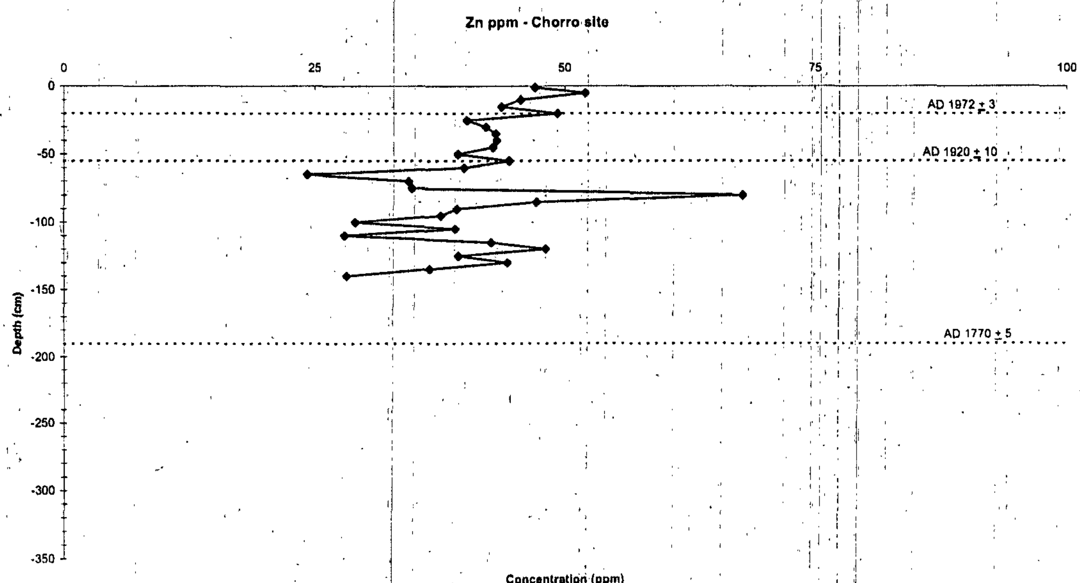

Pb ppm - Chorro site
0
10
20
30
40
50
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Depth (cm)
-50
-100
-150
-200
-250
-300
-350
Concentration (ppm)


Si ppm - Chorro site
0
50
100
150
200
250
300
350
400
450
500
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Depth (cm)
-50
-100
-150
-200
-250
-300
-350
Concentration (ppm)

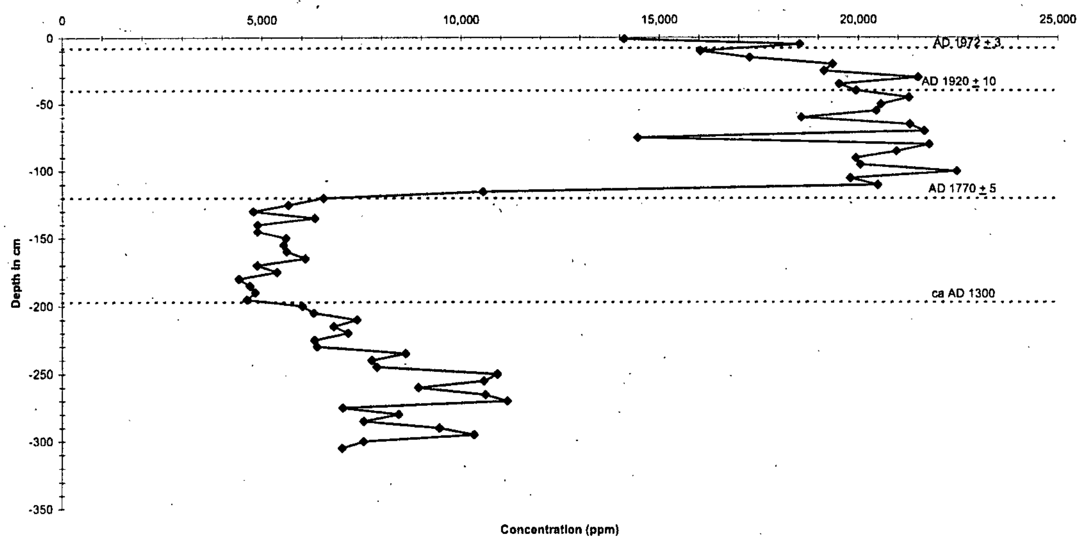

Mg ppm - Chorro site
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
0
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 + 3
AD 1920 + 10
AD 1770 + 5
Concentration (ppm)


Ni ppm - Chorro site
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
0
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 + 3
AD 1920 + 10
AD 1770 + 5
Concentration (ppm)

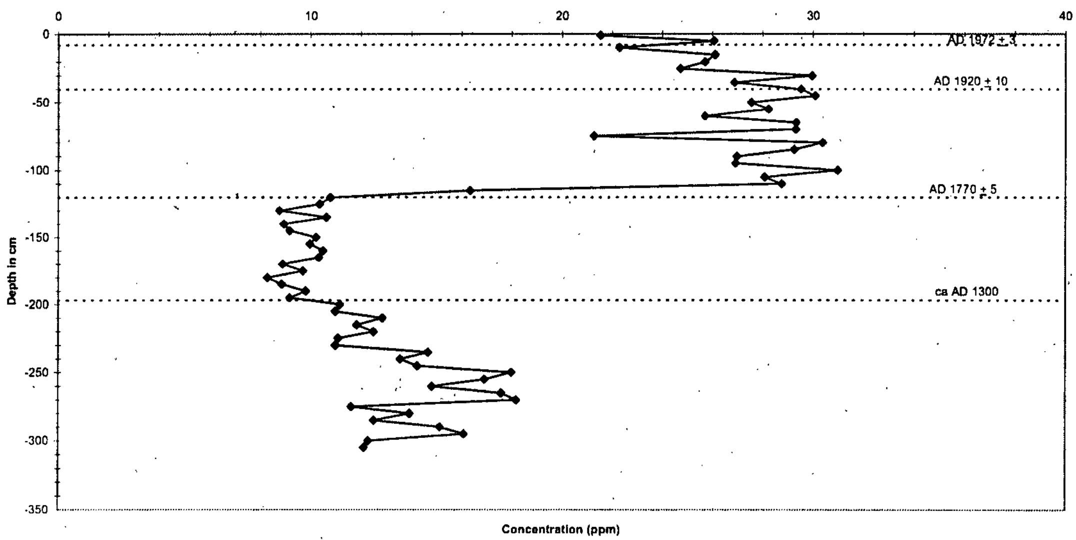

V ppm - Chorro site
0
25
50
75
100
125
150
175
200
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Depth (cm)
-50
-100
-150
-200
-250
-300
-350
Concentration (ppm)

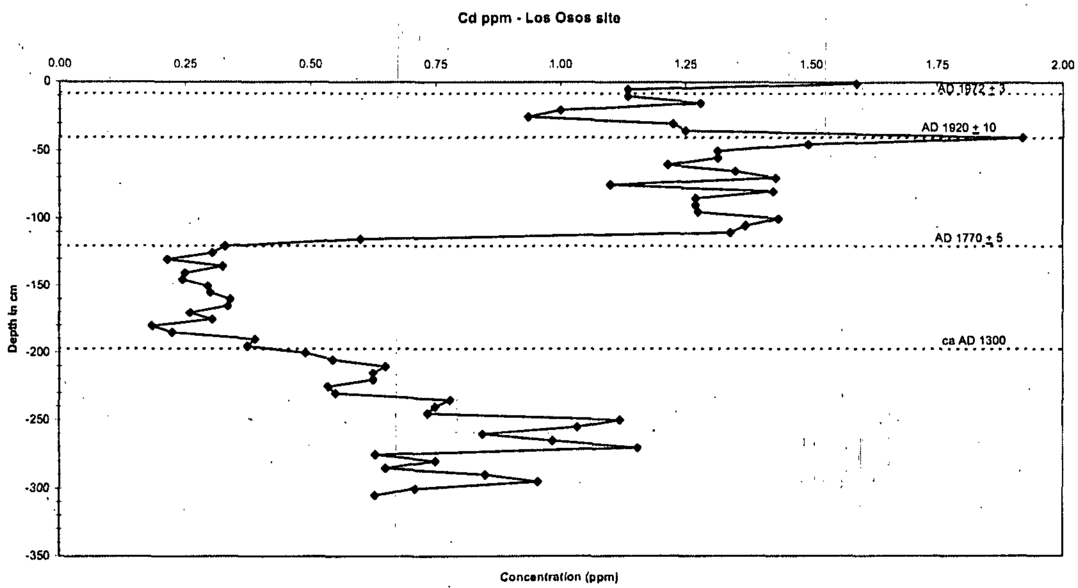

Zn ppm - Chorro site
0
25
50
75
100
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Depth (cm)
-50
-100
-150
-200
-250
-300
-350
Concentration (ppm)

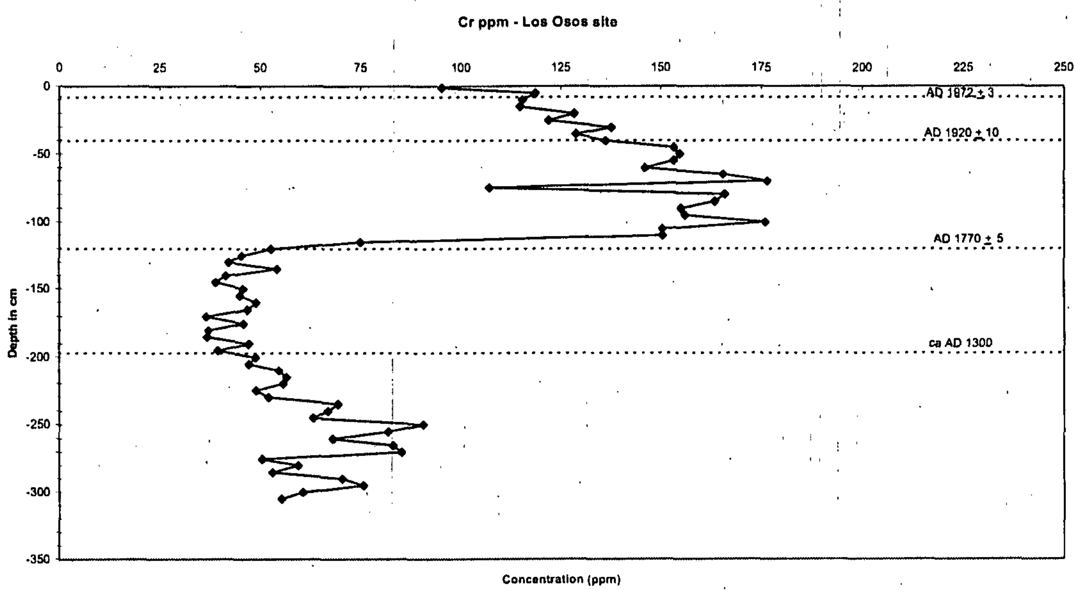
Al ppm - Los Osos site

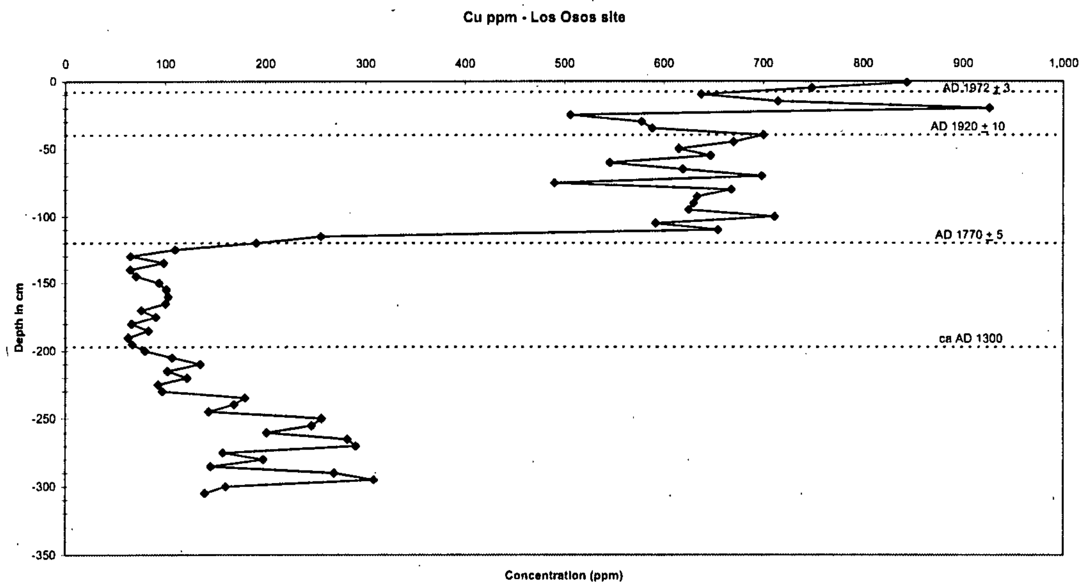


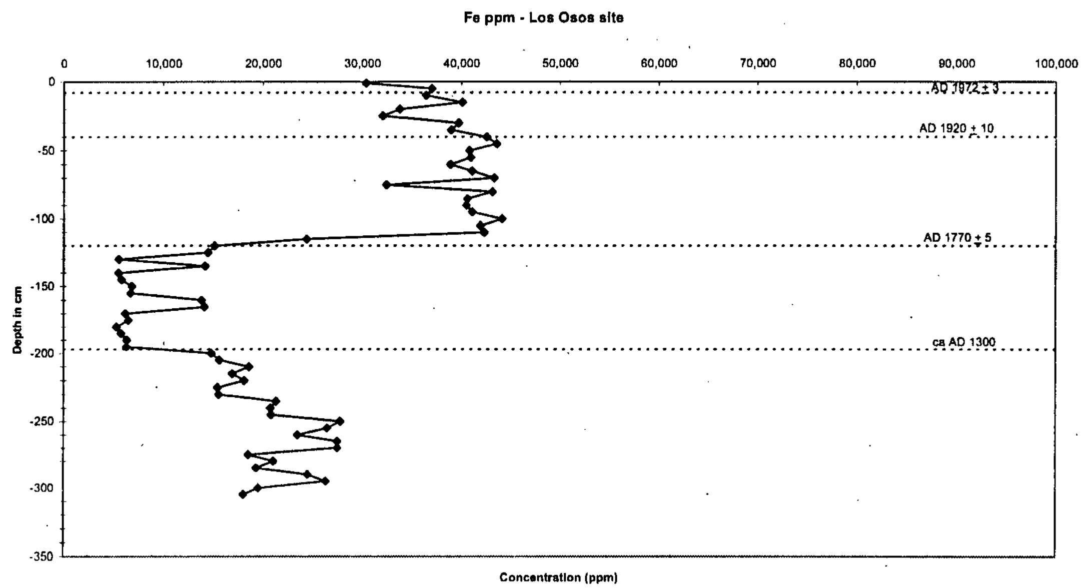
As ppm - Los Osos site

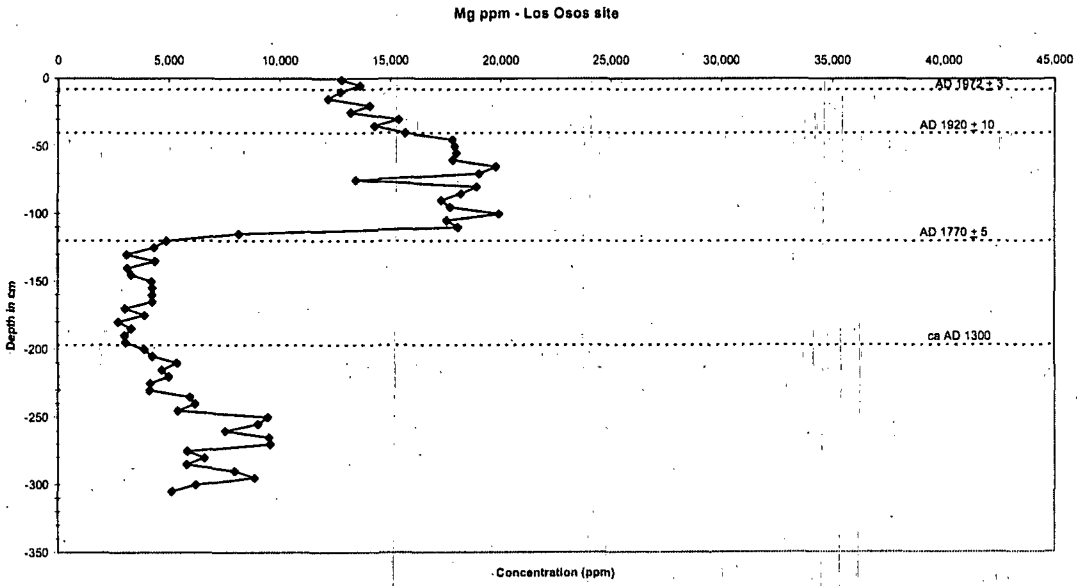



Cd ppm - Los Osos site
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
ca AD 1300
0
-50
-100
-150
-200
-250
-300
-350
Depth in cm
Concentration (ppm)

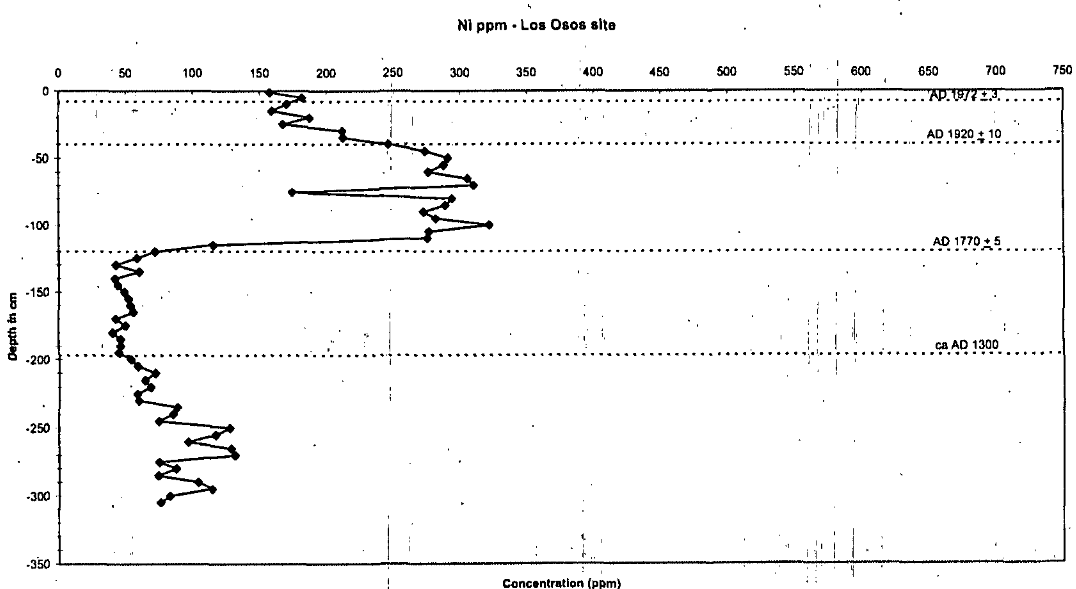

Cr ppm - Los Osos site
0
25
50
75
100
125
150
175
200
225
250
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
ca AD 1300
0
-50
-100
-150
-200
-250
-300
-350
Depth in cm
Concentration (ppm)


Cu ppm - Los Osos site
0
100
200
300
400
500
600
700
800
900
1,000
0
-50
-100
-150
-200
-250
-300
-350
Depth in cm
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
ca AD 1300
Concentration (ppm)

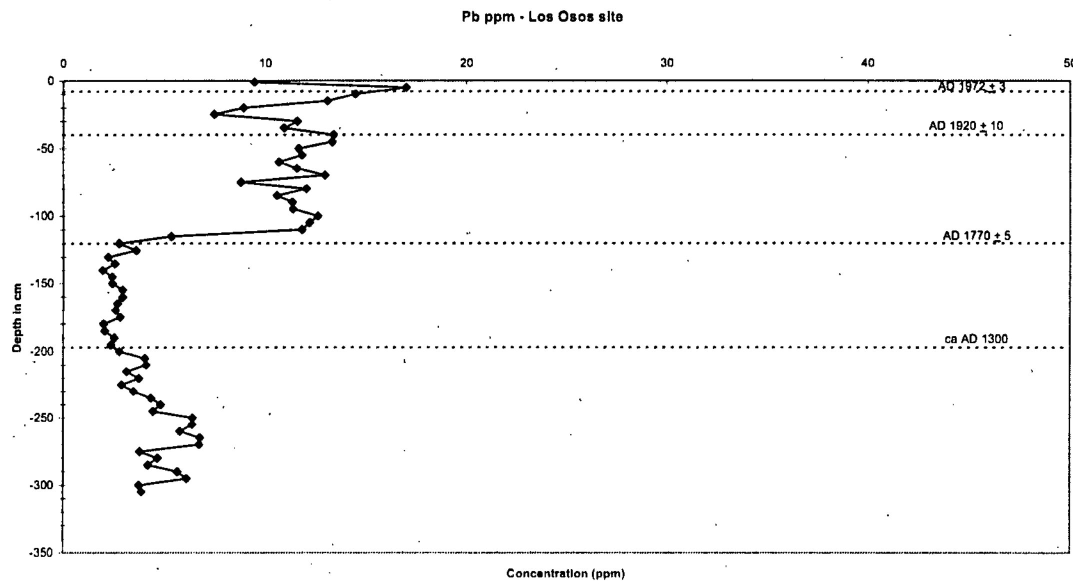

Fe ppm - Los Osos site
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
0
-50
-100
-150
-200
-250
-300
-350
Depth in cm
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
ca AD 1300
Concentration (ppm)

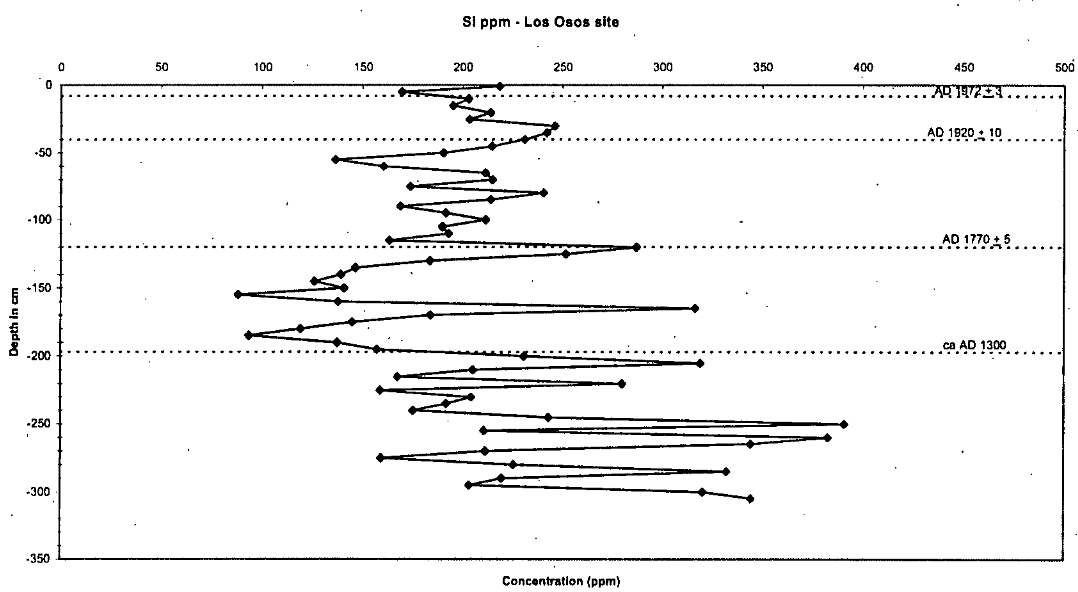


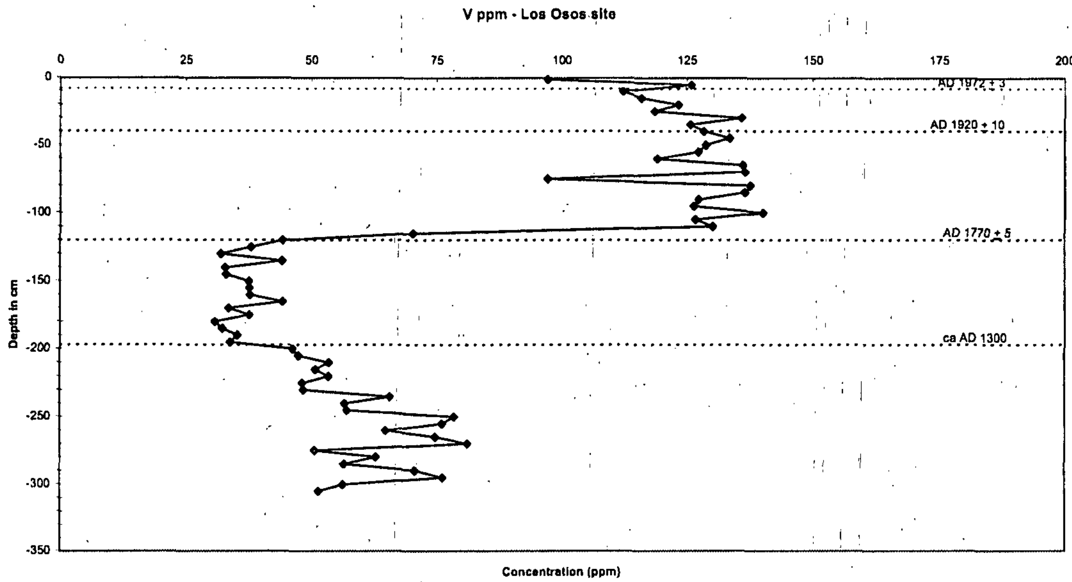
Mg ppm - Los Osos site
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
ca AD 1300
0
-50
-100
-150
-200
-250
-300
-350
Depth in cm
Concentration (ppm)

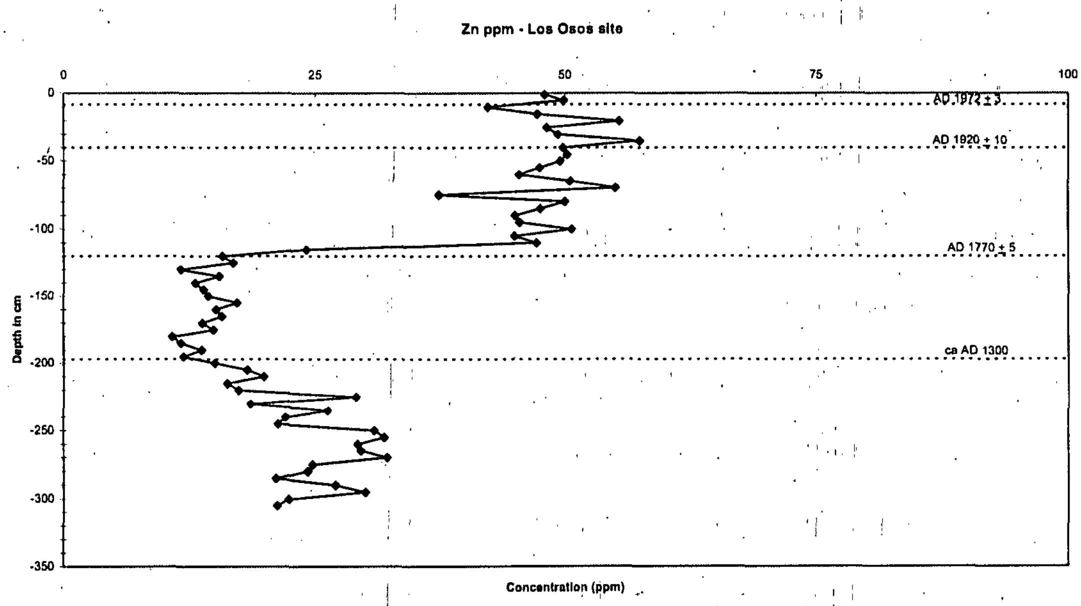


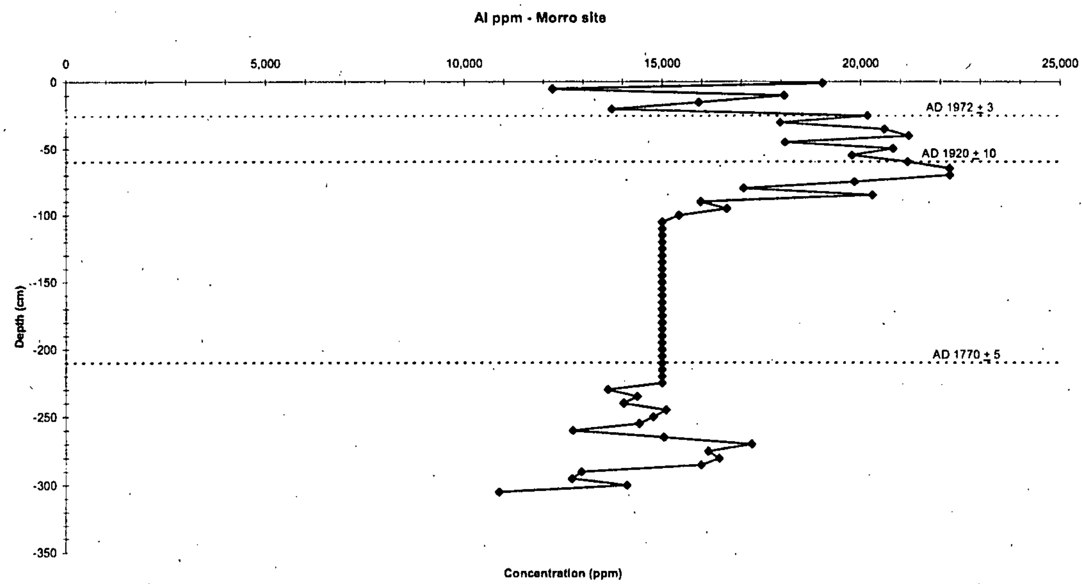
Ni ppm - Los Osos site
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
ca AD 1300
0
-50
-100
-150
-200
-250
-300
-350
Depth in cm
Concentration (ppm)

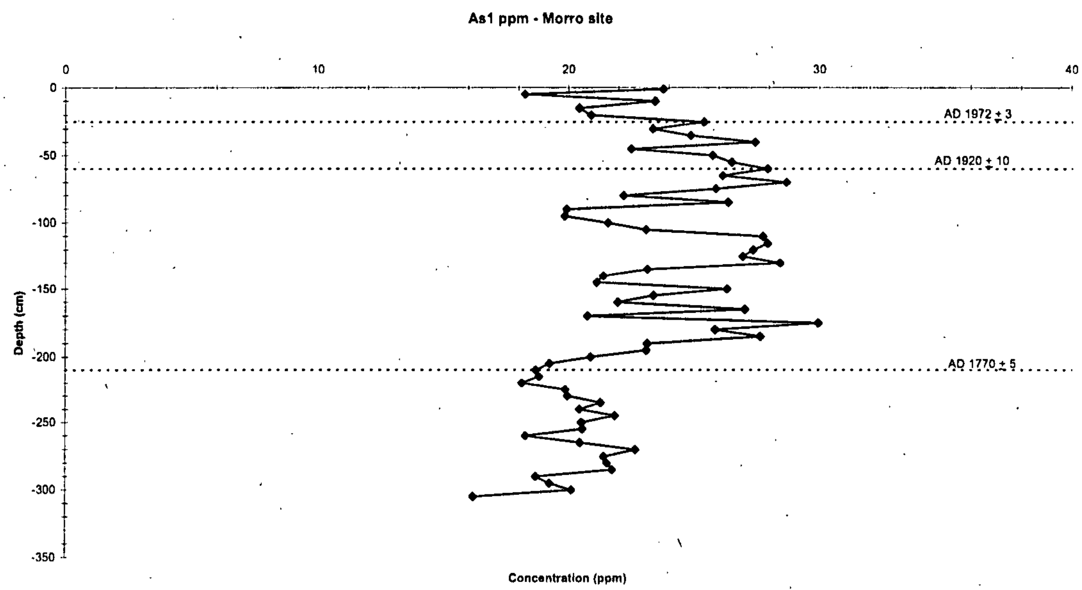

Pb ppm - Los Osos site
0
10
20
30
40
50
0
-50
-100
-150
-200
-250
-300
-350
Depth in cm
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
ca AD 1300
Concentration (ppm)

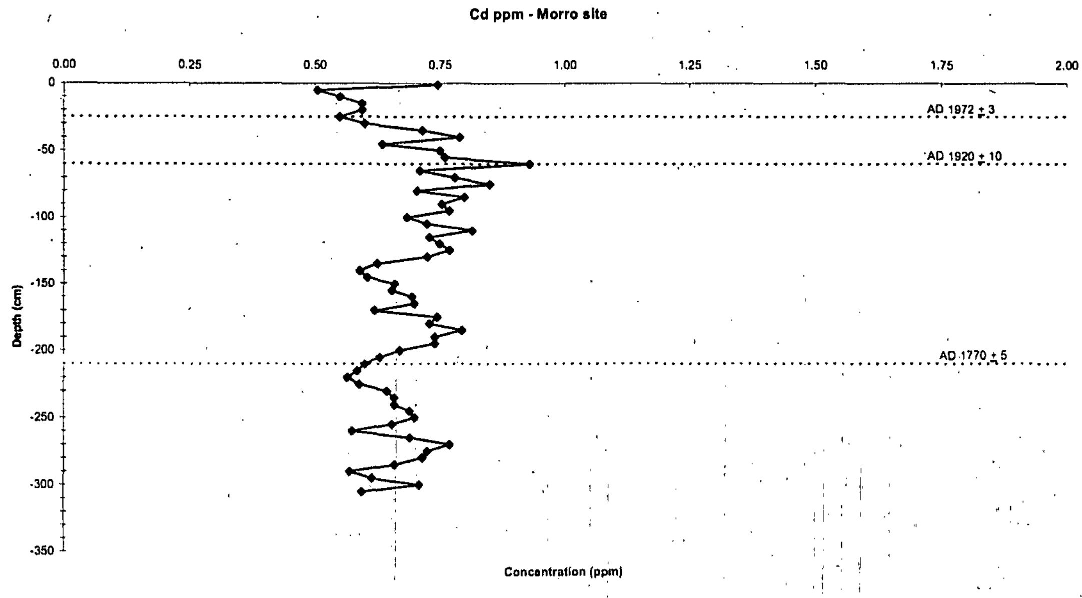

Si ppm - Los Osos site
0
50
100
150
200
250
300
350
400
450
500
0
-50
-100
-150
-200
-250
-300
-350
Depth in cm
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
ca AD 1300
Concentration (ppm)

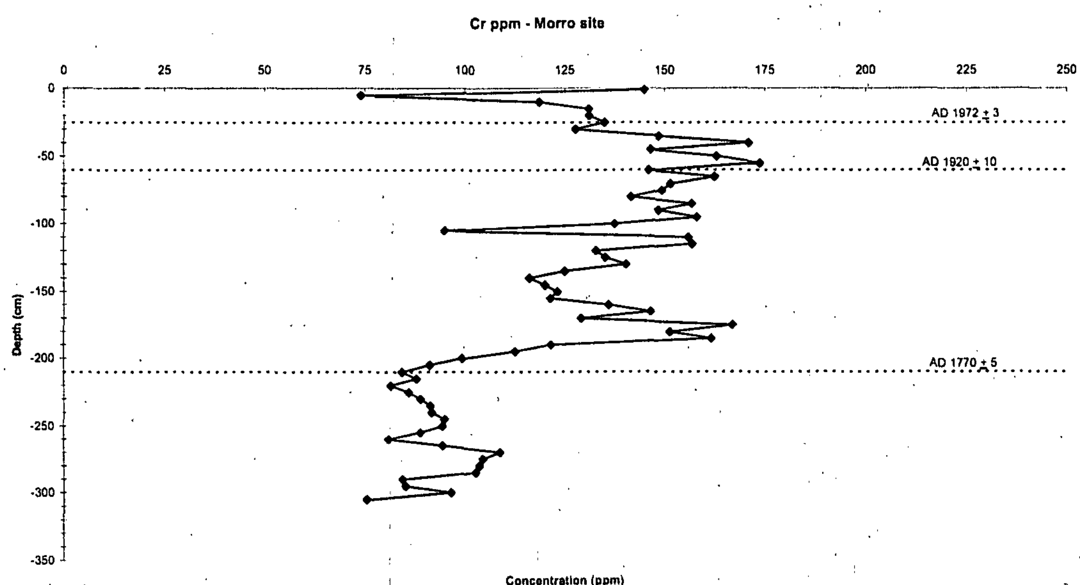

V ppm - Los Osos site
0
25
50
75
100
125
150
175
200
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
ca AD 1300
0
-50
-100
-150
-200
-250
-300
-350
Depth in cm
Concentration (ppm)

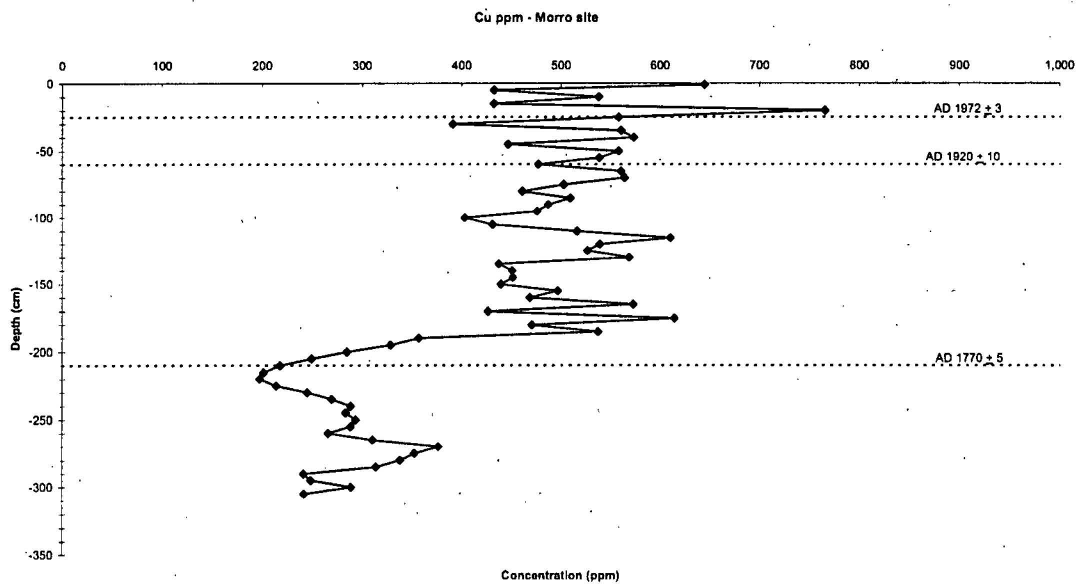

Zn ppm - Los Osos site
0
25
50
75
100
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
ca AD 1300
0
-50
-100
-150
-200
-250
-300
-350
Depth in cm
Concentration (ppm)

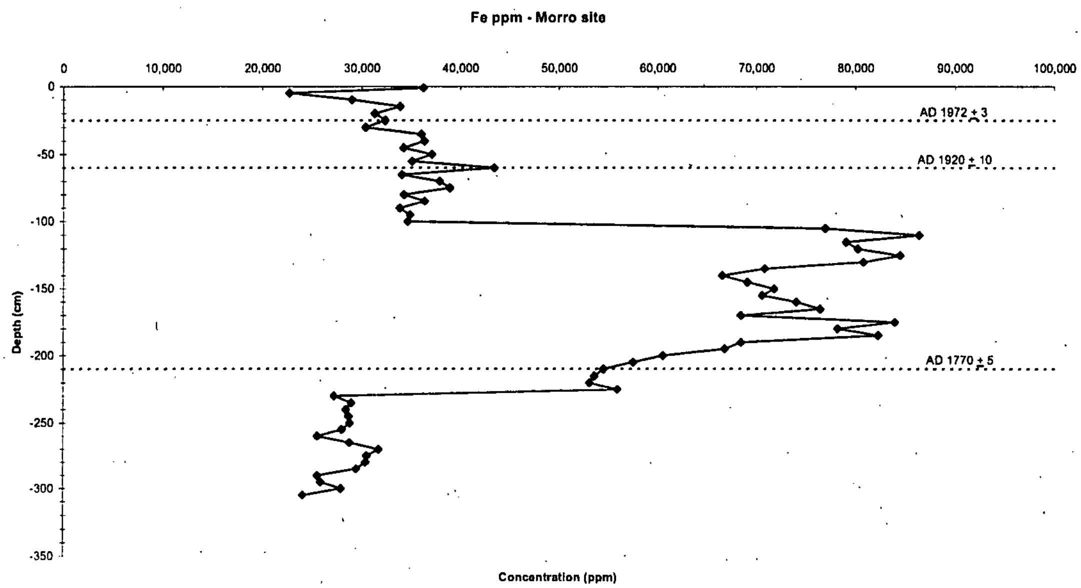

Al ppm - Morro site
0
5,000
10,000
15,000
20,000
25,000
0
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Concentration (ppm)

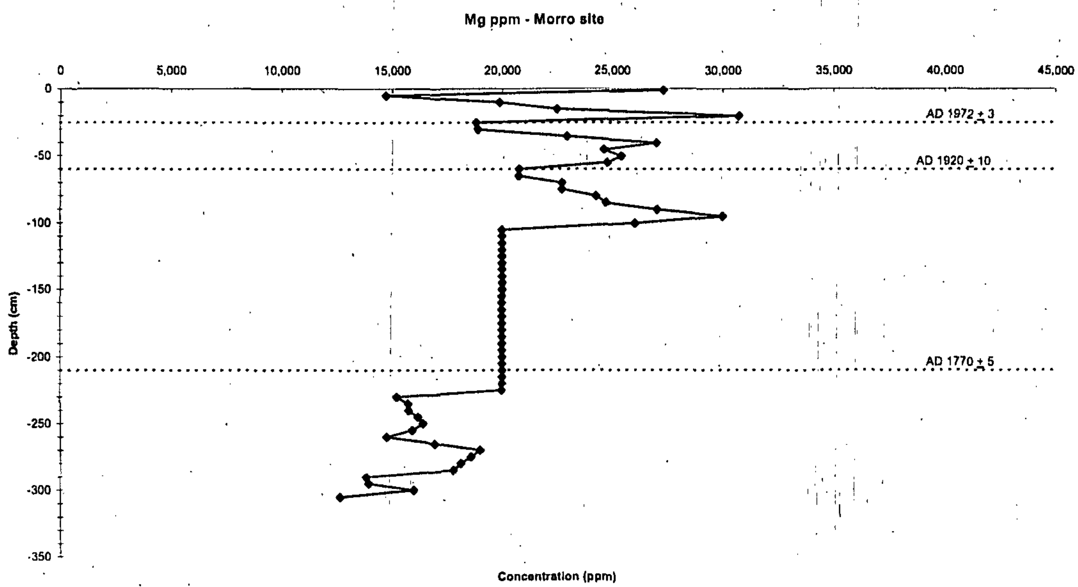

As1 ppm - Morro site
0
10
20
30
40
0
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Concentration (ppm)

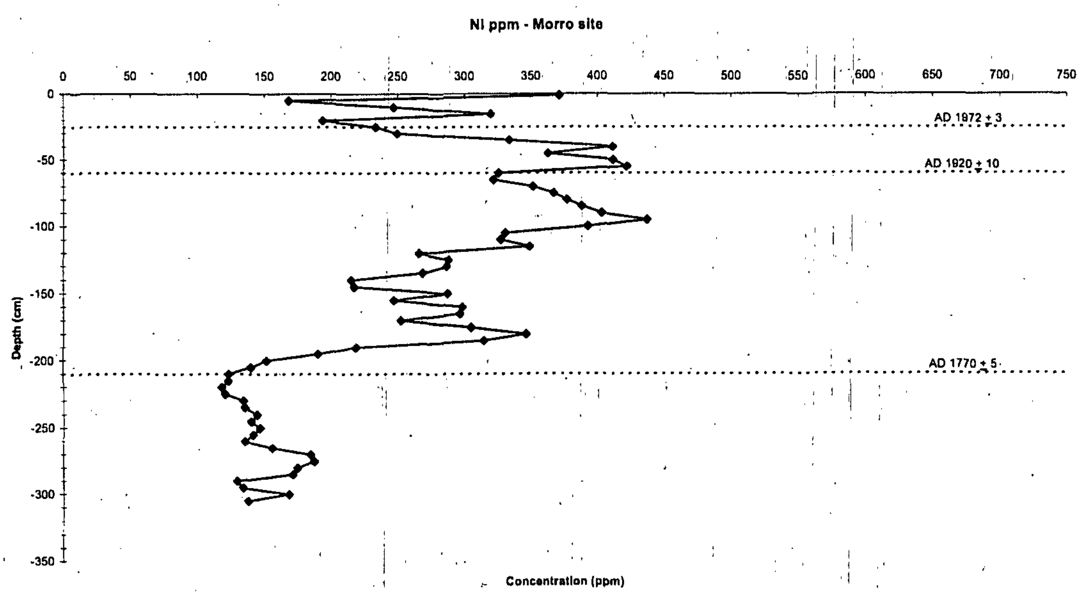

Cd ppm - Morro site
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
0
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Concentration (ppm)

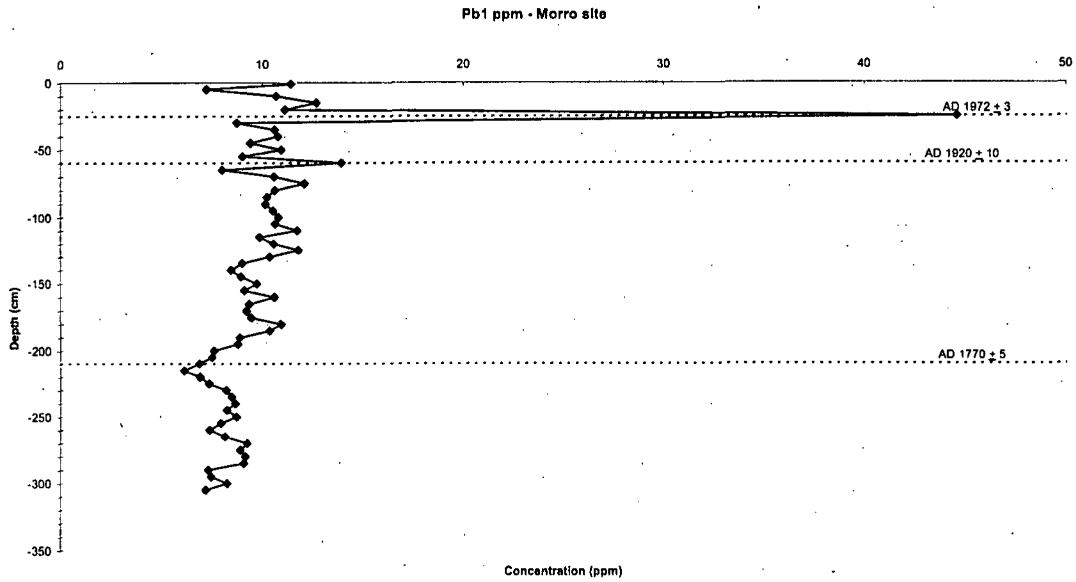

Cr ppm - Morro site
0
25
50
75
100
125
150
175
200
225
250
0
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Concentration (ppm)

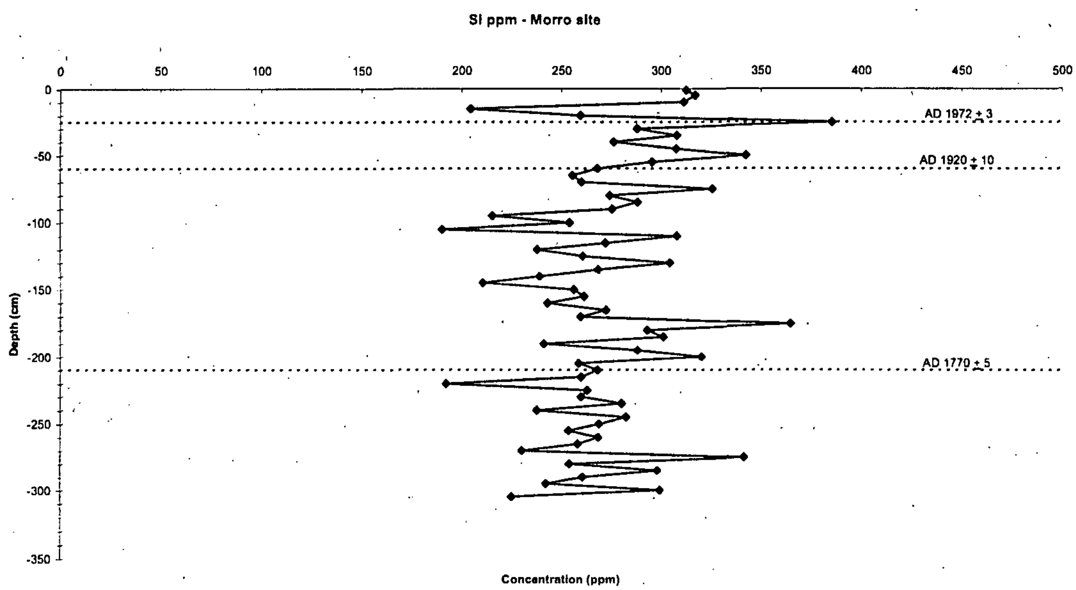

Cu ppm - Morro site
0
100
200
300
400
500
600
700
800
900
1,000
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
Concentration (ppm)

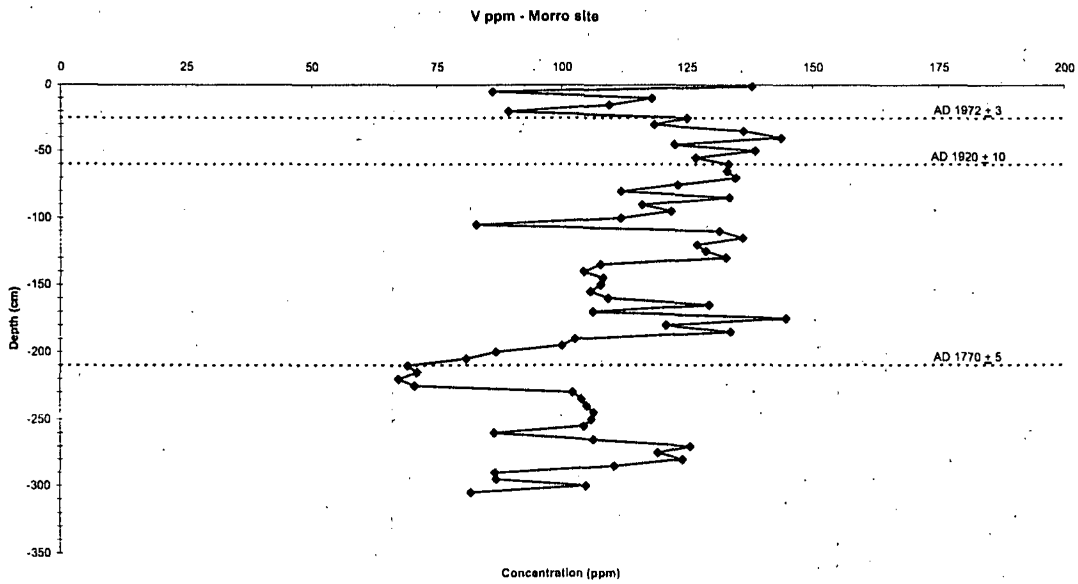

Fe ppm - Morro site
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
Concentration (ppm)

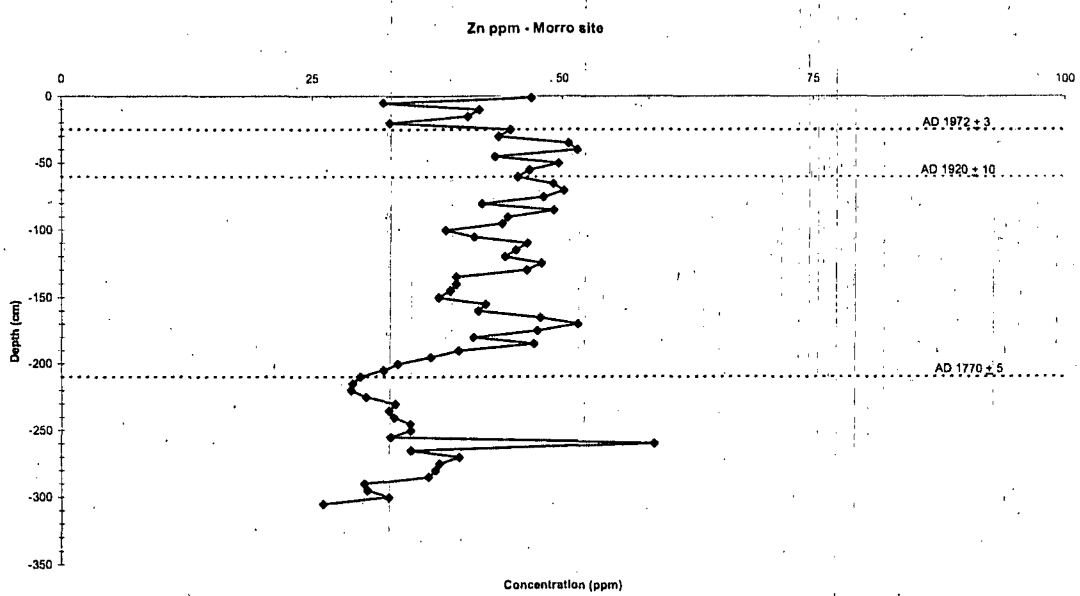

Mg ppm - Morro site
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
0
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Concentration (ppm)

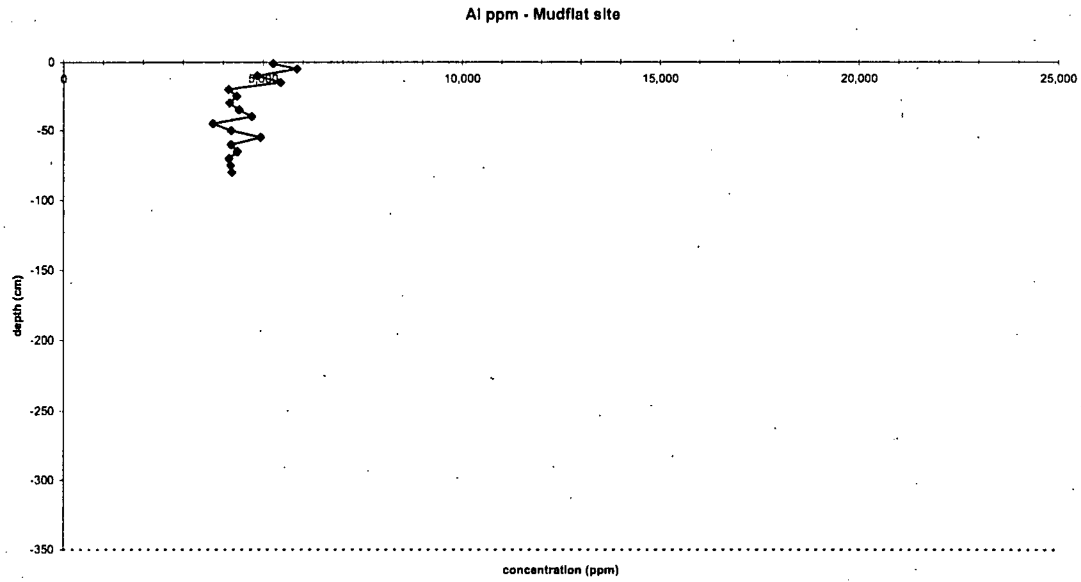

Ni ppm - Morro site
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
0
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Concentration (ppm)

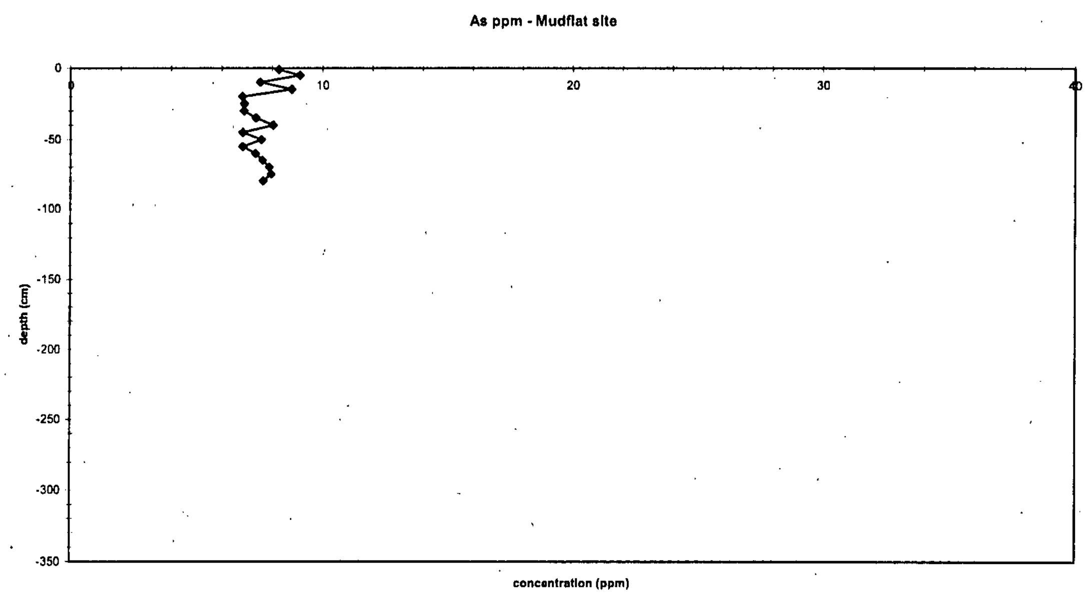

Pb1 ppm - Morro site
0
10
20
30
40
50
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Concentration (ppm)

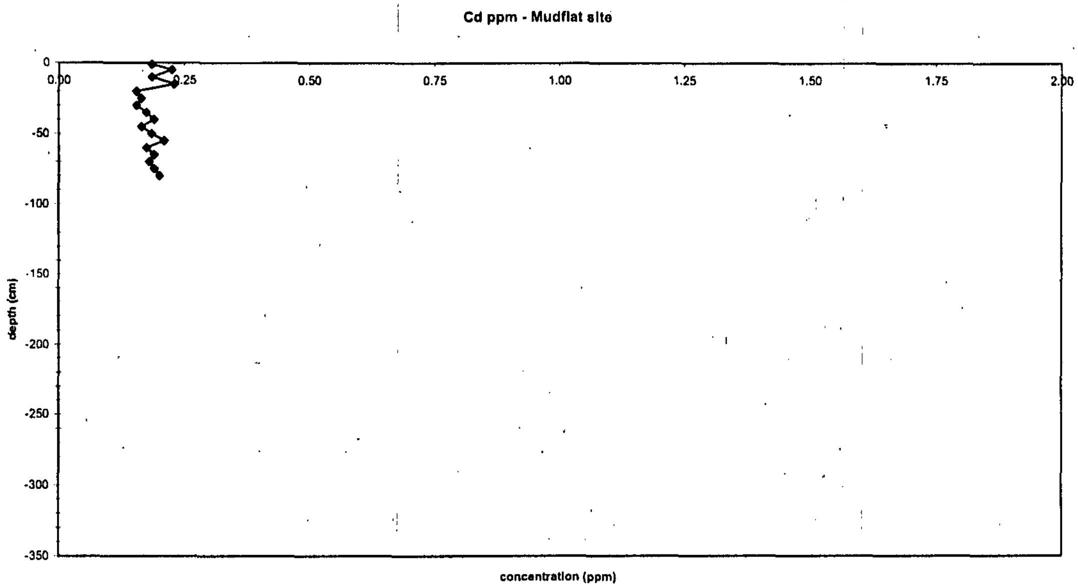

Si ppm - Morro site
0
50
100
150
200
250
300
350
400
450
500
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Concentration (ppm)

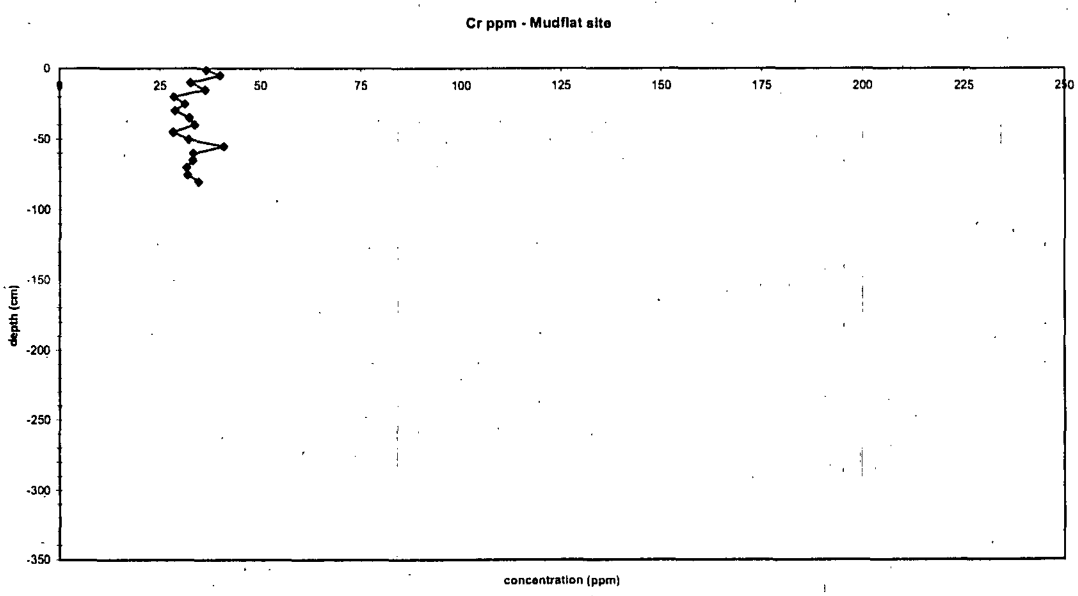

V ppm - Morro site
0
25
50
75
100
125
150
175
200
0
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Concentration (ppm)

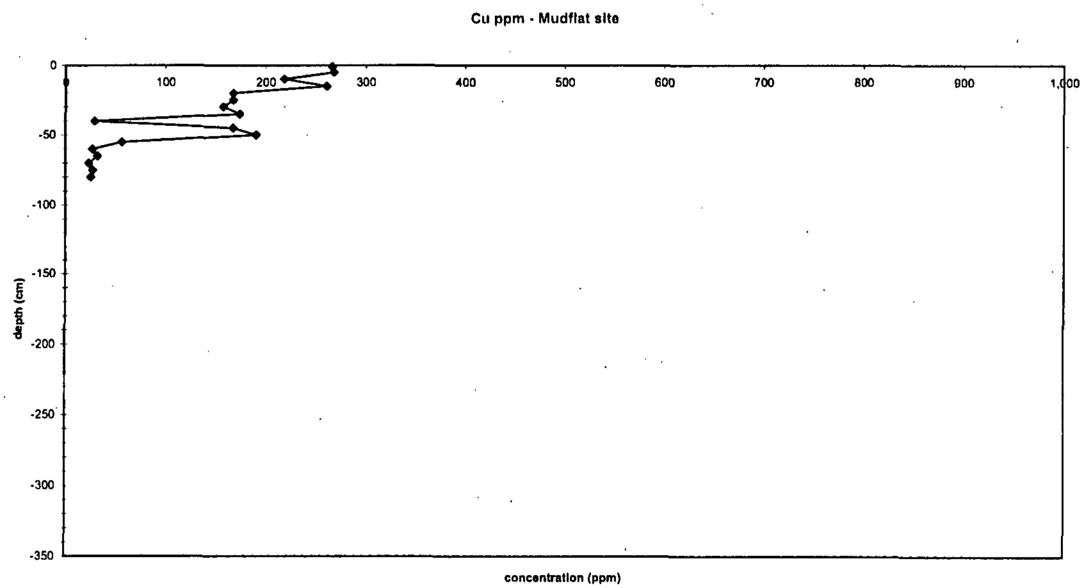

Zn ppm - Morro site
0
25
50
75
100
0
-50
-100
-150
-200
-250
-300
-350
Depth (cm)
AD 1972 ± 3
AD 1920 ± 10
AD 1770 ± 5
Concentration (ppm)

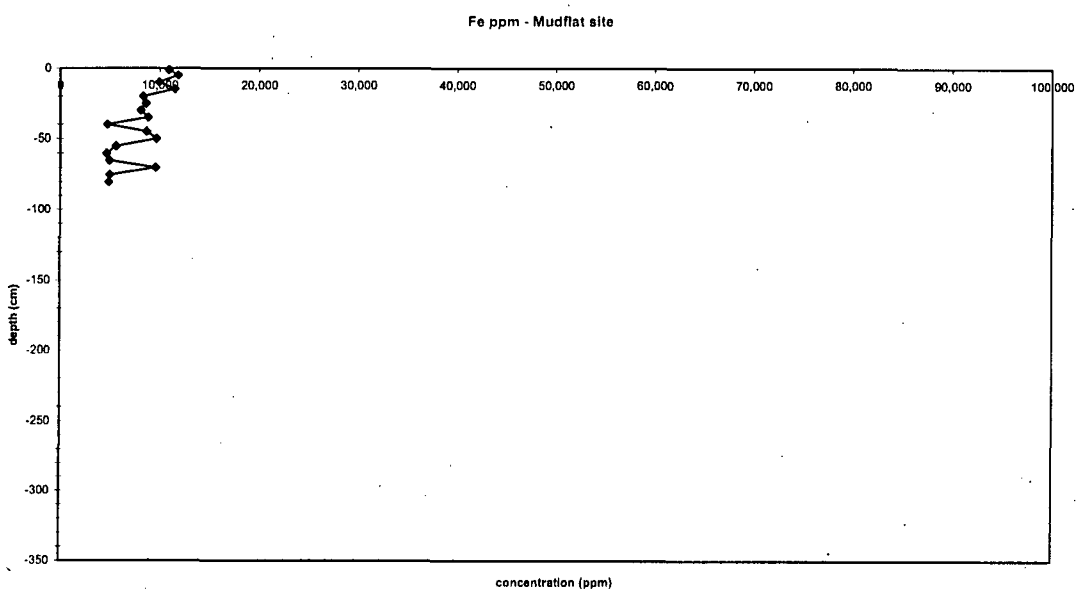

Al ppm - Mudflat site
0
-50
-100
-150
-200
-250
-300
-350
depth (cm)
0
5,000
10,000
15,000
20,000
25,000
concentration (ppm)

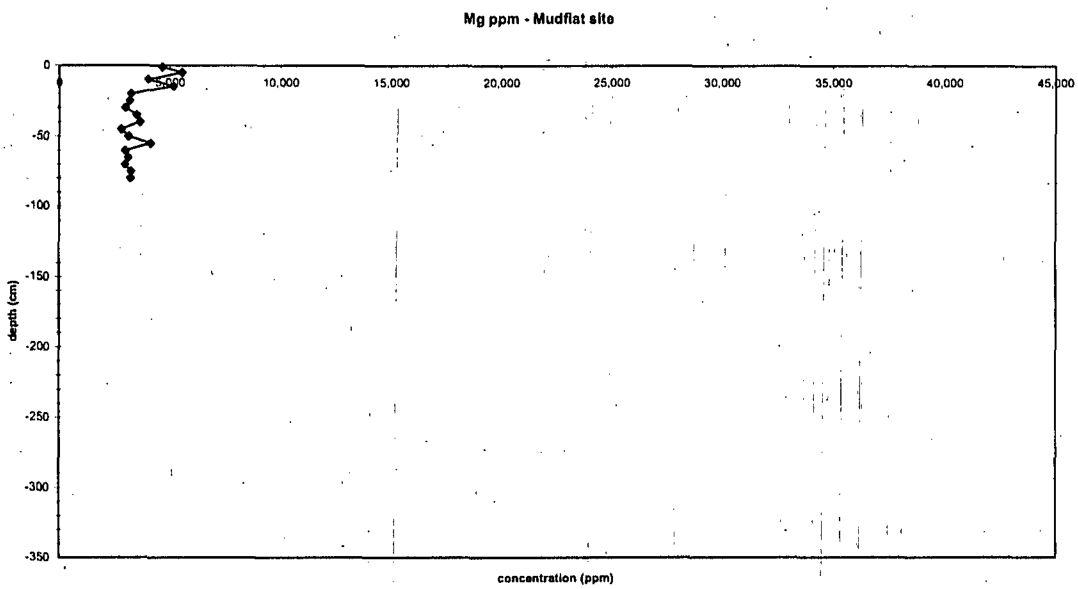

As ppm - Mudflat site
0
-50
-100
-150
-200
-250
-300
-350
depth (cm)
0
10
20
30
40
concentration (ppm)

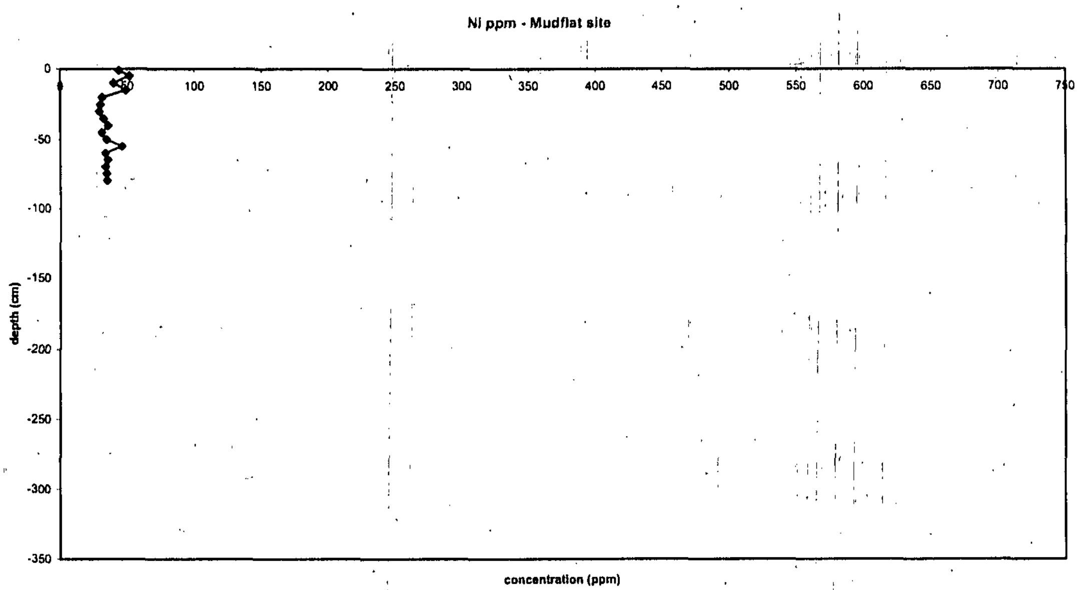

Cd ppm - Mudflat site
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
0
-50
-100
-150
-200
-250
-300
-350
depth (cm)
concentration (ppm)

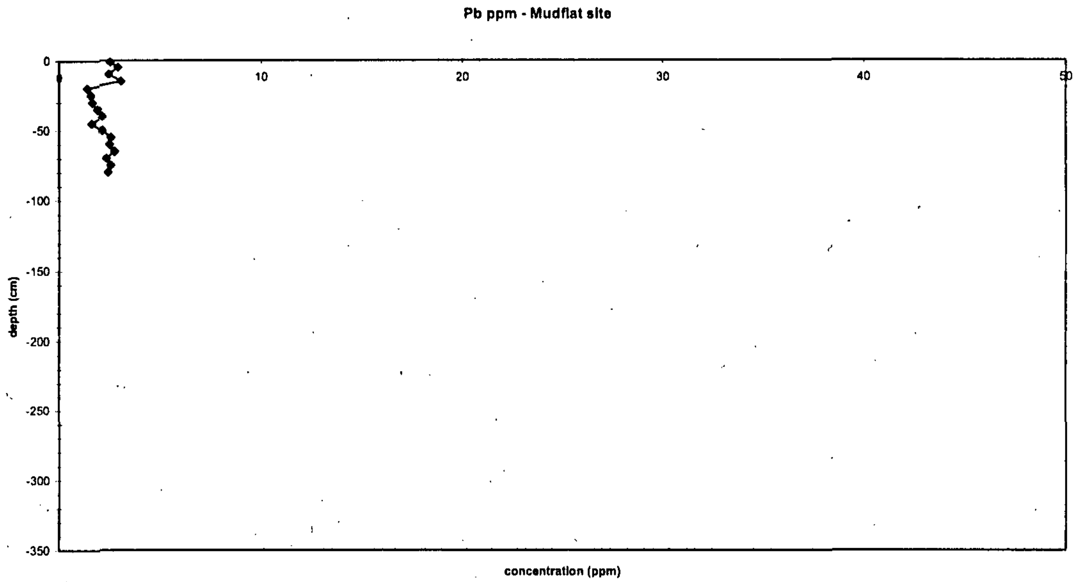

Cr ppm - Mudflat site
0
25
50
75
100
125
150
175
200
225
250
0
-50
-100
-150
-200
-250
-300
-350
depth (cm)
concentration (ppm)

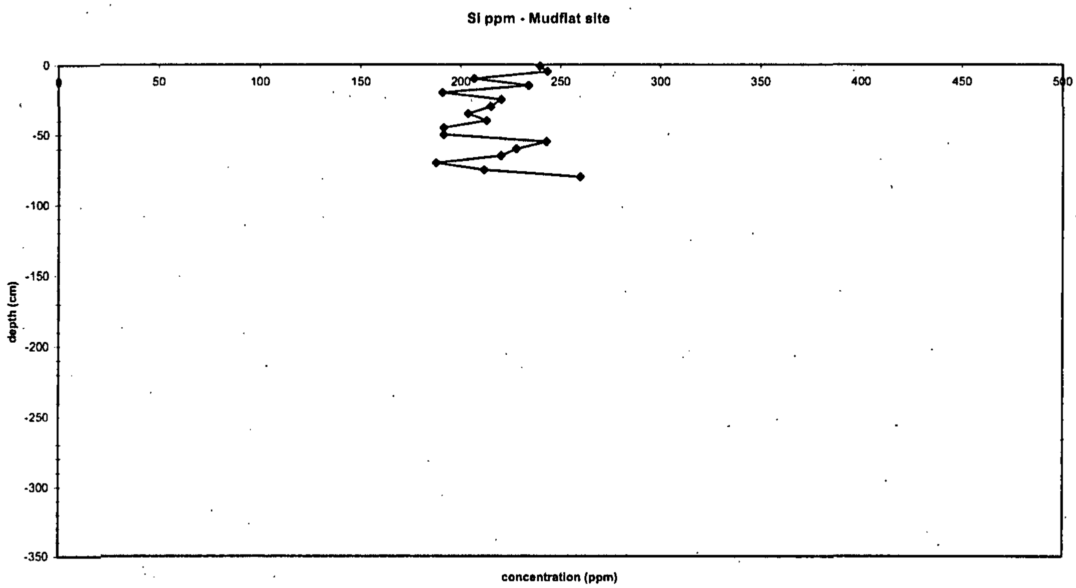

Cu ppm - Mudflat site
0
100
200
300
400
500
600
700
800
900
1,000
-50
-100
-150
-200
-250
-300
-350
depth (cm)
concentration (ppm)

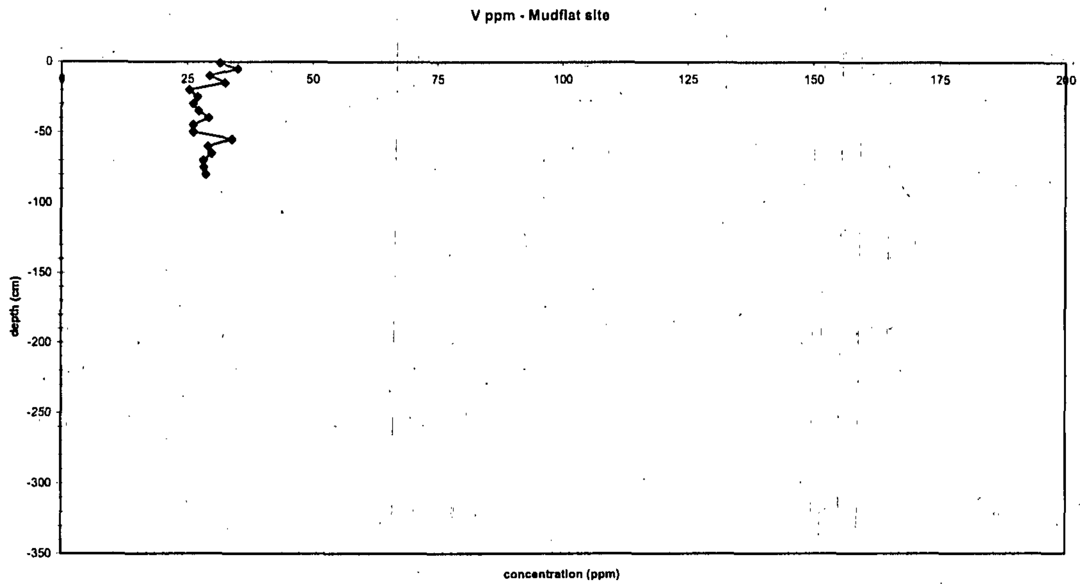

Fe ppm - Mudflat site
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
-50
-100
-150
-200
-250
-300
-350
depth (cm)
concentration (ppm)

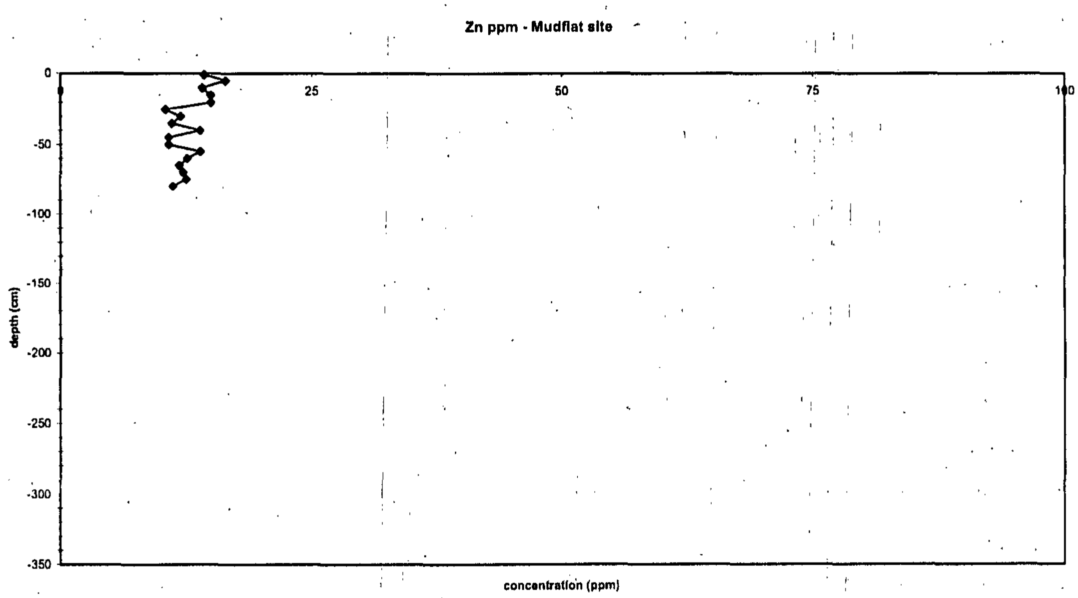

Mg ppm - Mudflat site
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
-50
-100
-150
-200
-250
-300
-350
depth (cm)
concentration (ppm)


Ni ppm - Mudflat site
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
-50
-100
-150
-200
-250
-300
-350
depth (cm)
concentration (ppm)


Pb ppm - Mudflat site
0
10
20
30
40
50
-50
-100
-150
-200
-250
-300
-350
depth (cm)
concentration (ppm)


Si ppm - Mudflat site
0
50
100
150
200
250
300
350
400
450
500
-50
-100
-150
-200
-250
-300
-350
depth (cm)
concentration (ppm)


V ppm - Mudflat site
0
25
50
75
100
125
150
175
200
-50
-100
-150
-200
-250
-300
-350
depth (cm)
concentration (ppm)


Zn ppm - Mudflat site
0
25
50
75
100
-50
-100
-150
-200
-250
-300
-350
depth (cm)
concentration (ppm)