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TRACE METAL ACCUMULATION IN HOUSTON AND
GALVESTON AREA AQUATIC BIOTA AS A
FACTOR OF THEIR ENVIRONMENT

THESIS

BY

FRALINE JUDITH CASTILLO

1996

TRACE METAL ACCUMULATION IN HOUSTON AND GALVESTON AREA
AQUATIC BIOTA AS A FACTOR OF THEIR ENVIRONMENT

THESIS

Presented in Partial Fulfillment of the Requirements for
the Degree Master of Science in the Graduate School
of Texas Southern University

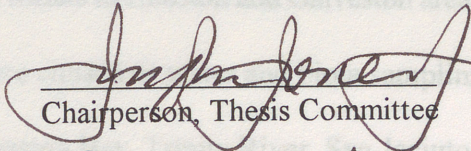
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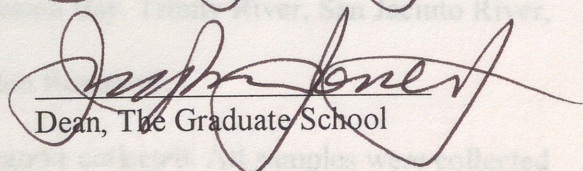
Fraline Judith Castillo, B.S.

Texas Southern University

1996

Approved By:


Chairperson, Thesis Committee


Dean, The Graduate School

TRACE METAL ACCUMULATION IN HOUSTON AND GALVESTON AREA AQUATIC BIOTA AS A FACTOR OF THEIR ENVIRONMENT

By

Fraline Judith Castillo, M.S.

Texas Southern University, 1996

Professor Joseph Jones, Advisor

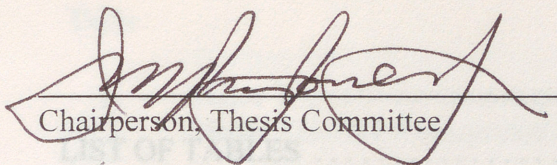
Trace metal concentration in natural waters depends on the location of the water site. Studies have shown that water sites that are closer to industrial waste dumping sites, agricultural farms, heavily populated areas and construction sites have a higher concentration of trace metals (1, 2). Aquatic organisms in these areas will also have a higher concentration of these metals (1, 2). The Concentration of lead, zinc and cadmium in water from sites in the urban areas will be lower than that in waters from rural areas (1, 2). The purpose of this study is to determine the concentrations of trace metals in Houston and Galveston area waters and aquatic biota. In this study, seven sites were chosen as water and biota sampling sites. These sites were a Galveston Bay Marsh, Galveston Bay, Trinity River, San Jacinto River, Lake Houston, and two sampling sites at Sheldon Reservoir.

The same procedure was used on each sample collected. All samples were collected

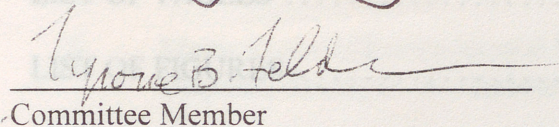
from the seven collection sites and kept in plastic bags. Upon returning to the laboratory the samples were placed in the freezer. Freezing the samples facilitated handling and kept the samples intact. The water samples were representative of the water source and free of any foreign matter that was introduced during collection. Each water sample was allowed to fill the collecting container several times so that it was rinsed adequately. Each container was filled to overflowing and the cap affixed securely to eliminate air bubbles. Surface water samples were collected in sterile tissue culture flasks. All samples were collected during the period of March through June 1996.

A La Motte portable water pollution detection outfit was used to measure alkalinity, chloride, chlorine, nitrates, pH, phosphorous, salinity, sulfide, calcium hardness, magnesium hardness and total hardness. This kit uses one of two typical chemical test methods: colorimetric comparison with standards of known value or titration of samples with solutions of known value. Trace metal analysis of water and aquatic biota samples were completed using a Perking Elmer Plasma 40 Atomic Emission Spectrometer.

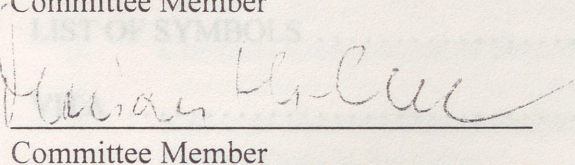
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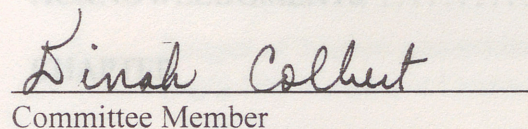
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Committee Member

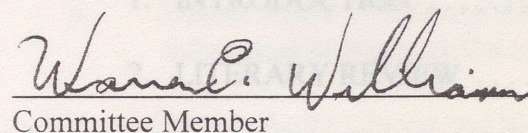
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Committee Member

12/3/96
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LIST OF SYMBOLS AND ABBREVIATIONS

>	greater than
<	less than
ppt	parts per thousand
ppm	parts per million
ppb	parts per billion
°C	Celcius
μg	microgram
μ L	microliter
mg	milligrams
Kg	Kilograms
CaCO ₃	Calcium Carbonate
Cd	Cadmium
Zn	Zinc
Pb	Lead
Fe	Iron
TNRCC	Texas Natural Resource Conservation Commission

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May 25, 1972 Born-Dangriga, Belize

1994 B.S., Texas Southern University
Houston, Texas

1995-1996 Graduate Teaching Assistant
Department of Biology
Texas Southern University

Major Field Biology

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also accumulate in the marshes surrounding Galveston Bay. A decline in the population of organisms that live in these marshes directly affects the population of marine organisms such as shellfish and finfish in the Bay since a large population of hatchlings develop in the marshes and migrate to Galveston Bay.

CHAPTER 1

INTRODUCTION

One of the negative consequences of human anthropogenic activity is the accumulation of a wide range of soluble and insoluble and often toxic organic and inorganic substances in the aquatic environment. These substances undesirably influence the quality of natural waters and raw seafood. The increase in public concern over the state of the global and local environments has led to the production of a large body of evidence which shows the extent to which trace metal pollution has caused adverse effects on human health, reproduction and growth of aquatic plants and animals. Presently, trace metal contamination of water and aquatic biota from major waterways in Houston and Galveston poses a serious threat to their population. Galveston Bay, the second largest estuary in Texas, and surrounding major waterways are susceptible to trace metal pollution from a variety of sources (1). Galveston Bay receives toxic substances from other tributaries such as the Trinity and the San Jacinto Rivers. The Houston-Galveston area is also intensely industrialized, especially by petroleum and petrochemical industries. Discharges by these industries (industrial and agricultural) along with stormwater runoff are the most important sources of pollution to Houston and Galveston area waterways. Stormwater runoff containing oils, fertilizers, and other chemicals has the potential to overwhelm the progress made in controlling contaminants discharged by area industries (2). Many of these pollutants

(Site 4, food source, recreation), Trinity River (Site 5, food source, recreation), a Galveston

also accumulate in the marshes surrounding Galveston Bay. A decline in the population of organisms that live in these marshes directly affects the population of marine organisms such as shellfish and finfish in the Bay since a large population of hatchlings develop in the marshes and migrate to Galveston Bay.

A major objective of this investigation of trace metals in water and aquatic biota of the Houston and Galveston areas is to assess the suitability of these sites for human activities such as fishing, swimming and skiing. Human exposure to toxic levels of trace metals occurs mainly from the consumption of contaminated foods and drinking water (3). Recorded outbreaks of poisoning from various types of seafoods such as shellfish have escalated with increases in trace metal pollution (7). High levels of trace metals in water and aquatic biota would indicate a potential for human exposure if they are consumed. A large portion of the population from the Houston and Galveston areas would be at a high risk of trace metal poisoning since the Texas Water Quality Board deemed some of these sites suitable for contact recreation, fishing and domestic raw water supply (8).

The specific objectives of this research are to investigate the distribution of trace metals in biota, to compare the concentrations with those in water, and to relate the bioconcentration to the different trace metals in biota obtained from sampling sites. An investigation of the distribution of trace metals in water and aquatic biota from a series of seven collection sites was conducted. The sites under investigation are as follows: a ditch adjacent to Sheldon Reservoir (Site 1, freshwater), Sheldon Reservoir fishing area (Site 2, food source), Lake Houston near dam (Site 3, food source, recreation), San Jacinto River (Site 4, food source, recreation), Trinity River (Site 5, food source, recreation), a Galveston

marsh (Site 6, food source, recreation) and Galveston West Bay (Site 7, food source, recreation). Biota samples (algae, rooted macrophytes, fish, freshwater crayfish and crab) will be used as indicators of trace metal pollution of these water sites. It is believed that the concentration of trace metals in waters and tissues of aquatic biota depends on the location of the water site (3). Water sites that are closer to industrial facilities, agricultural farms and heavily populated areas show an increase in trace metal pollution (3, 4). Trace metal concentrations in Galveston West Bay, the Trinity and San Jacinto Rivers are expected to be higher than that of Sheldon Reservoir and Lake Houston because they are closer to many of the industrial facilities in the Houston and Galveston areas. Fish, shellfish and plant samples collected from these sites are also expected to contain higher levels of trace metals as the degree of trace metal bioconcentration in aquatic biota increases with escalated levels of pollution in water (5). Bioindicators of pollutant stress range from organ damage responses in some species of fish to increased mortality rates of some affected organisms. Trace metal pollution also interferes with the normal life functions of an organism effecting growth and reproduction in its environment (6).

CHAPTER 2

LITERARY REVIEW

Classification of Hazardous Substances

Hazardous substances have been classified by the Environmental Protection Agency (EPA) under the authority of the Resource Conservation and Recovery Act (RCRA) of 1976 and its Hazardous and Solid Waste Amendments of 1984. Hazardous substances are classified in terms of their ignitability, corrosivity, reactivity and toxicity (8). Tables 1 and 2 show the major types of environmental pollutants and the environmental media they are transported or reside in. Their classifications are: F-Type (wastes from non-specific sources), K-Type (wastes from specific sources), P-Type (acute hazardous wastes) and U-Type (generally hazardous wastes) (8).

There is a wide range of possible sources of pollution. These include agricultural sources, electricity generation, metalliferous mining and smelting, metallurgical industries, chemical and electronic industries, general urban sources, waste disposal, transport, and incidental sources. Although some of these sources are related to land contamination, many of them contribute to water pollution and consequently bioaccumulation of pollutants in aquatic biota.

TABLE 1

*Major Types of Environmental Pollutants and the Environmental Media
They are Transported or Reside*

<i>1. Agricultural Sources</i>	
Air:	Pesticides, aerosols, feather dusts, NH_3 , H_2S , noxious odors, soil particles
Water:	Leachates from silage clamps and slurry lagoons, NO_3^- , HPO_4^{2-} , pesticide spillages, runoff, soil particles, Hcs (fuel spillages)
Soil:	Fertilizers e.g. As, Cd, Mn, U, V and Zn in some phosphate fertilizers Manures-e.g. As and Cu in pig and poultry manures Pesticides-As, Cu, Mn, Pb, Zn, persistent organics (e.g. Lindane) Corrosion of Metals-e.g. galvanized metal objects (fencing, troughs, etc.) Fuel Spillages-HCs Burial of dead livestock- pathogenic microorganisms
<i>2. Electricity Generation</i>	
Air:	Radioisotopes from nuclear fission
Water:	Heat, biocides from cooling water, soluble as compounds
Soil:	Ash, fallout-Si, heavy metals, coal dust
<i>3. Metalliferous Mining and Smelting</i>	
Air:	Pb, Cd, As, Hg, Ni, etc. particulates/aerosols
Water:	CN frothing agents, metal ions, tailings (ore minerals e.g. PbS , ZnS , CuFeS_2 , etc.)
Soil:	Spoil and tailings heaps-wind erosion, weathering ore particles Fluvially dispersed tailings-deposited on soil during flooding, river dredging, etc. Transported ore separates-blown from conveyance, etc. onto soil Ore processing- cyanides, range of metals Smelting- wind blown dust, aerosols from smelter (range of metals)
<i>4. Metallurgical Industries</i>	
Air:	Particulates/aerosols: As, Cd, Cr, Cu, Mn, Ni, Pb and Zn
Water:	Metal ions, acid wastes and solvents (VOCs) from metal cleaning
Soil:	Metals in wastes, solvents, acid residues, fallout of aerosols, etc. from casting and other pyrometallurgical processes
<i>5. Chemical and electronic Industries</i>	
Air:	Hg, numerous volatile compounds
Water:	Metal ions, acid wastes and solvents from metal cleaning
Soil:	Particulate fallout from chimneys Sites of effluent and storage lagoons, loading, packaging areas Scrap and damaged electrical components- metals, etc.
<i>6. General Urban and Industrial Sources</i>	
Air:	Particulates, aerosols (e.g. Pb, Cu, Zn, Cd, PCBs, dioxins, smoke), Fossil fuel combustion- As, Pb, U, V, Zn Bonfires-Pb, Cd, etc. Cement manufacture- particulates, Ca, SO_4^{2-} , Si, etc.
Water:	Wide range of effluents, Pb, Zn, etc., waste oils-HCs, detergents
Soil:	Pb, Zn, Cu, PCBs, dioxins, dumped cars

TABLE 2

*Major Types of Environmental Pollutants Transported by Waste
Disposal, Transport and Incidental Sources*

<i>1. Waste Disposal</i>	
Air:	Incineration- fumes, aerosols and particulates (Cd, Hg, Pb, etc.) Landfills-CH ₄ Livestock farming wastes: CH ₄ , NH ₃ , H ₂ S Scrapyards-combustion of plastics
Water:	Landfill Leachates, NO ₃ ⁻ , NH ₄ ⁺ , microorganisms Effluents from water treatment-organic matter, NO ₃ ⁻ , NH ₄ ⁺
Soil:	Sewage sludge- NH ₄ ⁺ , metals (Cd, Cr, Cu, Hg, Mn, Mo, Ni, Pb, V, Zn, Etc.) Scrapheaps- Cd, Cr, Cu, Ni, Pb, Zn, Mn Bonfires, coal ash, etc. - Cu, Pb, B, As Fallout from waste incinerators- Cd, PCBs Fly tipping of industrial wastes (wide range of substances) Landfill leachate- NO ₃ ⁻ , NH ₄ ⁺ , Cd, PCBs, microorganisms
<i>2. Transport</i>	
Air:	Exhaust gases, aerosols and particulates
Water:	Spillages of fuels, spillages of transported loads (e.g. hydrocarbons, pesticides, manufactures organic chemicals, wastes in transit-especially marine pollution from oil tanker operations and accidents)
Soil:	Particulates (PbBrCl) acid deposits, wide range of soluble/insoluble compounds at docks and marshaling yards and sidings, deposition of fuel combustion products, rubber tire particles (Containing Zn and Cd).
<i>3. Incidental Sources</i>	
Water:	Leakage from underground storage tanks e.g. solvents, petrol products
Soil:	Preserved wood, discarded batteries (hg, Cd, Ni, Zn) fishing and shooting (Pb), galvanized roofs and fences Zn, Cd All Media: Warfare (e.g. fuels, explosives, ammunition, bullets, electrical components, poison gases, combustion products), corrosion of metal objects-Cu, Zn, Cd, Pb Industrial accidents- wide range of pollutants

(Alloway and Ayres, 1993)

Chemical Properties of Some Trace Metal Pollutants

Cadmium is a soft silver-blue metal which is used mainly for anti-corrosion purposes. It may also be present as an impurity in zinc coatings, in nickel-cadmium batteries, or in copper alloys (9). Cadmium salts of organic acids are used as stabilizers and as catalysts in the manufacture of synthetic polymers. Other cadmium compounds are used as pigments and fungicides (9). Cadmium in the natural environment is subject to forming a complex with organic compounds, chelating agents and ligands excreted by some organisms. Natural organic compounds such as humic acid bind to cadmium and reduce its toxicity (10).

Cadmium has been shown to be more toxic to phytoplankton at lower rather than higher pH. Toxicity to algae at pH 7 was shown to be greater than at pH 8. The algae accumulated twice as much cadmium at the lower pH 7. Cadmium is also more toxic to animals in soft water than in hard water (10). In phytoplankton, cadmium was found to be more toxic to several species of algae in soft water (20 ppm as CaCO_3) than in hard water (300 ppm as CaCO_3). The solubility of cadmium in soft and hard water has been calculated to be the same due to an antagonistic effect of calcium (10).

Metallic lead is bluish white in color and has a bright luster. Important physical attributes of lead include high density, softness, flexibility and malleability, low melting point, low strength and low elastic limit. These properties as well as its low electrical conductivity, high corrosion resistance, high coefficient of expansion and weldability contribute to its widespread industrial applications. Lead is used as the base of a large

number of important industrial alloys (11). Lead has been used as a component of some paint pigments in the manufacture of various chemicals and as a gasoline additive (12). In systems containing carbonate ion, which is common in natural systems, lead carbonate compounds are formed as with other metals. There is an interaction between the forms depending on the pH and the redox potential of the system.

Zinc is a bluish-white, relatively soft metal with a density slightly less than that of iron. Zinc is a composite of five stable isotopes: $^{64}\text{Zinc}$, $^{66}\text{Zinc}$, $^{67}\text{Zinc}$, $^{68}\text{Zinc}$ and $^{70}\text{Zinc}$ (13). Pure zinc at ambient temperatures is highly resistant to attack by dry air, but in temperatures above 225°C the rate of corrosion increases rapidly. In the presence of carbon dioxide it accelerates to form the hydrated, basic zinc carbonate. Zinc also displays a vigorous reducing power, liberating hydrogen from sulfuric and hydrochloric acids. This property is the basis for the use of zinc dust or mossy zinc in many commercial organic chemical processes. Zinc is important in automobile production (die-casting, galvanizing, and oxidizing rubber tires) and industrial and residential construction activities (galvanizing, brass diecasting for appliances and oxidizing paint pigments).

Trace Metals in Seawater

Seawaters around the world may vary in chemical composition, salinity, total dissolved solids and many other characteristics. The reasons for these variations include river water mixing, differential evaporation, mixing from seawater currents as well as inputs from natural anthropogenic activities. The main criteria considered to define seawater are the amount of dissolved solids (salinity) and pH. These have been defined as a seawater with a pH of 8.1 and salinity of 35 parts per thousand (14).

The chemical composition of the dissolved fraction of seawater is classified into major, minor and trace constituents. Major constituents account for over 99.5% of the dissolved solids and their concentrations in seawater are generally more than several hundred ppm. These constituents include Sodium (Na^+), Potassium (K^+), Chloride (Cl^-), Sulfate (SO_4^{2-}) and Bicarbonate (HCO_3^-). The concentrations of these major elements in the standard seawater are listed in Table 3. The total dissolved solids concentrations of these constituents may vary as a function of seawater salinity (11).

The major dissolved constituent are divided into conservative and nonconservative components. Those elements whose residence time is long and whose concentration ratios to chloride generally remain constant are the conservative components. Na, K, Ca, Mg, Cl and SO_4 are examples of the conservative components. The concentrations of nonconservative components undergo rapid changes in seawater, such as bicarbonate. It is believed that the ratios of conservative components to Cl^- concentrations are constant throughout the open oceans and seas of the world (Table 4) (14).

Minor elements are generally present in much lower concentrations (ppm) than major elements in seawater (11, 14). Unlike major elements, minor elements may vary greatly in time and are affected by several natural and anthropogenic activities. A large variation in the concentrations of these elements may be expected in the vicinity of an anthropogenic or a natural input source. Trace elements are chemicals which are present in extremely low concentrations, generally in ppm (14).

TABLE 3

Chemical Composition of Seawater

Constituent	Concentration
<i>A. Major Element</i>	mg/L
Chloride	19350
Sodium	10760
Sulfide	2760
Magnesium	1290
Calcium	411
Potassium	399
Bicarbonate	142
<i>B. Minor Elements</i>	$\mu\text{g/mL}$
Fluoride	1.3
Lithium	0.18
Bromide	67
<i>C. Trace Elements</i>	$\mu\text{g/mL}$
Cadmium	0.05
Chromium	0.3
Iron	2.0
Lead	0.03
Zinc	2.0

(Sadiq, 1993)

TABLE 4

*Ratios of Element Concentration to Chlorinity (ppt)
and Salinity (ppt) in Seawater*

Element	Element/Chlorinity	Element/Salinity
Sodium	0.5555	1.0035
Potassium	0.0206	0.0372
Magnesium	0.06629	0.11976
Calcium	0.02127	0.03843
Chloride	0.99876	1.80467
Fluoride	0.000067	0.000121
Bicarbonate	0.00132	0.00238

(Sadiq, 1993)

Trace Metal Cycle in the Aquatic Environment

Some trace metals are biologically active and have the potential for bioaccumulation. Bioaccumulation refers to the ability of an organism to acquire a chemical from its surroundings by every means and route (14). Once entered, these elements undergo many individual or simultaneous occurring interactions (14, 15).

Bioaccumulation can be divided into direct bioaccumulation and indirect bioaccumulation. The direct bioaccumulation occurs mainly through the gills tissue from water and digestive tract by ingestion of sediment. Metals absorbed by this mechanism generally show good correlation with concentrations in the external media. The indirect bioaccumulation is mainly through the food chain.

The accumulation of metals by an aquatic organism can be divided into three phases: (1) metal uptake (2) metal transport and (3) metal excretion, the latter of which may be absent. Water and food represent the major routes of metal uptake by aquatic organisms. Facilitated diffusion and protein binding of incoming metals provide a sink with no significant backflow of metals. Metals continue to enter aquatic organisms against an apparent concentration gradient, contributing to high accumulated body concentrations (14).

Body concentrations of accumulated trace metals vary greatly between aquatic organisms, often between closely related species. Mussels and caridean decapods have been shown to have low body concentrations of zinc in comparison to their respective relatives, oysters and barnacles (Table 5) (5). Differences in the bioaccumulation of trace metals have been attributed to the ratio of trace metals taken up by the organism to the amount excreted. When metal uptake exceeds excretion bioaccumulation of the trace metal occurs. Zinc

accumulation in barnacles and the caridean decapod, *Palaemon elegans* exemplify the two extremes of the gradient of metal accumulation strategies (Table 5). Barnacles such as *Elminius modestus* are strong net accumulators of zinc with high zinc uptake rates and no significant zinc excretion (5)

Table 5. Typical Accumulated Concentrations
of Zinc in Crustaceans and Bivalve Molluscs

A) CRUSTACEANS	
Barnacles	
	Body Concentration Range ($\mu\text{g/g}$ Dry Weight)
<i>Semibalanus balanoides</i>	1,220-113,250
<i>Elminius modestus</i>	4,900-11,700
<i>Balanus amphitrite</i>	2,726-11,990
Caridean Decapods	
<i>Palaemon elegans</i>	76-138
<i>Pandatus montagu</i>	119-214
<i>Crangon crangon</i>	56-174
B) BIVALVE MOLLUSCS	
Oysters	
	Soft Tissue Concentration Range ($\mu\text{g/g}$ Dry Weight)
<i>Ostrea edulis</i>	660-3,280
<i>Crassostrea virginica</i>	322-12,675
<i>Saccostrea cucullata</i>	430-8,629
Mussels	
<i>Mytilus</i>	14-500
<i>Perna perna</i>	77-164
<i>Saxidomus virgatus</i>	74-116

(Chapman, 1992)

TABLE 5

*Ranges of Typical Accumulated Concentrations
of Zinc in Crustaceans and Bivalve Molluscs*

A) CRUSTACEANS	Body Concentration Range
Barnacles	($\mu\text{g/g Dry Weight}$)
<i>Semibalanus balanoides</i>	1,220-113,250
<i>Elminius modestus</i>	4,900-11,700
<i>Balanus amphitrite</i>	2,726-11,990
Caridean Decapods	
<i>Palaemon elegans</i>	76-138
<i>Pandalus montagui</i>	119-214
<i>Crangon crangon</i>	56-174
B) BIVALVE MOLLUSCS	Soft Tissue Concentration Range
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<i>Perna viridis</i>	77-164
<i>Septifer virgatus</i>	74-116

(Chapman, 1992)

A model of the metal cycle in the marine environment has been described and is illustrated in Figure 1. In the proposed model, seawater occupies the central position. Metal inputs from terrestrial emissions may dissolve in seawater or be directly transported to the marine sediments. If a metal exceeds a critical solubility limit in seawater, it may precipitate as a solid phase or adsorb on particulates and settle to the sediments (11, 14). Marine biota can bioaccumulate metals from seawater and release it back to the seawater on degradation of detrital biogenic matter. Many marine organisms may adsorb or release metal directly from the sediments. Metals may also form volatile compounds due either to biological activities or to a change in the redox conditions of the seawater and sediments. These may escape to the terrestrial environments. These transformations keep the metal moving from the terrestrial to the marine environments and is referred to as the metal cycle (11, 14).

Metal accumulation which may constitute metal uptake, sequestration and/or excretion differs between marine and freshwater organisms (5). The process of metal accumulation may be affected by the different physiochemistries of freshwater in comparison to that of the relatively stable marine environment. The physiological response of an organism to low or high levels of calcium in a freshwater environment, for example, might affect the rate of metal accumulation. Freshwater ecosystems are also more susceptible to anthropogenic influences than marine environments which are more stable. This is a consequence of the high natural variability exhibited by these systems (5).

Accumulation of Some Trace Metals in Aquatic Plants

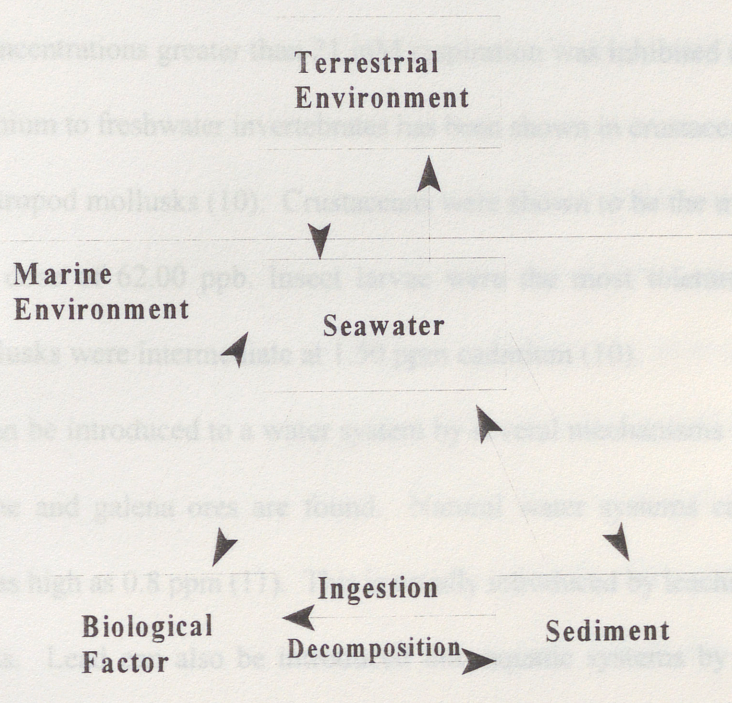
As primary producers in the marine environment, algae are capable of accumulating significant and other heavy metals. For example, green algae *Ulva lactuca* showed that cadmium could stimulate respiration (15). *Ulva lactuca* showed an increase in photosynthesis when exposed to cadmium concentrations (added as sulphate) below 21 mM. At concentrations greater than 21 mM, photosynthesis was inhibited (15). The acute toxicity of cadmium to freshwater invertebrates has been shown in crustacea, aquatic insect larvae, and gastropod mollusks (10). Crustaceans were shown to be the most sensitive to cadmium at a concentration of 0.0200 ppb. Insect larvae were the most tolerant at 3.90 ppb. Gastropod mollusks were intermediate at 1.90 ppb cadmium (10).

Lead can be introduced to a water system by several mechanisms in mining areas where limestone and galena ores are found. Natural water systems can contain lead concentrations as high as 0.5 ppm (11). Lead is also introduced to aquatic systems by several human activities. Unlike some sort of contamination in the environment, lead remains relatively insoluble in water and does not occur in large concentrations in aquatic systems (11). Lead is not readily bioaccumulated in aquatic organisms (3). *In vitro* and *in vivo* studies have shown that lead concentrations as low as 0.2 ppm can cause adverse effects in aquatic plants (12). Chronic exposure of fish to lead produces characteristic responses of black finning and tumor formation. Both effects are initially reversible but severe black finning develops into irreversible rotting of the fins.

Aquatic plants, especially algae, have been used extensively to investigate the role of heavy metals in the environment. Algae are capable of accumulating significant and other heavy metals. For example, green algae *Ulva lactuca* showed that cadmium could stimulate respiration (15). *Ulva lactuca* showed an increase in photosynthesis when exposed to cadmium concentrations (added as sulphate) below 21 mM. At concentrations greater than 21 mM, photosynthesis was inhibited (15). The acute toxicity of cadmium to freshwater invertebrates has been shown in crustacea, aquatic insect larvae, and gastropod mollusks (10). Crustaceans were shown to be the most sensitive to cadmium at a concentration of 0.0200 ppb. Insect larvae were the most tolerant at 3.90 ppb. Gastropod mollusks were intermediate at 1.90 ppb cadmium (10).

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(Sadiq, 1993)



Toxicity of Some Trace Metals in Aquatic Biota

As primary producers in the environment, algae are capable of accumulating cadmium and other heavy metals. Research conducted with the green algae *Ulva lactuca* revealed that cadmium could stimulate respiration (15). *U. Lactuca* showed an increase in respiration when exposed to cadmium concentrations (added as sulphate) below 21 mM. At cadmium concentrations greater than 21 mM respiration was inhibited (15). The acute toxicity of cadmium to freshwater invertebrates has been shown in crustacea, aquatic insect larvae, and gastropod mollusks (10). Crustaceans were shown to be the most sensitive to cadmium at a dose of 62.00 ppb. Insect larvae were the most tolerant at 5.90 ppm. Gastropod mollusks were intermediate at 1.50 ppm cadmium (10).

Lead can be introduced to a water system by several mechanisms in mining areas where limestone and galena ores are found. Natural water systems can contain lead concentrations as high as 0.8 ppm (11). This is usually introduced by leaching or from lead chromate paints. Lead can also be introduced into aquatic systems by several human activities. Unless some sort of contamination is present, lead remains relatively insoluble in all its forms and does not occur in large concentrations in aquatic systems (11). Lead generally does not bioaccumulate in aquatic organisms (3). *In vitro* and *in vivo* studies have shown that lead concentrations as low as 0.2 ppm can cause adverse effects in aquatic plants (3). Chronic exposure of fish to lead produces characteristic responses of black finning and spinal curvature. Both effects are initially reversible but severe black finning develops into irreversible rotting of the fins.

Aquatic plants, especially algae, have been used extensively to investigate the role

of zinc in plant metabolism. Rooted vascular hydrophytes that are submerged in water may take up zinc from either the sediments or the ambient water. The uptake of zinc by aquatic plants is thought to be influenced by their structures (13). Because of their suspended state, planktonic algae and free floating vascular plants can take up zinc from the water but not from sediments. Other biological, chemical, and environmental factors can influence the variation of zinc in aquatic plants, the factors are growth rate, supply of nutrients and temperature (13).

The presence of heavy metals in human food products of marine or freshwater origin has sparked interest in the bioaccumulation of zinc. The National Marine Fisheries Service has conducted extensive investigations into the concentration of zinc in numerous species of marine fish, mollusks, and crustaceans. The average zinc content of all finfish was about 6.5 ppb, and the mean for individual species ranged from 3.0 to 24.0 ppb (13). The results also showed that oysters are exceptionally high in zinc content. Their mean obtained was 22.0 ppb. Crustaceans contained slightly more zinc than finfish; the mean value for crustaceans was 12.5 ppb (13).

Water Quality Standards of Selected Sampling Sites

The marine acute criteria and marine chronic criteria of toxic substances in water has been determined by the Texas Natural Resource Conservation Commission (TNRCC) (Tables 6 and 7). Their criteria is based on water quality standards that are set by the Environmental Protection Agency (EPA). It is legal to imply that a water site has exceeded a criterium when four evenly spaced samples are detected with trace metal concentrations exceeding the criterium. A model of loading estimates from each pollutant source is

constructed in order to determine what source is responsible for the increase in pollution. The TNRCC then gathers data which shows that a particular business or industry in the model is responsible for the increase in pollution.

The criteria for Sites 3, 4, 5 and 7 are included in the list of Texas waterways. Trace metals such as lead are allowed at chronic levels in Lake Houston (Site 3) at 139.13 ppb a value that is not significantly lower than the permissible value of 140.00 ppb in the San Jacinto River, the Trinity River and Galveston West Bay. The same is true for cadmium and zinc which are permissible at 54.03 ppb and 166.86 ppb, respectively, at site 3 and at higher levels of 45.62 ppb and 98.00 ppb for sites 4, 5 and 7. The chronic criteria of these trace metals in sites 3, 4, 5 and 7 is significantly lower for some metals than the acute criteria. The ratio of the acute criteria to the chronic criteria for site 3 is also significantly higher than that of sites 4, 5 and 7. The water quality requirements represent arithmetic average conditions over a period of one year (18).

San Jacinto (Site 4)	Aluminum	None	None
	Arsenic	149.00	78.000
	Cadmium	45.620	10.020
	Chromium, Hexavalent	1100.000	50.000
	Copper	15.270	4.370
	Lead	140.000	5.600
	Mercury	2.100	1.100
	Nickel	119.000	13.200
	Selenium	564.00	136.000
	Zinc	98.000	89.000

TABLE 6

*Marine Acute Criteria and Marine Chronic Criteria (ppb) of
Toxic Substances in Water as Determined by the TNRCC*

Sites	Parameter (ppb)	Marine Acute Criteria	Marine Chronic Criteria
Lake Houston (Site 3)	Aluminum	991.000	None
	Arsenic	360.000	190.000
	Cadmium	54.030	1.576
	Chromium, Hexavalent	16.000	11.000
	Copper	28.477	18.300
	Lead	139.129	5.422
	Mercury	2.400	1.300
	Nickel	2021.112	224.686
	Selenium	20.000	5.000
	Zinc	166.856	151.129
San Jacinto (Site 4)	Aluminum	None	None
	Arsenic	149.00	78.000
	Cadmium	45.620	10.020
	Chromium, Hexavalent	1100.000	50.000
	Copper	16.270	4.370
	Lead	140.000	5.600
	Mercury	2.100	1.100
	Nickel	119.000	13.200
	Selenium	564.00	136.000
	Zinc	98.000	89.000

(Texas Natural Resource Conservation Commission, 1996)

TABLE 7

*Marine Acute Criteria and Marine Chronic Criteria (ppb) of Toxic Substances
in Water as Determined by the TNRCC*

Sites	Parameter (ppb)	Marine Acute Criteria	Marine Chronic Criteria
San Jacinto (Site 5)	Aluminum	None	None
	Arsenic	149.00	78.000
	Cadmium	45.620	10.020
	Chromium, Hexavalent	1100.00	50.000
	Copper	16.270	4.370
	Lead	140.000	5.600
	Mercury	2.100	1.100
	Nickel	119.00	13.200
	Selenium	564.00	136.000
	Zinc	98.000	89.000
Galveston West Bay (Site 7)	Aluminum	None	None
	Arsenic	149.00	78.000
	Cadmium	45.620	10.020
	Chromium, Hexavalent	1100.00	50.000
	Copper	16.270	4.370
	Lead	140.000	5.600
	Mercury	2.100	1.100
	Nickel	119.00	13.200
	Selenium	564.00	136.000
	Zinc	98.00	89.000

(Texas Natural Resource Conservation Commission, 1996)

Field Measurements and Water Chemistry of Selected Sampling Sites

Water chemistry changes with variations in uncontrollable factors such as temperature, time, tides, and weather. These changes are illustrated in some water quality factors that were measured from several of the sites that were sampled in this field investigation. Analytical results obtained by the TNRCC's Surface Water Quality Monitoring Program are shown in Tables 8, 9, 10 and 11. Surface water sampling and analysis of Lake Houston (Site 3), San Jacinto River (Site 4), Trinity River (Site 5) and Galveston West Bay (Site 7) were conducted on 7/1/96, 7/16/96, 5/7/96 and 6/4/96, respectively (18).

A wide variation in major constituents was observed in these sites. An alkalinity value of 114.00 ppm was detected in the San Jacinto river and Galveston West Bay. Lake Houston and Trinity River had lower values of 64.00 ppm and 108.00 ppm, respectively, and in decreasing order. The highest value for dissolved calcium was detected in Galveston West Bay (311.00 ppm). A value of 129.00 ppm calcium was detected in Galveston Bay and 19.30 ppm in Lake Houston. The concentration of dissolved calcium was not measured in Trinity River. Galveston West Bay also had the highest magnesium value of 989.00 ppm followed by San Jacinto River with 353.00 ppm and Lake Houston with 2.71 ppm.

Sample Collection Date: 7/1/96

Sample Depth: 1.0 feet

(Texas Natural Resource Conservation Commission, 1996)

TABLE 8

*Surface Water Quality Data of Lake Houston
Collected by the TNRCC*

Parameter Name	Analytical Results	Units
Silver, Dissolved	<0.5	ppb
Alkalinity, Total	64	ppm
Calcium, Dissolved	19.3	ppm
Cadmium, Dissolved	<4	ppb
Chloride	42	ppm
Coliforms, Fecal	<10	col/100
Chromium, Dissolved	<3	ppb
Copper, Dissolved	<4	ppb
Mercury, Dissolved	0.012	ppb
Mecury, Total	0.023	ppb
Hardness, Calculated	59	ppm
Magnesium, Dissolved	2.71	ppm
Ammonia Nitrogen	0.03	ppm
Nitrate (N ₂) + Nitrite (N ₂)	<0.05	ppm
Lead, Dissolved	<1	ppb
Phosphorous, Total	0.14	ppm
Sulfate	22	ppm
Volatile Suspended Solids	3	ppm
Zinc Dissolved	<3	ppb
Volitile Suspended Solids	3	ppm

Sample Collection Date: 7/1/96

Sample Depth: 1.0 feet

(Texas Natural Resource Conservation Commission, 1996)

TABLE 10

Surface Water Quality Data of the San Jacinto River at Interstate
Highway 10 Collected by the TNRCC

Surface Water Quality Data of the San Jacinto River at Interstate
Highway 10 Collected by the TNRCC

Parameter Name	Analytical Results	Units
Salinity	9.7	ppt
Silver, Dissolved	<3	ppb
Alkalinity, Total	114	ppm
Calcium, Dissolved	129	ppm
Cadmium, Dissolved	<4	ppb
Chloride	5520	ppm
Chromium, Dissolved	<3	ppb
Copper, Dissolved	<4	ppb
Mercury, Dissolved	<0.010	ppb
Mercury, Total	<0.010	ppb
Hardness, Calculated	1770	ppm
Magnesium, Dissolved	353	ppm
Ammonia Nitrogen	N/A	N/A
Nitrate (N ₂) + Nitrite (N ₂)	<0.01	ppm
Phosphorous, Total	0.43	ppm
Sulfate	830	ppm
Volatile Suspended Solids	8	ppm

Sample Collection Date: 7/16/96

Sample Depth: 1.0 feet

(Texas Natural Resource Conservation Commission, 1996)

TABLE 10

*Surface Water Quality Data of Trinity River at Interstate
Highway 10 Collected by the TNRCC*

Parameter Name	Analytical Results	Units
Salinity	<1	ppt
Alkalinity, Total	108	ppm
Chloride	42.1	ppm
Coliforms, Fecal	<10	col/100
Ammonia Nitrogen	0.06	ppm
Nitrate (N ₂) + Nitrite (N ₂)	0.080	ppm
Phosphorous, Total	0.08	ppm
Sulfate	39.8	ppm
Volatile Suspended Solids	6	ppm

Sample Collection Date: 5/7/96

Sample Depth: 1.0 feet

(Texas Natural Resource Conservation Commission, 1996)

TABLE 11

*Surface Water Quality Data of Galveston
West Bay Collected by the TNRCC*

Parameter Name	Analytical Results	Units
Salinity	28	ppt
Silver, Dissolved	<3	ppb
Alkalinity, Total	114	ppm
Calcium, Dissolved	311	ppm
Cadmium, Dissolved	<4	ppb
Chloride	16900	ppm
Coliforms, Fecal	N/A	N/A
Chromium, Dissolved	<3	ppb
Copper, Dissolved	<4	ppb
Mercury, Dissolved	<0.010	ppb
Mercury, Total	0.012	ppb
Hardness, Calculated	4840	ppm
Magnesium, Dissolved	989	ppm
Ammonia Nitrogen	<0.01	ppm
Nitrate (N ₃) + Nitrite (N ₂)	<0.01	ppm
Phosphorous, Total	0.08	ppm
Sulfate	39.8	ppm
Volatile Suspended Solids	6	ppm

Sample Collection Date: 6/4/96

Sample Depth: 1.0 feet

(Texas Natural Resource Conservation Commission, 1996)

Toxic Effects of Heavy Metals

Cadmium is said to be the most insidious and most widespread health hazard among all of the trace metals (15). It has been known that cadmium is an extremely toxic element and probably more lethal than most other elements when breathed as a fume or gas in industrial situations (11). Cadmium is a highly toxic non-essential trace metal which accumulates in the kidneys of mammals and can cause kidney failure (8). An indication of the relative toxicity of cadmium is provided in Table 8. The acute lethal dose (LD_{50}) of cadmium in mammals has been determined at 1.3 mg/kg body weight. A dose of 3.330 mg/day is considered to be toxic in most mammals (8). Cadmium also has the capability of replacing zinc in several physiological processes in the body, resulting in further bodily disorders (11). The increase in cadmium use in industry has made it more bioavailable and the presence of cadmium in the human food chain from contaminated soil and water poses a greater danger to human health than most other metals (Table 12) (8). Serious cases of cadmium poisoning can develop in areas where individuals consume fish, shellfish and other aquatic organisms from contaminated waters.

Zinc directly affects the activities of carbohydrates, lipids and proteins. Yet, in terms of nutritive factors, carbohydrates, lipids, and proteins can affect zinc concentrations and thereby change organ function and behavior. Excess zinc affects the endocrine system but much less than lead or cadmium. Increasing the concentration of zinc has been shown to influence hormonal secretion in the hypothalamic-pituitary axis, the anterior pituitary target gland axis, hormonal synthesis with target glands, and activities at several peripheral organs (13). In the context of pollution, zinc is mainly a cause of phytotoxicity (toxicity in

It is believed that toxicity due to zinc in humans and animals is relatively low. Zinc's natural association with cadmium implies that zinc-cadmium antagonism may mitigate some of the effects of cadmium contamination.

Several well known but nonspecific illnesses in humans have been associated with lead poisoning. Recent medical evidence suggests that some of these syndromes exhibited are a function of time and dose relationships associated with lead intake. Some of these include pale skin, fatigue, irritability, and mild headaches (11). The primary target for lead is the nervous system. Children have been shown to develop behavioral abnormalities and learning problems due to lead (19). Lead poisoning in children results principally from the ingestion of lead from agents in their environment. These include water, dust, soil, paint chips and medication (19). Lead is deposited in the organs of humans and other animals in various quantities but there is no known useful biological function for lead (20).

Lead is not as bioavailable or as toxic as other metals such as cadmium. Lead, however, is a cumulative toxin in the the mammalian body. Persons who are not occupationally exposed to lead gradually store lead in different body compartments. Fortunately, limited quantities of lead can be stored by human beings in an inactive form in bone. It has been estimated that about 110 mg are stored in the skeleton (21). However, if this is mobilized or if lead cannot be stored at an adequate rate, lead poisoning develops (20).

TABLE 12

*Relative Mammalian Toxicity of Elements
in Injected Doses and Diets*

Element	Acute Lethal Doses (LD50) Injected into Mammals (mg/kg bodyweight)	Dose in Human Diet (mg/day)	
		Toxic	Lethal
Ag	5-60	60	1.3k-6.2k
Cd	1.3	3-330	1.5k-9k
Cr	90	200	3k-8k
Cu	-	-	175-250
Hg	1.5	0.4	150-300
Mn	18	-	-
Ni	110-220	-	-
Pb	70	1	10
Se	1.3	5	-
Zn	-	150-600	6K

(Alloway and Ayres, 1993)

CHAPTER 3

DESIGN OF STUDY

Sampling Procedures

Seven sampling sites were selected which best represented major waterways in the Houston and Galveston area that are open to public and industrial use. Aquatic biota samples (Table 13) were placed in quart size and gallon size ziploc freezer bags. In addition, surface water samples (Table 13) were collected in 500 mL acid washed polyethylene containers. Each water sample was allowed to fill the collecting container several times so that it was rinsed adequately. Each container was filled to overflowing and the cap affixed securely to eliminate air bubbles. All samples were collected during the period of March through June 1996. Upon returning to the laboratory, the samples were placed in the freezer. Freezing the samples facilitated handling and kept the samples intact.

Testing Water Quality Factors

A La Motte portable water pollution detection outfit was used to measure alkalinity, ammonia chloride, chlorine, nitrates, pH, phosphorous (phosphates), salinity, sulfide, calcium hardness, magnesium hardness and total hardness. This kit uses one of two typical chemical test methods: colorimetric comparison with standards of known value or titration of samples with solutions of known value.

TABLE 13

*Numerical Allocation and Description of Samples
Collected at Each Site*

Site #	Collection Site	Location	Water Uses	Samples Collected
1	Drainage Ditch Adjacent to Sheldon Reservoir	Pineland and Vindale Streets	Bait Collection Fish Hatchery Drainage water from Sheldon Reservoir	Water <i>Fundulus grandus</i> (Gulf Killifish) <i>Chara</i> sp. (Algae) <i>Astacus astacus</i> L. (Freshwater Crayfish) <i>Sorghum</i> sp. (Grass)
2	Sheldon Reservoir	Sheldon Fishing Area	Seasonal Fishing Fish Hatchery Game Preserve	Water <i>Fundulus grandus</i> (Gulf Killifish) <i>Chara</i> sp. (Algae) <i>Astacus astacus</i> L. (Freshwater Crayfish)
3	Lake Houston	Alexander Deussen Park Houston Dam	Industry Irrigation Mining Municipal Raw Water Supply Recreation	Water <i>Sorghum</i> sp. (Grass)
4	San Jacinto River	Interstate Highway 10	Fishing Transportation of Industrial Products	Water
5	Trinity River	Interstate Highway 10	Recreation Fishing	Water <i>Sorghum</i> sp. (Grass)
6	Galveston Marshland	Near Galveston West Bay	Fishing Crabbing Surrounds Picnic Areas	Water <i>Ulva lactuca</i> (Sea Lettuce) <i>Spartina</i> sp. (Seagrass) <i>Dardanus insignis</i> (Red Brocade Hermit)
7	Galveston West Bay	Galveston West Bay	Recreation Fishing Transportation of Industrial Products	Water <i>Mugil cephalus</i> (Striped Mullet) <i>Ulva lactuca</i> (Algae) <i>Dardanus insignis</i> (Red brocade hermit) <i>Callinectes sapidus</i> (Blue Crab)

Testing Water Quality Factors

A La Motte portable water pollution detection outfit was used to measure alkalinity, ammonia chloride, chlorine, nitrates, pH, phosphorous (phosphates), salinity, sulfide, calcium hardness, magnesium hardness and total hardness. This kit uses one of two typical chemical test methods: colorimetric comparison with standards of known value or titration of samples with solutions of known value (see procedure below).

Instructions for Using the Direct Reading Titrator

The titration tube was filled to the line with the water sample. The reagents, as specified in the instructions for the individual test method, are added to the titration tube. The tube was capped with the special titration tube cap. The reagent and the water sample are mixed by swirling gently. The plunger of the titrator are depressed to expel air. The titrator was inserted into the plastic fitting of the titrating solution bottle. To fill the Titrator, the bottle was inverted and the plunger was slowly withdrawn until the bottom of the plunger was opposite the zero mark on the scale. The bottle was turned right-side-up and the titrator was removed. The tip of the titrator was inserted into the opening of the titrator tube cap. The plunger was depressed slowly to dispense the titrating solution. The tube was swirled gently to mix. A slight rotation or twist permitted the plunger to move more smoothly. The titrating solution was added continuously until the specified color change occurred if no color change occurred by the time the plunger tip reached the bottom of the scale, the titrator was refilled to the zero mark. The titration was continued and both titration amounts were included in the final test result. The test results were read directly from the scale opposite the bottom of the tip of the plunger.

Preparation of Biota and Water Samples

All samples were removed from the freezer. A small amount of each sample was placed on a watch glass. The name of the sample, collection site, date of sample collection, and current date were marked on the watchglass. The samples were then placed in the oven at 50°C for 48 hours to dry. After 48 hours all samples were removed from the watchglass with forceps and ground up with an agate mortar and pestle. The sample was then weighed and placed in a stoppered plastic storage bottle. One gram of each sample was digested with 50ml of concentrated nitric acid in beakers covered with a watchglass. The organic matter was oxidized with 10ml of 30% hydrogen peroxide. The samples were filtered and diluted to 100ml with deionized water and stored in 150ml polyethylene storage bottles. Water samples were filtered and kept as 1% nitric acid solutions in 150ml polyethylene storage bottles.

Analysis by Inductively Coupled Plasma (ICP) Atomic Emission Spectroscopy

All analyses were completed using the Perkin Elmer Plasma-40 Emission Spectrometer. This instrument incorporates several of the most important features for ICP atomic emission spectroscopy. It performs at high speeds when automated as well as highly precise individual analyses. The Plasma-40 has the capability to perform sequential multi-element analyses of liquid samples. Samples are introduced to the instrument through a capillary tube on the front control panel. A nebulizer then converts the liquid into a fine aerosol which is injected into an argon supported inductively coupled plasma (ICP). The high temperature of the plasma atomizes the sample and promotes atomic and ionic transitions which are observable at ultraviolet and visible wavelengths (Table 10).

TABLE 14

*Wavelengths Used to Measure Some Trace Metals
Using The Plasma-40 Emission Spectrometer*

Element	Wavelength (nm)
Sodium (Na)	766.490
Potassium (K)	588.995
Iron (Fe)	238.304
Zinc (Zn)	213.856
Cadmium (Cd)	214.438

TABLE 15

*Instruments, Supplies, Reagents and Samples
Used to Complete this Research*

Instruments

Perkin Elmer Plasma - 40 ICP Spectrometer
Water Pollution Detection Outfit
Fisher Isotemp Oven
Hot Plates
Flow Hood

Supplies

Test Tubes
Glass Vials
Watchglasses
Funnel (Plastic)
Forceps
Pipettes
Spatula
Scissors
Disposable Latex Gloves
Weighing Paper
Filter Paper
Mortar and Pestle
Hammer

Supplies (Continued)

Clear Catch Net (7/8 inch mesh)
Ziploc freezer bags
Reagents

Reagents

Deionized Water
Lead Standard (1000 ppm)
Cadmium Standard (1000 ppm)
Zinc Standard (1000 ppm)
Sodium Standard (1000 ppm)
Iron Standard (1000 ppm)

Samples

Water
Algae
Freshwater Crayfish
Red Brocade Hermit
Blue Crab
Aquatic Macrophytes
Fish

CHAPTER 4

RESULTS AND DISCUSSION

Surface Water Quality of Sample Sites

Trends in water quality of sample sites are shown in Tables 15, 16 and 17. These values indicate the minimum, maximum and mean values of water quality factors tested bimonthly (from March 23, 1996 to June 5, 1996) in water from the drainage ditch adjacent to Sheldon Reservoir (Site 1), Sheldon Reservoir fishing area (Site 2), Lake Houston (Site 3), the San Jacinto River at Interstate Highway 10 (Site 4), Trinity River at Interstate Highway 10 (Site 5), the Galveston marsh (Site 6) and Galveston West Bay (Site 7). Mean values were calculated from the values obtained for five sampling expeditions.

The drainage ditch and Sheldon Reservoir exceeded the standard freshwater temperature criterium of 35 °C as determined by the Texas Natural Resource Conservation Commission (TNRCC) (18). These sites had mean average temperatures of 36.40 °C and 35.60°C, respectively. This criterium was not exceeded at San Jacinto River, Galveston West Bay and the Galveston Marsh. The mean temperature measured for Lake Houston (32.20 °C) did not exceed the standard criterium of 32.22 °C that has been determined by the TNRCC.

Figure 2 shows the mean pH of water sampled from sites 1-7. Water sampling of

sites 1-7 indicated a stable pH for Lake Houston and San Jacinto River. Small variations in pH were observed in Galveston West Bay and the Galveston marsh. Maximum pH values of 9.00 were detected in water sampled from Sheldon Reservoir and the drainage ditch that is adjacent to it. This value exceeded the standard pH criteria for freshwater sites (namely, Lake Houston, the Trinity River and the San Jacinto River). Waters more alkaline than pH 8.5 should be viewed with suspicion because alkaline industrial discharges containing trace metals are the cause for these high pH values. Treatments such as aeration, neutralization and softening will have to be employed in order to maintain this reservoir for domestic uses.

Similar to water temperature and pH, the highest alkalinity was detected in the drainage ditch (234.80 ppm) (Figure 3). The Galveston marsh followed with a mean alkalinity of 134.60 ppm (Figure 5). The mean alkalinity of San Jacinto River was almost similar to that of Galveston West Bay (Figure 4). These sites had alkalinity values of 126.60 ppm and 127.80 ppm, respectively and in increasing order. The lowest alkalinity values were detected in the Trinity River (117.60 ppm), Lake Houston (68.00 ppm) and Sheldon Reservoir (51.20 ppm) (Figures 3 and 4). The results obtained for Lake Houston (64.00 ppm), the San Jacinto River (114.00 ppm), the Trinity River (108.00 ppm) and Galveston West Bay (108.00 ppm) by TNRCC's surface water quality monitoring program were not significantly different than the results obtained in this study. The small differences can be attributed to the changes in weather and inputs from human economic activities such as industry.

Calcium, magnesium and total hardness factors of a water source are considered as

a group since the total hardness represents the total concentration of calcium and magnesium ions expressed as calcium carbonate. Drinking water quality standards as determined by the U.S. Public Health Service sets limits of total hardness in the range of 0-60 ppm as soft water; from 60-120 ppm as medium hard; from 120-180 ppm as hard water and above 180 ppm as very hard water (5). Results of this field investigation classifies Lake Houston (50.80 ppm) and Sheldon Reservoir as softwater (42.40 ppm), the San Jacinto River as hard water (125.20 ppm), and the Trinity River (1548.00 ppm), the Galveston Marsh (5555.55 ppm), Galveston West Bay (5160.00 ppm) and the drainage ditch (183.20 ppm) as very hard water.

Summer water testing (July 1, 1996) by the TNRCC classified Lake Houston as medium hard water with a total hardness concentration of 64 ppm. San Jacinto River (1770 ppm) and Galveston West Bay (4840.00 ppm) were classified as very hard water. The result of total water hardness obtained by the TNRCC for Galveston West Bay was similar to the result obtained in this study but the result obtained for Lake Houston and the San Jacinto River were not. Higher total hardness values were obtained.

Water sources vary in salinity (Tables 15, 16 and 17). Some reasons for this variation, as previously mentioned, include river water mixing, differential evaporation, and mixing from seawater currents as well as input from natural anthropogenic activities (14). The results obtained in this study concur with these observations. Mean salinity values of 112.56 ppt and 137.20 ppt were detected in Galveston West Bay and the Galveston Marsh, respectively. These sources were observed to have the highest salinity values with Galveston Bay having a maximum salinity of 520.00 ppt followed by the marsh with 420.00

ppt (Figure 3). Freshwater source, the San Jacinto River, also had a maximum salinity concentration of 320.00 ppt. The mean salinity concentration, however, was 72.88 ppt. This value classifies this water source, during the collection period, as seawater has been defined as water with a pH of 8.1 and salinity of 35 parts per thousand (14). During the collection period (March 23, 1996 to June 2, 1996), the San Jacinto River could have been defined as seawater. Salinity concentrations were lower in the drainage ditch (4.32 ppt), Sheldon Reservoir (3.32 ppt) and Lake Houston (3.32 ppt). The results obtained by the TNRCC for Trinity River and Galveston West Bay did not concur with these results. Significantly lower salinity concentrations of <1 and 28 ppt were obtained for these sites, respectively. These observations, as well as the observations for alkalinity and hardness, points to changes in the environments as the cause of the high variability in water quality exhibited in these water sources. Even though it is believed that freshwater environments are believed to be more susceptible to changes in natural sources such as weather, the results from this study show that both freshwater and saltwater sites are susceptible to these sources (5). The salinity and hardness of these water sites, in most instances, did not maintain any constancy. Major constituent concentrations (sodium, potassium, chloride, magnesium and calcium) are believed to remain constant in seawater (14) (Table 6). This tendency is observed in both seawater sites (Galveston West Bay and the Galveston Marsh). The concentration values obtained for these major constituents did not indicate any rapid increases or decreases in concentration (Table 6). The values obtained however are higher than the standard composition of the constituents for seawater. Potassium concentration of seawater has been

observed at this site compared to a concentration of (72.88 ppt) detected at the San Jacinto

shown to be 399 ppm (14). Results from this study showed elevated levels of Potassium in Galveston West Bay (913.33 ppm) and the Galveston marsh (837.67 ppm) (Figure 6). While sodium and chloride concentrations values from these salt water sites were slightly under the concentration of standard seawater (10760.00 and 19350.00 ppm), magnesium and calcium obtained from these sites exceeded the standard seawater concentration of 1290.00 and 411.00 ppm, respectively (Figure 6).

Overall, the San Jacinto River exhibited a wide variation in salinity concentrations (0.40 - 320 ppt) (Table 17) (Figure 4). Its minimum salinity concentration of 0.40 ppt is similar to those collected from the other freshwater sites (1, 2 and 3). Its increase in salinity to a maximum value of 320.00 ppt shows that when compared to the rest of the sample sites the salinity of this water source was the most variable in concentrations (Figure 4). This can be attributed to river water mixing with seawater from Galveston West Bay and high runoff from its drainage area when it rains. The drastic change in salinity concentration was observed as the hardness concentration for the sample water sample increased. This inverse relationship was not observed for the first three water testing of the San Jacinto River (Figure 4).

Mean hardness (125.20 ppm) and alkalinity (117.60 ppm) of Trinity River was higher than that exhibited by other freshwater sources (Figure 4). At this source the changes in hardness appears to be proportional to the changes in alkalinity. This relationship is opposite to the relationship observed between these two factors at the San Jacinto River (Figure 4). This appears to be a result of a lower mean salinity concentration of (5.13 ppt) observed at this site compared to a concentration of (72.88 ppt) detected at the San Jacinto

River. Overall, salinity concentrations of the drainage ditch, Sheldon Reservoir and the Trinity River show a large increase in salinity for the fifth sampling expedition (Figure 3).

The relationship between alkalinity, temperature, salinity, and hardness exhibited at Sheldon Reservoir (Figure 3) was observed in water samples tested from Galveston West Bay and the Galveston marsh (Figure 5). A wide variation in salinity was observed for these sites. The maximum salinity values for these sites were also detected in the fifth water samples (Figures 3 and 5). The same was observed for total water hardness of these sites. These results suggests large inputs of organic compounds from rainwater runoff leading to the direct increases of salinity and hardness for these water sources.

Phosphate levels detected at all of the sites were outside the mean and standard criteria for phosphates as determined by the Texas Natural Resource Conservation Commission (TNRCC) (Figure 7). Phosphate values obtained for all of the sample sites exceeded the freshwater standard criteria of 0.20 ppm and saltwater criteria of 0.40 ppm. A maximum mean value of 2.00 ppm was detected in Galveston West Bay followed by the Galveston marsh, the San Jacinto River, the Trinity River and Lake Houston with equal concentrations of 1.00 ppm. Waste from livestock farming is the most common source of phosphate pollution in water sources and is the possible source of pollution in these sites.

Sulfides are environmental pollutants that are transported in the air along with aerosols and pesticides. This pollutant was not detected in any water sample testing from sites 1-7 (Tables 15, 16 and 17). Possible sulfide concentrations in these water would have been attributed to improper disposal of waste from livestock farming (8). Nitrates were detected at a mean concentration of 1.75 ppm in the San Jacinto.

TABLE 16

Surface Water Quality Factors (ppm) of Sites 1, 2 and 3

Parameter	Screening Levels	Site 1			Site 2			Site 3		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Water Temp (°C)	-	28.00	41.00	36.40	36.00	39.00	35.60	24.00	35.00	32.20
pH	-	8.00	9.00	8.20	6.30	9.00	7.52	7.00	8.00	7.40
Alkalinity	4.0	96.00	400.0	234.8	40.00	62.00	51.20	28.00	88.00	68.00
Chlorine	0.1	0.10	0.10	9.10	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b
Chloride	0.1	86.00	216.0	151.0	26.00	32.00	29.00	>600 ^c	>600 ^c	>600 ^c
Calcium, dissolved	4.0	158.0	208.0	183.0	24.00	34.00	29.00	48.00	62.00	55.00
Magnesium,	4.0	48.00	62.00	55.00	48.00	16.00	18.00	8.50	4.00	4.00
Total, hardness	4.0	52.00	222.0	183.2	28.00	52.00	42.40	40.00	66.00	50.80
Cyanide	4.0	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b
Salinity	4.0 ^d	.40	20.00	4.32	0.40	20.00	4.32	0.40	15.00	3.32
Phosphate	0.3	0.30	0.50	0.40	.13	1.00	.57	1.00 ^c	1.00 ^c	1.00 ^c
Sodium	1.0	55.00	94.00	78.3	5.00	9.00	7.00	7378	7772	7575
Potassium	1.0	2.00	3.00	2.67	ND ^b	1.00	.50	1.00	2.00	1.67
Nitrate	0.4	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b
Sulfide	0.4	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b

^dSalinity values in ppt^bND - Factors were not detected in the screening levels

TABLE 17
Surface Water Quality Factors (ppm) of Sites 4 and 5

Parameter	Screening	Site 4			Site 5		
	Levels	Min	Max	Mean	Min	Max	Mean
Water Temp (°C)	-	32.00	35.00	33.60	34.00	37.00 ^c	35.20
pH	-	7.80	8.00	7.88	7.800	8.00	7.90
Alkalinity	4.0	114.00	141.00	127.80	112.00	125.00	117.60
Chlorine	0.1	.01	1.00.00	.55	ND ^b	0.10	0.05
Chloride	0.1	>600 ^c	>600 ^c	>600 ^c	86.00	216.00 ^c	151.00 ^c
Calcium, dissolved	4.0	1258.00	1878.00	534.00	92.00	116.00	104.00
Magnesium, dissolved	4.0	774.00	1806.00	1290.00	16.00	22.00	19.00
Total, hardness	4.0	1032.00	2064.00	1548.00	108.00	140.00	125.20
Cyanide	4.0	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b
Salinity	4.0 ^d	0.40	320.00	72.88	.40	24.00	5.13
Phosphate	0.3	1.00 ^c	1.00 ^c	1.00 ^c	1.00 ^c	1.00 ^c	1.00 ^c
Sodium	1.0	7378.00	7772.00	7575.00	36.00	150.00	80.00
Potassium	1.0	274.00	299.00	286.50	4.00	18.00	9.30
Nitrate	0.4	1.50 ^c	2.00 ^c	1.75 ^c	ND ^b	ND ^b	ND ^b
Sulfide	0.4	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b

^dSalinity values in ppt

^bND - Factors were not detected in the screening levels

Table 18
Surface Water Quality Factors (ppm) of Sites 6 and 7

Parameter	Screening Levels	Site 6 Min	Max	Mean	Site 7 Min	Max	Mean
Water Temp (°C)	-	27.00	37.00	28.80	27.00	37.00 ^c	28.80
pH	-	7.80	8.50	8.10	7.80	8.50	8.18
Alkalinity	4.0	122.00	151.00	134.60	108.00	138.00	126.60
Chlorine	0.1	ND ^b	0.10	.05	0.10	0.10	0.10
Chloride	0.1	>600	>600	>600	>600 ^c	>600 ^c	>600 ^c
Calcium, dissolved	4.0	774.00	1548.00	1161.00	1999.50	2322.00	2160.75
Magnesium, dissolved	4.0	3741.00	5108.00	4424.50	2044.50	3354.00	2999.25
Total, hardness	4.0	5289.00	5822.00	5555.55	4644.00	5676.00	5160.00
Cyanide	4.0	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b
Salinity	4.0 ^d	30.80	420.00	112.56	28.00	520.00	137.20
Phosphate	0.3	1.00	1.00	1.00	0.50 ^c	1.00 ^c	.75 ^c
Sodium	1.0	27689.00	29555.00	28593.33	19657.00	21690.00	20673.50
Potassium	1.0	792.00	1018.00	913.33	811.00	855.00	837.67
Nitrate	0.4	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b
Sulfide	0.4	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b	ND ^b

^dSalinity values in ppt

^bND - Factors were not detected in the screening levels

FIGURE 2

Mean pH of Water Collected from Sites 1-7

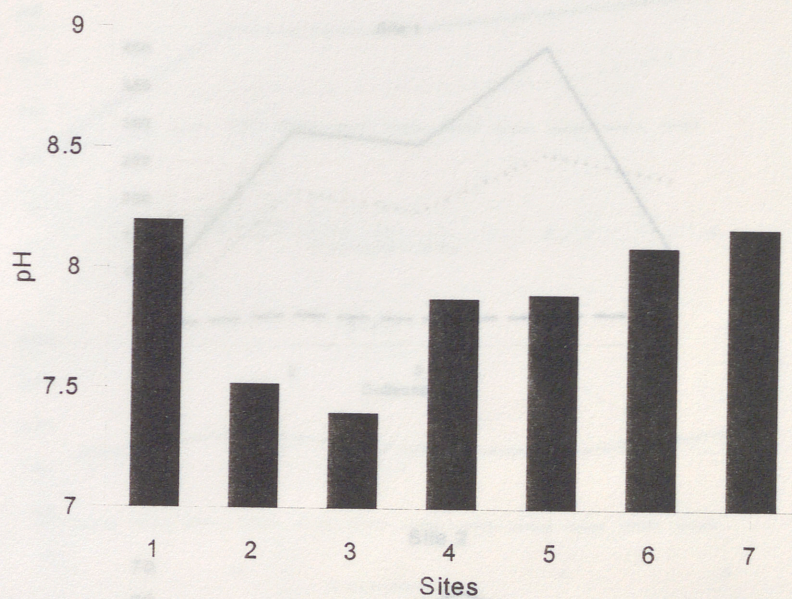


FIGURE 3

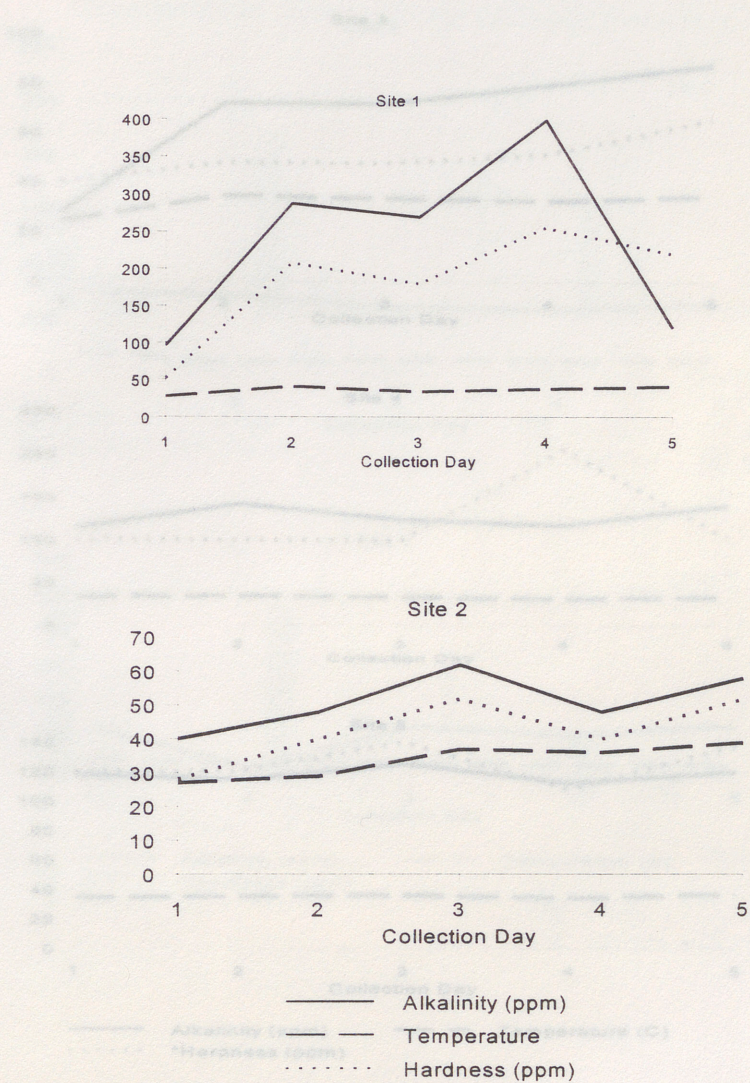
Surface Water Quality of Sites 1 and 2

FIGURE 4

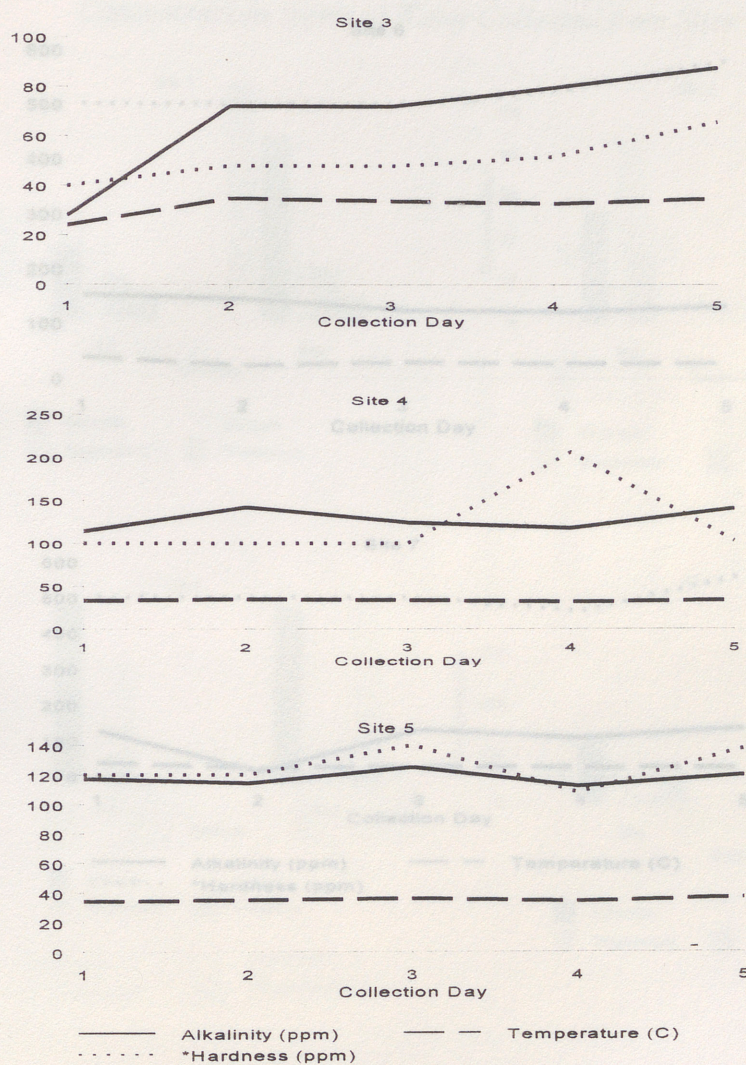
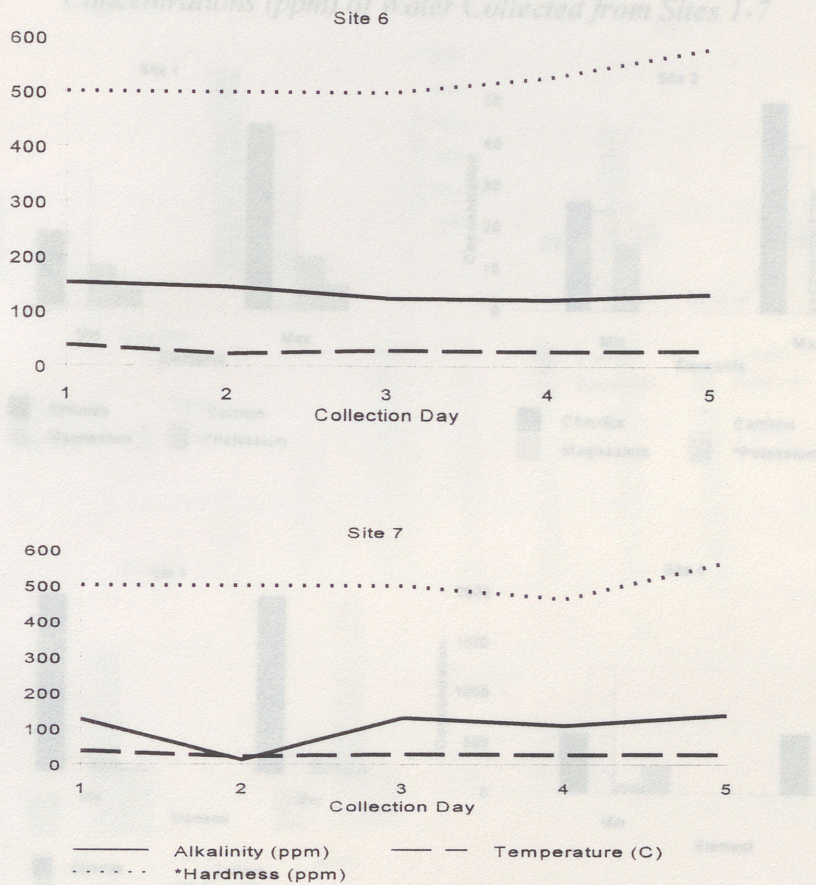
Surface Water Quality of Sites 3, 4 and 5*Site 3 Hardness values $\times 10^{-1}$

FIGURE 5

Surface Water Quality of Sites 6 and 7

Changes in Potassium, Chloride, Calcium and Magnesium Concentrations (ppm) of Water Collected from Sites 1-7

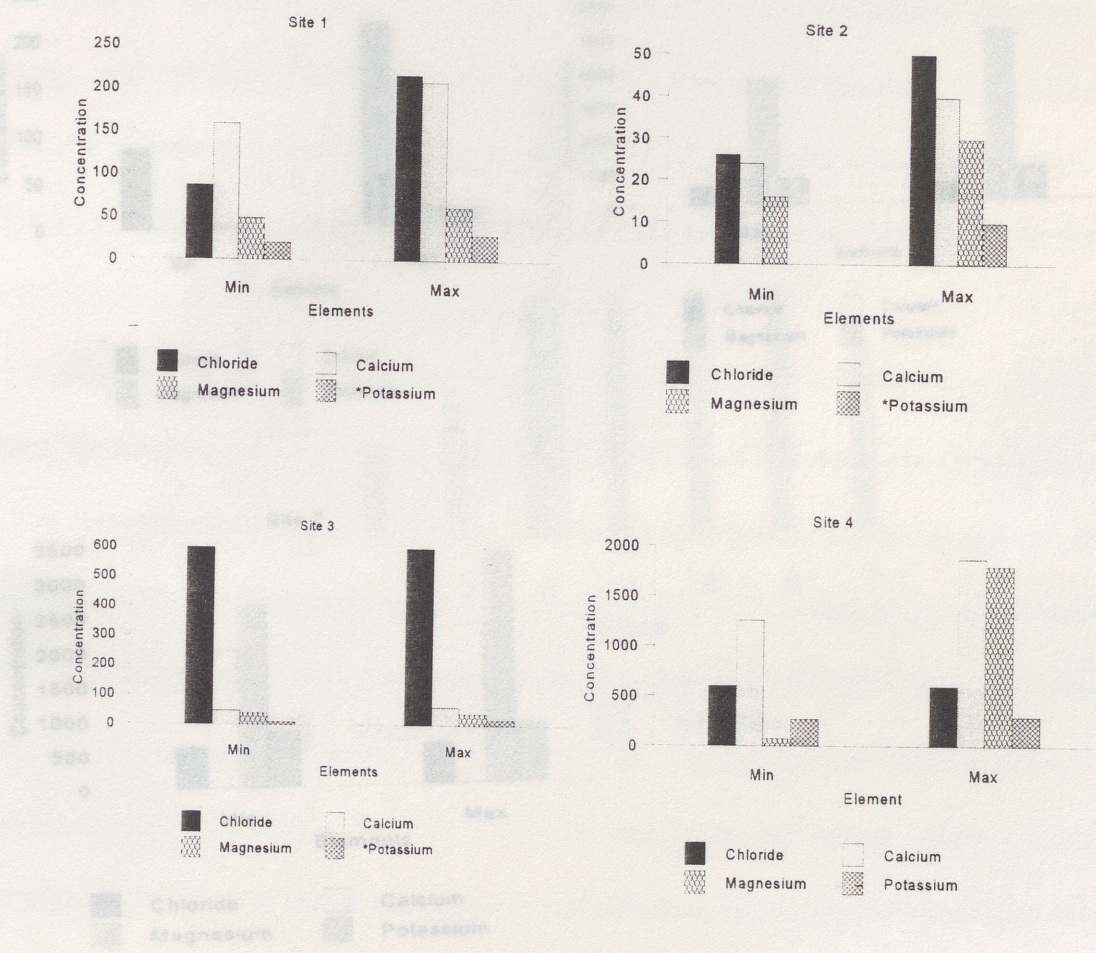


*Sites 6 and 7 Hardness $\times 10^{-1}$

CONTINUED

FIGURE 6

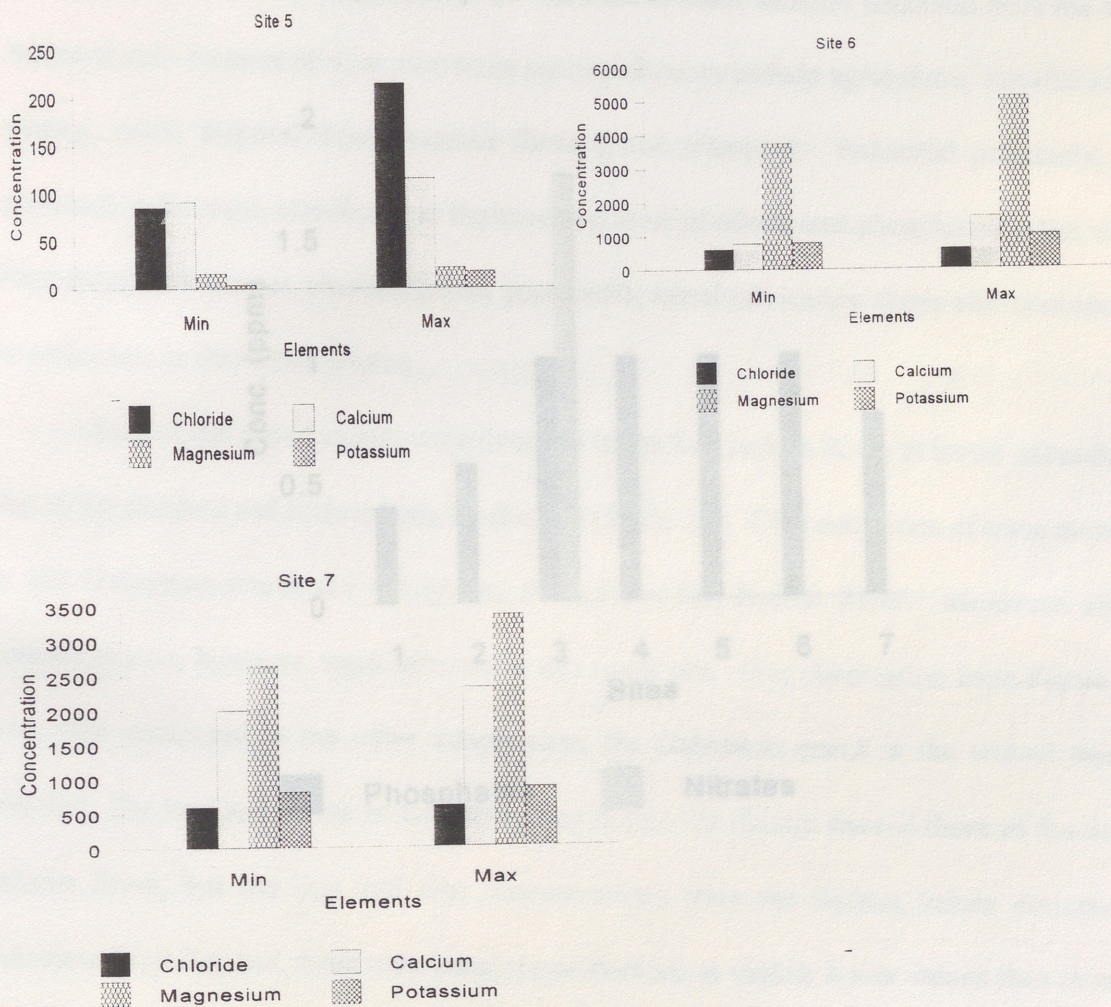
Changes in Potassium, Chloride, Calcium and Magnesium Concentrations (ppm) of Water Collected from Sites 1-7



**Potassium Concentration x 10-1*

FIGURE 7

Phosphate and Nitrate Concentrations (ppm) in
Water Samples Collected from Sites 1-7

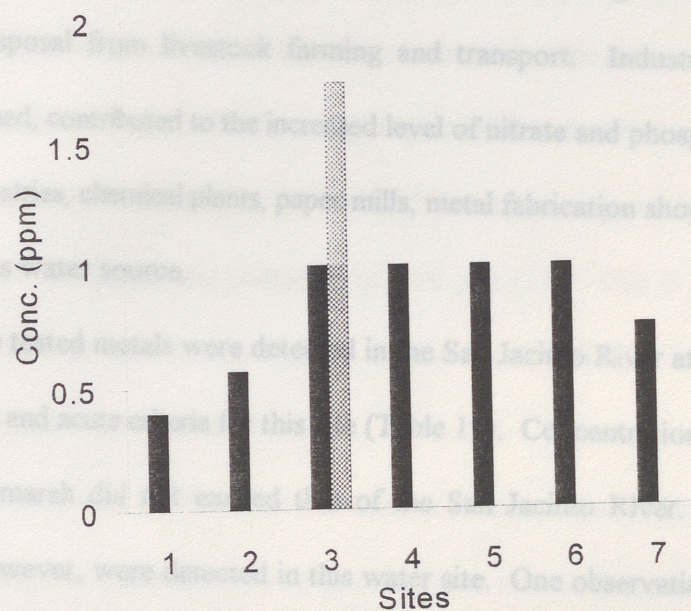


Water Chemistry of Sample Sites

The results of trace metal analysis of water samples from sites 1-7 are summarized in Table 19. Maximum, minimum and mean concentrations (ppm) of the tested trace metals

FIGURE 7

*Phosphate and Nitrate Concentrations (ppm) in
Water Samples Collected from Sites 1-7*



■ Phosphates ▨ Nitrates

Water Chemistry of Sample Sites

The results of trace metal analysis of water samples from sites 1-7 are summarized in Table 19. Maximum, minimum and mean concentrations (ppm) of the tested trace metals (lead, zinc, cadmium and iron) are shown in Table 19. Maximum concentrations of lead (16.00 ppm) and cadmium (8.00 ppm) were detected in water samples collected from the San Jacinto River. Sources of these two trace metal pollutants include agriculture, metalliferous mining, waste disposal from livestock farming and transport. Industrial pollutants, as previously mentioned, contributed to the increased level of nitrate and phosphates at this site. Petrochemical industries, chemical plants, paper mills, metal fabrication shops also contribute to pollutants in this water source.

Four of the tested metals were detected in the San Jacinto River at levels exceeding that of the standard and acute criteria for this site (Table 19). Concentrations of trace metals in the Galveston marsh did not exceed that of the San Jacinto River. Maximum zinc concentrations, however, were detected in this water site. One observation from Figure 8 was, that compared to the other sample sites, the Galveston marsh is the second most polluted. The lead and cadmium concentrations in this site did not exceed those of the San Jacinto River, but the iron and zinc concentrations were the highest values detected. Galveston West Bay had mean trace metal concentrations at slightly lower values than those of the marsh (Figure 8). Lead appears to be more abundant in this source (4.00 ppm) followed by iron (2.00 ppm) and equal values of zinc and cadmium (1.33 ppm). Marine import and export activities increases the levels of pollutants in Galveston Bay.

Zinc was detected in samples from lake Houston at a mean concentration of 4.00 ppm. A lower concentration of 3.33 ppm was detected in water collected from the Trinity River. Equal iron concentrations (1.33 ppm) were detected at these sites but the cadmium concentration was higher in Lake Houston (91.00 ppm) than Trinity River (0.67 ppm). The mean acute and chronic criteria of lead and cadmium for these sites were also exceeded.

A range of .50 to 1 was calculated for lead and cadmium ratios in water sampled from sites 1-7. This observation further suggest that lead is the more abundant metal in all of the water sources (Figure 8). It has been reported that the frequency of occurrence of lead and cadmium in freshwater is 19% and 2.5%, respectively, with lead occurring at a concentraion of 23.00 ppb and cadmium at 9.50 ppb (11). This is a ratio of lead to cadmium levels in U.S. freshwaters of 2.45. Ratios of 3.0, 1.0, 4.0, 1.8 and and 3 were calculated from sites 1-5, respectively.

Lead and cadmium are found in seawater at concentrations of 0.03 ppb and 0.05 ppb, thus indicating that cadmium is more abundant than lead in these environments (14). The results obtained in this field investigation exceeded these values. Lead was found to be more abundant in both of the saltwater sources (Figure 8). Zinc is naturally a more abundant metal than both lead and cadmium. The frequency of occurrence of zinc in United States freshwaters has been reported at 77% at a concentration of 79.00 ppm. Zinc concentrations in standard seawater have been reported at 2.00 ppm. Results obtained in this study concur with these reports. Zinc was detected in San Jacinto River at 1.00 ppm, the Galveston marsh at 2.00 ppm and Galveston West Bay at 1.33 ppm. Values obtained for iron also fell within the standard range for seawater of 2.00 ppm.

FIGURE 8

TABLE 19

Toxic Metals in Water Collected From Sites 1, 2, 3, 5, 6 and 7

Site	Trace Metal	Acute Criteria (ppm)	Chronic Criteria (ppm)	Mean Conc. (ppm)	Mean Exceeds Acute Criteria	Mean Exceeds Chronic Criteria
1	Pb	NA ^a	NA ^a	3.00	-	-
	Zn	NA ^a	NA ^a	ND ^b	-	-
	Cd	NA ^a	NA ^a	1.00	-	-
	Fe	NA ^a	NA ^a	1.00	-	-
2	Pb	NA ^a	NA ^a	1.67	-	-
	Zn	NA ^a	NA ^a	ND ^b	-	-
	Cd	NA ^a	NA ^a	1.67	-	-
	Fe	NA ^a	NA ^a	1.50	-	-
3	Pb	1.390	.005	4.00	yes	yes
	Zn	.167	.151	ND ^b	no	no
	Cd	.054	.002	1.00	Yes	yes
	Fe	NA ^a	NA ^a	1.33	-	-
4	Pb	.140	.006	10.00	yes	yes
	Zn	.098	.084	1.00	yes	yes
	Cd	.046	.010	5.50	yes	yes
	Fe	NA ^a	NA ^a	2.00	-	-
5	Pb	.140	.006	3.33	yes	yes
	Zn	.046	.089	ND ^b	no	yes
	Cd	.098	.010	0.67	yes	yes
	Fe	NA ^a	NA ^a	1.33	-	-
6	Pb	NA ^a	NA ^a	4.67	-	-
	Zn	NA ^a	NA ^a	2.00	-	-
	Cd	NA ^a	NA ^a	1.67	-	-
	Fe	NA ^a	NA ^a	2.67	-	-
7	Pb	.140	.006	4.00	yes	yes
	Zn	.098	.089	1.33	yes	yes
	Cd	.046	.010	1.33	yes	yes
	Fe	NA ^a	NA ^a	2.00	-	-

^aNA-Standard Criterion is Not Available For Sample Site

^bND - Metal was not detected in the screening level

Bioaccumulation of Trace Metals in Aquatic Biota

Water represents one of the major sources of metal uptake by marine invertebrates. The order of metal concentrations in water collected from Sites 1-7 is as follows: Lead > Zinc > Cadmium > Iron.

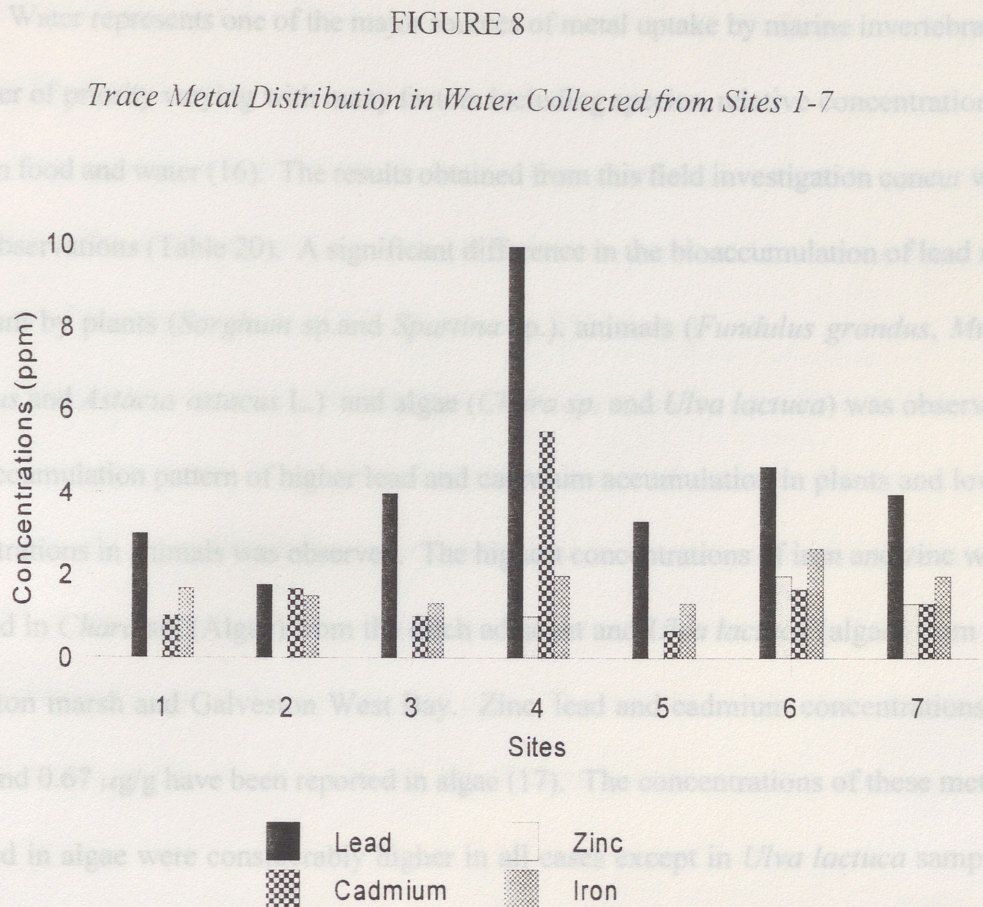
The results obtained from this field investigation concur with these observations (Table 20). A significant difference in the bioaccumulation of lead and cadmium in plants (*Sorghum* sp. and *Spartina* sp.), animals (*Fundulus grandis*, *Mugil cephalus*, *Astacus astacus* L.) and algae (*Chara* sp. and *Ulva lactuca*) was observed.

A bioaccumulation pattern of higher lead and cadmium accumulation in plants and lower concentrations in animals was observed. The highest concentrations of lead and zinc were detected in *Chara* sp. and *Ulva lactuca* from the drainage ditch and *Ulva lactuca* from the Galveston marsh and Galveston West Bay.

Zinc, lead and cadmium concentrations of 71.82 and 0.67 µg/g have been reported in algae (17). The concentrations of these metals obtained in algae were consistently higher in *Ulva lactuca* except in *Ulva lactuca* sampled from the Galveston marsh.

Iron was detected at the highest concentration of 10,767.73 ppm in *Chara* sp. sampled from Sheldon Reservoir. This was followed by mean concentrations of 7575.00 ppm, 4703.48 ppm and 4595.00 in *Ulva lactuca* collected from the Galveston marsh, *Chara* sp. collected from the drainage ditch and *Ulva lactuca* collected from Galveston West Bay, respectively, and in decreasing order.

The highest lead concentration was also detected in *Sorghum* sp. (Grass) (99,485.00 ppm) collected from the Galveston marsh. This was followed by *Astacus astacus* L. from the drainage ditch with 2,500.00 ppm.



Bioaccumulation of Trace Metals in Aquatic Biota

Water represents one of the major sources of metal uptake by marine invertebrates, the order of priority varying with many factors including species, relative concentration of metal in food and water (16). The results obtained from this field investigation concur with these observations (Table 20). A significant difference in the bioaccumulation of lead and cadmium by plants (*Sorghum* sp. and *Spartina* sp.), animals (*Fundulus grandis*, *Mugil cephalus* and *Astacus astacus* L.) and algae (*Chara* sp. and *Ulva lactuca*) was observed. A bioaccumulation pattern of higher lead and cadmium accumulation in plants and lower concentrations in animals was observed. The highest concentrations of iron and zinc were detected in *Chara* sp. (Algae) from the ditch adjacent and *Ulva lactuca* (algae) from the Galveston marsh and Galveston West Bay. Zinc, lead and cadmium concentrations of 71.82 and 0.67 $\mu\text{g/g}$ have been reported in algae (17). The concentrations of these metals obtained in algae were considerably higher in all cases except in *Ulva lactuca* sampled from the Galveston marsh.

Iron was detected at the highest concentration of 10,767.73 ppm in *Chara* sp. sampled from Sheldon Reservoir. This was followed by mean concentrations of 7575.00 ppm, 4703.48 ppm and 4595.00 in *Ulva lactuca* collected from the Galveston marsh, *Chara* sp. collected from the drainage ditch and *Ulva lactuca* collected from Galveston West Bay, respectively, and in decreasing order.

The highest lead concentration was also detected in *Sorghum* sp. (Grass) (99,485.00 ppm) collected from the Galveston marsh. This was followed by *Astacus astacus* L. from the drainage ditch with 2,500.00 ppm.

The highest cadmium concentration was detected in *Dardanus insignis* (red brocade hermit) (137.77 ppm) followed by equal mean concentrations of 101.00 ppm in *Sorghum* sp. from the drainage ditch and the Trinity River.

Astacus astacus L. had the highest mean zinc concentration (416.70 ppm). This was followed by *Dardanus insignis* from the Galveston marsh and Galveston West Bay with mean zinc concentrations of 275.40 ppm and 252.50 ppm.

Trace metal concentrations obtained for fish samples far exceeds concentrations that have been detected in freshwater fish samples. Various freshwater fish species such as trout, carp and bream have been shown to have lead concentration ranges of 59-71, 54-73 and 30-60 ppm, respectively. Cadmium concentrations detected in *Fundulus grandus* fell in a previously reported range of 13-48 ppm. The same is true for zinc. Previously reported ranges of 220-260, 500-520 and 390-820 ppm have been seen in trout, carp and bream.

1	<i>Fundulus grandus</i> (Galveston Marsh)	137.77	137.77	137.77	137.77
2	<i>Dardanus insignis</i> (Galveston Marsh)	101.00	101.00	101.00	101.00
3	<i>Dardanus insignis</i> (Galveston West Bay)	101.00	101.00	101.00	101.00
4	<i>Sorghum</i> sp. (Drainage Ditch)	101.00	101.00	101.00	101.00
5	<i>Sorghum</i> sp. (Trinity River)	101.00	101.00	101.00	101.00
6	<i>Astacus astacus</i> L. (Galveston Marsh)	416.70	416.70	416.70	416.70
7	<i>Astacus astacus</i> L. (Galveston West Bay)	275.40	275.40	275.40	275.40
8	<i>Astacus astacus</i> L. (Trinity River)	252.50	252.50	252.50	252.50

137.77 - mean concentration of lead detected
 101.00 - mean concentration of lead detected
 101.00 - mean concentration of lead detected
 101.00 - mean concentration of lead detected
 101.00 - mean concentration of lead detected
 416.70 - mean concentration of lead detected
 275.40 - mean concentration of lead detected
 252.50 - mean concentration of lead detected

TABLE 20

*Trace Metal Concentrations (ppm) of Aquatic Biota
Collected from Sites 1, 2, 3, 5, 6 and 7*

Site	Organism	Zinc	Cadmium	Lead	Iron
1	<i>Fundulus grandus</i> (Gulf Killifish)	63.60	ND ^e	66.32	637.47
2	<i>Fundulus grandus</i> (Gulf Killifish)	207.56	45.87	427.83	264.93
7	<i>Mugil cephalus</i> (Striped Mullet)	79.53	ND ^e	238.59	1829.12
1	<i>Astacus astacus</i> L. (Crayfish)	416.70 ^a	ND ^e	2,500.00	2083.50
2	<i>Astacus astacus</i> L. (Crayfish)	202.00	101.00	ND ^e	403.00
6	<i>Dardanus insignis</i> (Hermit Crab)	275.40	137.77 ^b	377.31	449.28
7	<i>Dardanus insignis</i> (Hermit Crab)	252.50	50.50	ND ^e	404.00
7	<i>Callinectes sapidus</i> (Blue Crab)	101.00	ND ^e	303.00	505.00
7	<i>Ulva lactuca</i> (Sea Lettuce)	50.50	50.50	202.00	4595.50
6	<i>Ulva lactuca</i> (Sea Lettuce)	101.00	ND ^e	8181.00	7575.00
2	<i>Chara</i> sp. (Green Algae)	118.25	68.25	336.49	4703.48
1	<i>Chara</i> sp. (Green Algae)	83.94	83.94	570.50	10,767.73 ^d
6	<i>Spartina</i> sp. (Seagrass)	101.00	50.50	9,485.00 ^c	454.50
5	<i>Spartina</i> sp. (Grass)	101.00	101.00	404.00	606.00
3	<i>Sorghum</i> sp. (Grass)	100.00	ND ^e	500.00	202.00
1	<i>Sorghum</i> sp. (Grass)	ND ^e	101.00	303.00	200.00

^a-Maximum concentration of zinc detected

^b-Maximum concentration of cadmium detected

^c-Maximum concentration of lead detected

^d-Maximum concentration of iron detected

^eND - Element was not detected in the screening level (1 ppm)

Trace Metal Bioconcentration Factors (BCFs) in Aquatic Biota

The bioconcentration factor (BCF) represents the ratio of heavy metals in aquatic organisms to their surroundings (23). Zinc, Cadmium, Lead and Iron BCFs of animals (*Astacus astacus* L., *Fundulus grandis*, *Mugil cephalus*, *Dardanus insignis* and *Callinectis sapidus*), plants (*Spartina* sp. and *Sorghum* sp.) and algae (*Ulva lactuca* and *Chara* sp.) are shown in Table 21. The BCF of zinc, cadmium, lead and iron in the aquatic organisms shows the differences in trace metal uptake from freshwater and saltwater. The BCF of lead is higher in most instances than the BCF of cadmium and zinc.

The iron BCF of fish collected from the drainage ditch (637.47) was higher than that of Sheldon Reservoir (264.93) but lower than the concentration detected in fish from Galveston West Bay (914.56) (Figure 9). Of these sources, a higher concentration of zinc was observed in Galveston West Bay (2.00) followed by Sheldon Reservoir (1.67) and the drainage ditch (1.00). Iron BCF in fish from Galveston West Bay shows a correlation with this water source. This correlation was not observed for the drainage ditch and Sheldon Reservoir.

The highest lead BCF in fish was observed in samples collected from Sheldon Reservoir (256.18). This was followed by fish collected from Galveston West Bay (59.65) and the drainage ditch (22.12). There was no correlation between lead BCF in fish and the water sources. The highest lead concentration in water sources were detected in Galveston Bay (94.00 ppm) followed by the drainage ditch (3.00 ppm) and Sheldon Reservoir (1.67 ppm) in decreasing order (See Table 19).

Sheldon Reservoir had a mean cadmium concentration of 1.67 ppm. This was

higher than the cadmium concentrations detected in Galveston West Bay (1.33 ppm) and the drainage ditch (1.00 ppm) (Figure 9). Cadmium BCFs for fish from these sites show no correlation with the concentrations in these water sources. Cadmium was not detected in fish from the drainage ditch but the BCFs for fish from Galveston West Bay and Sheldon Reservoir were 38.00 and 30.58, respectively, and in increasing order.

Zinc was not observed in fish from Sheldon Reservoir and the drainage ditch (See Table 20). This was in correlation with this metal not being detected in the water sources. Galveston West bay, however, had a mean zinc concentration of 1.33 ppm. Zinc BCF of fish from this site was 59.80.

Crayfish collected from the drainage ditch had an iron BCF of 2083.50 (See Table 21). This was higher than the BCFs for blue crab (151.50) from Galveston West Bay and red brocade hermit from the Galveston Marsh (168.27) and Galveston West bay (0.00) (Table 21). This showed no correlation with mean lead concentrations in Sheldon Reservoir (1.67 ppm), the drainage ditch (3.00 ppm), Galveston West Bay (4.00 ppm) and the Galveston Marsh (4.67 ppm), in increasing order (See Table 19). Similar to fish collected from the drainage ditch, cadmium was not detected in crayfish collected from this site even though it was detected in water at a concentration of 1.00 ppm (See Table 21). A small difference in cadmium BCFs for crayfish collected from Sheldon Reservoir (60.48) and red brocade hermit (82.50) collected from the Galveston Marsh was observed. These water sources had equal lead concentrations of 1.67 ppm.

Zinc was not detected in crayfish collected from the drainage ditch and Sheldon Reservoir (Figure 10). This accumulation pattern of zinc was also observed in fish samples

collected from these sites. This metal, however, was not observed in the drainage ditch and Sheldon Reservoir (See Table 19). The zinc BCF of blue crab (25.22) was lower than that of red brocade hermit collected from the Galveston Marsh (137.70) and Galveston West Bay (190.00) (See Table 21). These BCFs showed no correlation with zinc concentrations in water from these sources.

Iron BCFs were found to be the highest in algae (Table 21). Compared to lead, zinc and cadmium, iron was observed to be the metal most absorbed from the aquatic environment. There was no correlation between iron concentration in algae and that of its aquatic environment. These results show that algae are strong net accumulators of iron.

There was a small difference in the zinc BCF in red brocade hermit from Galveston Marsh (137.70) and Galveston West Bay (190.00). These BCFs showed no correlation with zinc concentrations in water from these sources.

Lead BCFs of algae collected from the Galveston Marsh show that they are strong net accumulators for lead as they are for iron (Figure 11). Algae collected from the Galveston marsh, however, had a high lead BCF of 1751.82. This suggests that the mean lead concentration observed at that site (4.67 ppm) might have been an influence on this rapid increase in lead absorption by this organism (Table 21) (Figure 11).

Cadmium was not detected in algae collected from the Galveston Marsh (Table 21). This might have been affected by the high lead BCF (1751.82) previously observed. Cadmium BCFs for algae collected from Sheldon Reservoir (41.00) was almost similar to that of algae collected from Galveston West Bay (38.00). This shows a good correlation between cadmium in water and uptake of this metal by algae (this metal being independent

of differences in water quality of salt and freshwater) (Figure 11).

Similar to the aquatic organisms sampled from Sheldon Reservoir, zinc was not observed in algae (Table 20). This further shows that the bioaccumulation of zinc in this organisms is dependent on the concentration in its environment. The BCFs of algae from the Galveston marsh (50.50) and Galveston West Bay (38.00) shows a good correlation with the zinc concentrations in the water sources (Table 21).

Rooted macrophytes, as observed in the results obtained, are not strong bioaccumulators of iron (Table 20). Iron BCFs for these organisms show that the concentration of iron in these water sources (Table 19) had no significant effect on the bioaccumulation of zinc. The same was observed for lead. The accumulation of this metal by rooted macrophytes for the Galveston marsh, however, was significantly higher than that of rooted macrophytes from the other sites (the drainage ditch, Lake Houston and Trinity River), but there was no correlation with the concentration in water (Figure 12). These results suggest an increase in lead uptake from the soil. They also concur with previous reports of trace metal uptake of plants from soil (13).

Cadmium BCFs of plants were related to those of algae, crayfish and fish in many instances (Table 21). Those of rooted macrophytes from the drainage ditch (101.00), Lake Houston (0.00), Trinity River (1.80) and the Galveston Marsh (50.50) showed a significant correlation of the metals in the water sources.

The accumulation of zinc in submerged aquatic plants appears to be dependent on its concentration in the water source. Zinc BCFs of rooted macrophytes collected from the drainage ditch, Lake Houston and Trinity River were all 0.00 as the zinc concentration in

these water sources were detected at 0.00 ppm. As previously mentioned, biological, chemical and environmental factors can influence the variation of zinc in aquatic plants (13). Factors such as growth rate, supply of nutrients and temperature might have affected the zinc accumulation patterns of the plant species studied.

It has been reported that the BCF is related to the exposure time and the zinc concentration of the surrounding water. Red brocade hermit collected from the Galveston marsh and Galveston West Bay had the high average BCFs of zinc and low BCFs for cadmium, lead and iron. It can be concluded that red brocade hermit has a high uptake and low excretion rate of zinc or that it has a higher exposure time to these trace metals. The same can be concluded for crayfish from the drainage ditch which had escalated lead and iron BCFs of 833.40 ppm and 2083.50 ppm, respectively (Table 20).

The iron BCF of bass collected from the drainage ditch was higher than that of Sheldon Reservoir but slightly lower than the concentration detected in bait fish from Galveston West Bay (Table 20). Cadmium BCF for fish collected from Sheldon Reservoir and Galveston West Bay were almost similar (Table 20). The differences in cadmium and iron BCFs show that the absorption of these metals in fish are independent of each other and not affected by salinity. The absorption of lead, however, appears to decrease with an increase in iron concentrations (Figure 9).

TABLE 21

*Average Bioconcentration Factors (BCFs) of Aquatic Organisms
Collected from Sites 1, 2, 3, 5, 6, and 7*

Site	Organism	Zinc	Cadmium	Lead	Iron
1	<i>Fundulus grandus</i> (Gulf Killifish)	ND ^a	ND ^a	22.12	637.47
2	<i>Fundulus grandus</i> (Gulf Killifish)	ND ^a	30.58	256.18	176.62
7	<i>Mugil cephalus</i> (Striped Mullet)	59.80	38.00	59.65	914.56
1	<i>Astacus astacus</i> L. (Crayfish)	ND ^a	ND ^a	833.40	2083.50
2	<i>Astacus astacus</i> L. (Crayfish)	ND ^a	60.48	ND ^a	269.33
6	<i>Dardanus insignis</i> (Hermit Crab)	137.70	82.50	80.80	168.27
7	<i>Dardanus insignis</i> (Hermit Crab)	190.00	38.00	ND ^a	202.00
7	<i>Callinectes sapidus</i> (Blue Crab)	25.22	ND ^a	227.819	151.5
1	<i>Chara</i> sp. (Green Algae)	ND ^a	83.94	3.00	10,767.73
2	<i>Chara</i> sp. (Green Algae)	ND ^a	41.00	201.49	3135.65
6	<i>Ulva lactuca</i> (Sea Lettuce)	50.50	ND ^a	1751.82	2837.00
7	<i>Ulva lactuca</i> (Sea Lettuce)	38.00	38.00	50.50	2287.75
1	<i>Sorghum</i> sp. (Grass)	ND ^a	101.00	101.00	202.00
3	<i>Sorghum</i> sp. (Grass)	ND ^a	ND ^a	202.00	151.88
5	<i>Sorghum</i> sp. (Grass)	ND ^a	1.80	121.32	455.64
6	<i>Spartina</i> sp. (Seagrass)	50.50	30.24	21,303.80	170.22

^aND - Element was not detected in the screening level (1 ppm)

FIGURE 10

FIGURE 9

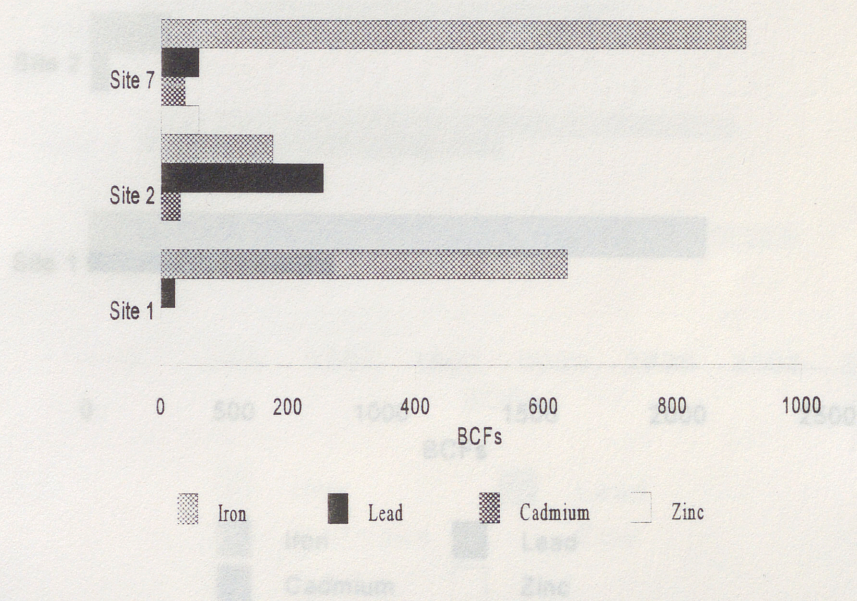
*Bioconcentration Factors of Trace Metals in Astacus astacus L.**Bioconcentration Factors of Fish Collected from Sites 1, 2 and 7*

FIGURE 10

*Bioconcentration Factors of Trace Metals in Astacus astacus L.
Collected from Sites 1 and 2*

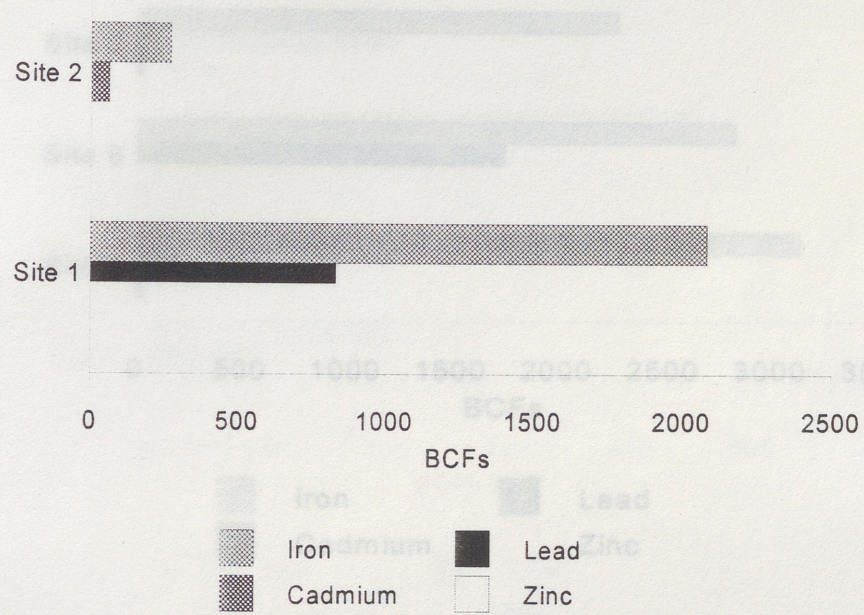


FIGURE 11

*Bioconcentration Factors (BCFs) of Trace Metals in Chara sp.
and Ulva lactuca Collected from Sites 7, 6 and 2*

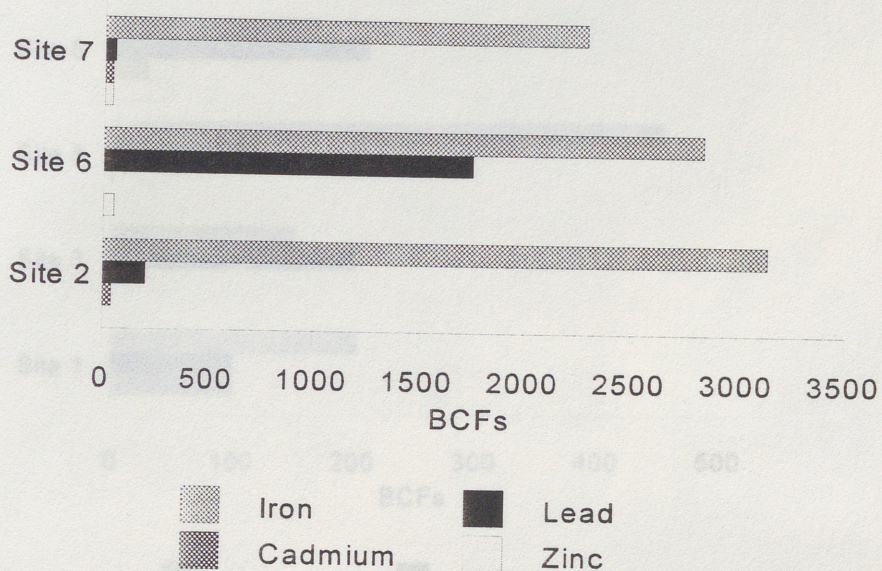
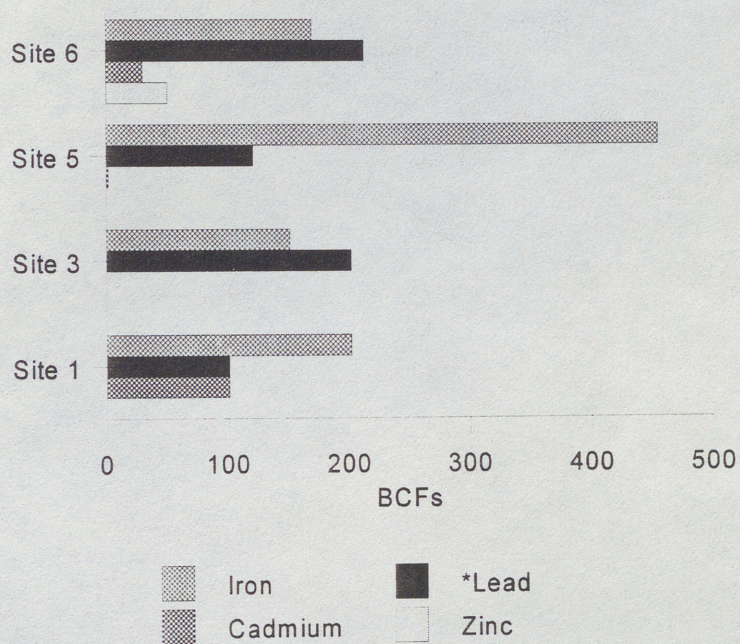


FIGURE 12

*Bioconcentration Factors (BCFs) of Trace Metals in Sorghum sp.
and Spartina sp. Collected from Sites 1, 3, 5 and 6*



*Site 4 Lead Concentration $\times 10^{-1}$

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The results obtained in the study of surface water quality of sites 1-7 in the spring of 1996 (March 23, 1996 to June 5, 1996) show that both Freshwater and saltwater sites, namely the drainage ditch, Sheldon Reservoir and Trinity River, exhibited high natural variabilities in their physiochemistries. This points to the possibility that all of these sites, regardless of salintiy, are susceptible to anthropogenic influences. Compared to the remaining six sample sites, the drainage ditch that is adjacent to Sheldon Reservoir was the most alkaline of the sample sites with a mean alkalinity of 234.80 ppm. This was followed by Galveston West Bay which exhibited a mean alkalinity of 126.60 ppm. The pH of the ditch and Sheldon Reservoir exceeded the standard pH criteria of 8.5 as determined by the TNRCC for the other freshwater sources. Waters more alkaline that pH 8.5 to 9.0, as previously mentioned, should be viewed with suspicion because alkaline industrial discharges containing trace metals are the cause for these high pH values.

Escalated chloride concentrations (>600 ppm) in Lake Houston indicates pollution from seawater or industrial and domestic wastes. The concentrations detected (>600 ppm) exceeded the standard criterium of 100 ppm established by the Texas Natural Resource Conservation Commission (TNRCC) for this site. These results would be helpful for the

Municipal Water Treatment Plant that are responsible for treating water from this source. A knowledge of the changes in quality of this water source over time is necessary to adequately treat water as its chemistry is altered. Fortunately, cyanide, which is very toxic, was not present in water from any of the sample sites. Cyanide may be present in water containing waste from a metal finishing plant. A positive test is evidence of untreated or incompletely treated waste which calls for more careful disposal control by the offending facility.

Nitrate and phosphate enrichment was observed in the San Jacinto River for the duration of the sampling period. This pollution problem is related to the fertilization of water by added nitrogenous materials and phosphates in sewage. This can produce heavy blooms of algae which can cause an imbalance of the food chain system.

From the data collected, it can be concluded that of the tested trace metals the highest mean concentration of lead and zinc were detected in the San Jacinto River. The highest mean concentrations of zinc and iron were detected in the Galveston marsh. A comparison of the two most toxic tested trace metals, lead and cadmium, shows that the San Jacinto River poses the greatest risk of human exposure to these metals. This is followed by the Galveston marsh, Galveston West Bay, Lake Houston, Sheldon Reservoir, Trinity River and the drainage ditch adjacent to Sheldon Reservoir.

The patterns of changes in heavy metals in water from the sample sites was quite diverse. The uniformity of release of a specific metal into a specific water sample site could not be determined for the data acquired. This observation leads to the skepticism that the source of trace metal pollution was not continuous or uniform. Each of these water sources,

however, has an individual pattern of physical and chemical characteristics which are determined largely by the climatic, geomorphological and geochemical conditions and anthropogenic activities. The chemical characteristics, which have been described in the results, affect the residence time of some of these metals in the water source, therefore causing an increase or decrease in the levels of trace metals.

Water represents one of the major routes of metal uptake by aquatic organisms, the order of priority varying with many factors including species. A continuous, low-level metal content in aquatic systems may have a gross biological impact comparable to those of higher concentrations. The analytical results of this field investigation suggests that the uptake of pollutants from the water may be the major source of trace metal accumulation in the different species of aquatic systems studied. This relationship was observed when comparing trace metal concentrations in crayfish, fish and crabs to those of the rooted macrophytes. The presence of absolutely toxic metals (lead and cadmium) in the aquatic organisms points to extreme contamination of the water sites. The trace metal analysis of these toxic metals in fish show that fish collected from Sheldon Reservoir is more contaminated with lead and cadmium than fish collected from Galveston Bay and the drainage ditch. However, the concentrations of these metals in fish from all three of these sites were higher than the levels previously detected in various fresh and salt water fish species. Crayfish collected from the drainage ditch also had high lead and iron concentrations than previously reported concentrations. The mechanisms by which these materials build up in the food chain and fish, and the eventual effects upon the behavior, growth and longevity of fish has been well established (10, 12,14). It is, therefore, advisable not to drink water from the sample sites

or eat the Gulf Killifish and Mugil Cephalus from Sheldon Reservoir and Galveston West Bay, respectively. This will avoid the potential risk to human health arising from the high toxicity and persistence of trace metals since human exposure to toxic levels of trace metals occurs mainly from the consumption of food and water.

The results obtained in this study will contribute to the knowledge base of the levels of lead, zinc, cadmium and iron in water and aquatic organisms in the Houston and Galveston areas. This data will be available for federal and state agencies which are concerned about the levels of these pollutants in major waterways. It will also be a major contribution to the attempts by the Texas Natural Resource Conservation Commission (TNRCC) to protect major aquatic environments from large scale degradation, thereby making them unfit for municipal or industrial use.

Recommendations

There is a relative lack of available data on the biology of trace metals in aquatic organisms. Results from this study show that algae might be a good marker for trace metal studies in aquatic organisms since trace metal kinetics through freshwater invertebrates are lacking. Such studies allow concrete conclusions to be drawn on metal uptake and excretion rates and on the presence of regulation as an accumulation strategy in aquatic biota. Such data are prerequisites to the use of any freshwater or saltwater organism as a biomonitor of metals.

REFERENCES

1. Lucotte, M., Mucci, A., Hillaire-Marcell, C., Pichet, P., and Grondin, A. (1996). Anthropogenic Mercury Enrichment in Remote Lakes. Netscape: World Wide Web.
2. Jop, K.M. (1991). Concentrations of Metals in Various Larval Stages of Four *Ephemeroptera* Species. Bulletin of Environmental Contamination and Toxicology, 46, 901-905.
3. Sadiq, M. (1992). Toxic Metal Chemistry in Marine Environments. New York: Marcel Dekker.
4. Margeli, A.P., Theocharis, S.E., Giannakou, N.N., and Ghiconti, I.K. (1991). Heavy Metals in the Environment (1). Cadmium Induced Hepatotoxicity in Different Rat Strains. Edinburgh: CEP Consultants Limited.
5. Chapman, D. (1992). Water Quality Assessments. London: Chapman and Hall.
6. Netscape. (1996). Early Signs of Environmental Damage and Recovery. Netscape: World Wide Web.
7. Platt, A.E. (1996). Reversing the Course of Destruction. Netscape: World Wide Web.
8. Alloway, B.J., and Ayres, D.C. (1993). Chemical Properties of Environmental Pollution. Oxford: Alden Press.
9. Schuller, P.L., and Egan, H. (1976). Cadmium, Lead, Mercury and Methylmercury Compounds: A Review of Methods of Trace Analysis and Sampling with Special Reference to Food. Rome: Food and Agriculture Organization of the United Nations.
10. Nriagu, J.O., and Sprague, J.B. (1987). Cadmium in the Aquatic Environment. New York: Wiley-Interscience Publication.
11. Waite, T.D. (1984). Principles of Water Quality. Orlando: Academic Press.

12. World Health Organization. (1977). Environmental Health Criteria for Lead Printed in the United Kingdom.
13. Subcommittee on Zinc, and Committee on Medical Biologic Effects of Environmental Pollutants. (1991). Zinc. Baltimore: University Park Press.
14. Sadiq, M. (1993). Toxic Metal Chemistry in Marine Environments. New York: Marcel Dekker.
15. Webster, E.A., and Gadd, G.M. (1991). Heavy Metals in the Environment (II). Effects of Heavy Metals on Respiration of Marine Macroalgae. Edinburgh: CEP Consultants Limited.
16. Mance, G. (1987). Pollution Threat of Heavy Metals in Aquatic Environments. London and New York: Elsevier Applied Science.
17. Schumacher, M. Domingo, J.L., Llobet, and J.M., Corbella, J. (1995). Variations of Heavy Metals in Water, Sediments, and Biota from the Delta of Ebro River, Spain. Journal of Environmental Science Health, A3096, 1361-1372.
18. Texas Natural Resource Conservation Commission (1996). Texas Water Quality Monitoring Program. Houston: Texas Natural Resource Conservation Commission.
19. Sandhir, R., and Gill, K.D. (1993). Alterations in Calcium Homeostasis on Lead Exposure in Rat Synaptosomes. Molecular and Cellular Biochemistry, 131, 25-33.
20. Conrad, M.E., and Barton, J.C. (1978). Factors Affecting the Absorption and Excretion of Lead in the Rat. Gastroenterology, 74, 731-40.
21. Bernard, S.R. (1977). Dosimetric Data and Metabolic Model for Lead. Health Physics, 32, 44-6.
22. Meyer, W., Kretschmer, M., Hoffmann, and Harisch, G. (1991). Biochemical and Histochemical Observations on Effects of Low-Level Heavy Metal Load (Lead, Cadmium) in Different Organ Systems of the Freshwater Crayfish, *Astacus astacus* L. (Crustacea:Decapoda). Ecotoxicology and Environmental Safety, 21, 137-156.
23. Lee, C.W., and Kwon, Y.T. (1994). Distribution of Heavy Metals in Seawater, Sediment and Biota. Water Science Technology, 30, 173-177.

