Profiles of Selected Pollutants in Bayou Texar, Pensacola, FL

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FOREWORD

This study is a component of the "Assessment of Environmental Pollution and Community Health in Northwest Florida, " supported by a USEPA Cooperative Agreement award X-9745502 to The University of West Florida (Project Director: Dr. K. Ranga Rao). The contents of this report are solely the responsibility of the authors and do not necessarily represent the official views of the USEPA. The study was undertaken because of the increasing concern for environmental pollution and potential impacts on human health in Northwest Florida. It was designed to assess environmental impacts of toxic pollutants in Bayou Texar with an emphasis on possible superfund site impacts upon the bayou. Kristal Flanders managed the spatial databases for the project and drafted the maps. Her assistance has been invaluable. Alan Knowles, Jason Moore, Jeff Seebach, Kevin Bradley, and Tony DiGirolamo helped with the fieldwork and some laboratory procedures. We wish also to thank Michael Lewis, Ecosystem Assessment Branch of the US EPA Gulf Ecology Division for discussing some data from US EPA studies on Bayou Texar with us.

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ABBREVIATIONS and ACRONYMS

2378 TCDD - Tetrachlorodibenzo-p-dioxin

ACC - Agrico Chemical Company

APHA -American Public Health Association

ATSDR - Agency for Toxic Substances and Disease Registry

CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act

Cfs - Cubic feet per second

CFU - Colony forming units

CWA - Clean Water Act

DNAPL - Dense Non-Aqueous Phase Liquid

DNT - Dintrotoluene

DWS - Drinking water standard (used on maps)

ECHD - Florida Department of Health Escambia County Health Department

E. coli - Escherichia coli

ECUA - Emerald Coast Utilities Authority

ETC - Escambia Wood Treating Company

DGPS - Differential GPS

FDEP - Florida Department of Environmental Protection

FDEP MCL - Florida Department of Environmental Protection, Maximum Contaminant Level

FDOT - Florida Department of Transportation

FLAAS - Flame atomic absorption spectrometry

ECHD - Florida Department of Health Escambia County Health Department

GFAAS - Graphite furnace atomic absorption spectrometry

GIS - Geographical Information Systems

HAL - Health advisory level

HRL - Health reference level

HPLC - High Performance Liquid Chromatography

HDPE - High density polyethylene

IARC - The International Agency for Research on Cancer (IARC), part of the World Health Organization.

ICER - The Institute for Coastal and Estuarine Research at the University of West Florida

LDPE - Low density polyethylene

MPRSA - Marine Protection, Research and Sanctuaries Act

MCL - Maximum contaminant level

MPZ - Main producing zone of the aquifer

NPL - National Priorities List

OU 2 - Operable Unit Two

PAH - Polycyclic Aromatic Hydrocarbons or Polynuclear Aromatic Hydrocarbon

PEL - The probable effects level are concentrations above which adverse effects on biota are probable.

PERCH - Partnership for Environmental Research and Community Health

PCB - Polychlorinated biphenyls are a group of synthetic polychlorinated aromatic hydrocarbons.

pCi or picoCurie - One trillionth of a Curie; A unit of radioactivity which is equal to 3.7 x 1010 Bq (Becquerel)

PCP - Pentachlorophenol

ppb - Parts per billion (ppb or 1μg/L)

ppt - For salinity parts per thousand

P&A - Pensacola and Atlantic Railroad

PRP - Principal responsible party

r - Correlation coefficient, reflects the degree of linear relationship between two variables.

Ra - Radium

RCRA - Resource Conservation and Recovery Act

RI/FS - Remedial investigation/feasibility study

RO - Reverse osmosis

ROD - Record of Decision

RPM - Revolutions per minute

SIM - Selected ion monitor mode

SCL - Soil cleanup level

SO_4 - Sulfate ions

SVOC - Semivolatile organic compounds

TEL - Threshold effect level

TEQ - Dioxin toxic equivalents

TMDL - Total maximum daily loads

USACE - United States Army Corps of Engineers

USEPA - United States Environmental Protection Agency

USEPA TAL - Target analytes list for metals

USEPA TCL VOCs - Target compound list volatile organic compounds

EXECUTIVE SUMMARY

The PERCH (Partnership for Environmental Research and Community Health) Project on Bayou Texar was designed to answer community concerns relating to environmental health issues for Bayou Texar. The Bayou Texar/Carpenter's Creek system in Pensacola, FL, is adjacent to an aquifer impacted by Agrico Chemical Company, Escambia Wood Treating Company, and the Palafox Industrial Corridor. The bayou is subject to urban runoff along its entire length and numerous stormwater outfalls discharge into it. Pollutants affecting the water quality of the bayou, and the effect of water quality on bayou flora and fauna, have been the subject of numerous investigations. The State of Florida classifies Bayou Texar as suitable for recreational uses and as suitable for the propagation of fish and wildlife.

Human activities have likely adversely affected Bayou Texar from the time European settlers entered the area. Initially impacts would have been caused by land clearing for agricultural and logging activities. Residential and industrial development intensified the impacts during the 20th century. By the 1950's governmental entities within the State of Florida were aware that environmental problems existed in the Pensacola Bay System and its bayous. In the 1970's it was reported that nutrient loading and siltation were converting the bayou into a shallow eutrophic system unsuitable for recreational and aesthetic utilization. Numerous fish kills occurred in that period. More recently, efforts have been undertaken to reduce pollution and its adverse effects.

Review of the literature shows that the quality of the water and sediments in Bayou Texar has been and still is affected by an assortment of pollutants. The main contaminants of concern include fluoride, heavy metals, polycyclic aromatic hydrocarbons, sediments, nutrients, and bacteria. Pesticides have also been reported in Bayou Texar sediments.

The present study initially used existing data to examine the location and concentration of contaminants affecting water and sediment quality of the Bayou. The information was incorporated into a geographic information system (GIS) and was utilized in prioritizing research efforts based on perceived gaps in the existing information. Consequently, the present study examined fluoride and radium in bayou sediments, two forms of pollution previously not studied. The present study also included a bathymetric survey and a systematic study of the effect of sediment particle size on pollution, two efforts that other studies had not been focused on. The present study examined various types of pollution in Bayou Texar and in Carpenter's Creek in a systematic approach with consistent methods because previous data are sometimes hard to compare because of different methodological approaches. This study relies heavily on spatial patterns as an aid in data interpretation and, therefore, provides insights into the pollution issues of Bayou Texar/Carpenter's Creek that were hitherto not available.

Phase 1 of the fieldwork of this project took place from June 2003 to March 2004. It was intended to gather information on pollutants such as total petroleum, industrial polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), pesticides, and metals. Phase 2 of the project was carried out in the summer of 2004 and was a more specific effort to answer several questions that arose out of the results of Phase 1 and new concerns of the community about radium in groundwater. Phase 2 was completed before Hurricane Ivan made landfall in the area in September 2004.

For this project 32 vibracores with depths up to 5 m were collected. Forty-nine composite sediment samples were obtained throughout the Bayou with a ponar grab sampler. One-meter deep sediment cores were collected at 15 sites with a sludge sampler. At these 15 sites and 10 others water samples were collected with a Van Dorn sampler. To help identify optimal locations for the Phase 2 sampling sites, the bathymetry of the Bayou was surveyed with an echosounder and differential GPS.

Results of this project are consistent with earlier studies and indicate that fluoride from the groundwater plume under the bayou enters shallow sediments and porewater in the northern section of the bayou. The zone where the groundwater fluoride interacts with the bayou system is approximately in the same location as it was when last studied 10 years ago. Fluoride from the groundwater also seems to enter the water column of the bayou but the concentrations remain well below the Florida FDEP water cleanup target levels for fresh and marine surface water (10 mg/L and 5 mg/L, respectively).

Evidence suggests that radium is also entering the northern section of the bayou from the groundwater plume. The activity of radium in surface sediments and bayou water is higher in the northern section of the bayou than in other parts of the bayou/creek system, but in general the activity of radium is low (< 1.76 pCi/L for water; and < 5.00 pCi/g for sediment, except for one value of 7.97 pCi/g for surface sediment). The activities measured in water from Bayou Texar are an order of magnitude lower than in other water bodies in the nation that are still deemed to be safe for wildlife.

Concentrations of heavy metals in sediments are highest in the northern section of the bayou. The probable effects level (PEL) (concentrations above which adverse effects on biota are probable) is exceeded in the northern part of the bayou by lead, mercury, copper, and zinc. The PEL for lead and zinc is also locally exceeded in the midsection of the bayou. Arsenic and chromium concentrations vary throughout the bayou but remain below the PEL. Cadmium was reported only at three sites in the northern part of the bayou. Concentrations of thallium and antimony are below reportable levels. Concentrations for all metals are low south of the Cervantes Street Bridge.

Potential sources of metals in Bayou Texar include stormwater outfalls and non-point sources along the Bayou. A relatively large number of known outfalls are present along the western shore of the northern part of the bayou where metal concentrations are high. Diminished flushing of the Bayou by tidal currents may also explain the elevated metal concentrations in the northern part of the Bayou.

The concentrations of polycyclic aromatic hydrocarbons (PAHs) in surface sediments are highest in the northern section of the bayou, as was the case for other pollutants. Naphthalene was not detected in the sediment. It appears that the PAHs detected in sediments of Bayou Texar are primarily derived from surface sources including the combustion of petroleum and non-petroleum products as suggested by PAH ratios and to some extent from releases of petroleum products. More sensitive analytical methods were not utilized to test for PAHs in porewater as they are scheduled to be performed by other agencies.

The present study shows that elevated concentrations of most pollutants are present in surficial sediments only, and in the northern section of the bayou specifically. This suggests that not all clayey surficial sediments may have to be disposed of as hazardous waste if the bayou is dredged and that possibly only the most contaminated surficial sediment rather than a thick layer of sediment has to be disposed of at hazardous waste disposal sites. Further studies are needed to formulate disposal options.

Many pollutants, and metals in particular, are particle bound. They often enter the bayou system via sediments in stormwater. It is therefore advised that the recommendations of the multi-agency Citizens Task Force on Urban Stormwater Runoff continue to be implemented.

This project showed that Bayou Texar is affected by a variety of contaminants. The concentrations of various contaminants as sampled during this project are not generally elevated. Some heavy metals, however, occur in the northern section of the bayou in concentrations that are likely to adversely affect biota living in sediments. Soft sediments that extensively cover most of the bayou between the Cervantes Street and 12th Ave Bridges present the most serious impact to the bayou. These sediments do not provide a substrate suitable for many desirable organisms and communities and have an affinity for metals and other pollutants. They also are easily stirred up and suspended to block light transmission through increased turbidity. These aspects need to be considered in plans for clean up of contaminated sediment.

1. INTRODUCTION

Bayou Texar is a Gulf Coast estuary having Carpenter's Creek as its sole tributary and is part of the Pensacola Bay System. Bayou Texar is one of Pensacola's most important watersheds and recreational water bodies. It is the best known and most frequented bayou in Pensacola, and the scenic vistas that it offers are generally enjoyed by the public. Presently the primary human use of the bayou waters is the recreational use of watercraft. Water skiing and related sports are the most popular activities on the bayou waters with minimal amounts of fishing and swimming. Water skiing is an important activity on Bayou Texar with it having been the site of the U.S. Open Water Ski and Wakeboard Championships in 1998. An important city park provides a site for community recreation, and the entire length of the bayou is lined with residential yards and private boat docks. The environmental state of this body of water is of importance to the people of Pensacola. However, Bayou Texar has been manifesting obvious signs of environmental degradation for more than half a century. Fish kills, sewage spills, and increased turbidity were obvious indicators that raised public concerns. There have been many studies on Bayou Texar dealing with concerns and issues ranging from environmental to navigational. These studies have for the most part dealt with aspects of the same problem: transport of materials into the bayou is greater than removal of materials by tidal efflux. The bayou is filling in with sediment and associated pollutants, and high nutrient import has threatened the bayou with eutrophication.

Fecal and total coliforms have been important non-point pollution sources. Elevated counts of fecal coliform and Enterococcus bacteria released by sewage spills are of concern and periodically result in Department of Health advisories on recreational usage of the bayou. An assessment by the Florida Department of Health Escambia County Health Department (1995) states that Bayou Texar is affected by two USEPA Superfund sites, Agrico Chemical Company (ACC) and Escambia Wood Treating Company (ETC), via a plume of contaminated groundwater. Recently there have been civil suites against a PRP (Potentially Responsible Party) over pollution in the contaminated aquifer. The bayou is also subject to urban runoff along its entire length and numerous documented and undocumented stormwater outfalls discharge into the bayou/creek system. Factors affecting the water quality of the bayou and the effect of water quality on bayou flora and fauna have been the subject of a number of investigations. These studies include Hannah et al. (1973), Moshiri and Elawad (1990), Moshiri et al. (1978a; b; c; 1981), Cason (1978), Olinger et al. (1975), Pasko (2001), Stone and Morgan (1990a; b), and Wolfe et al. (1988).

In the present study we used existing data to profile the location and concentration of contaminants in water and sediment in the Bayou. The focus of our assessment was upon the presence of contaminant plumes in the aquifer originating from the two superfund sites. The existing information was incorporated into a geographic information system (GIS) and was utilized in prioritizing our research efforts. The initial phase of the project (Phase I) took place during the second half of 2003 and winter of 2004. It was intended to gather background information the full length of the bayou/creek system relative to releases of contaminants of concern such as total petroleum, Aroclor polychlorobiphenyls (PCB), dioxins, polycyclic aromatic hydrocarbons (PAH), organochlorine pesticides, pentachlorophenol (PCP), dinitrotoluenes (DNT), and metals. The second phase of the project (Phase II) was carried out in the summer of 2004 and was a more specific effort to answer several questions that arose out of the results of Phase I and new concerns of the community about radium in groundwater. There was also a need to relate the distribution of radium, fluoride, and metals to specific sediment grain sizes and location within the bayou system.

2. STUDY AREA

2.1 Description

Bayou Texar, a component of the Pensacola Bay System, is located in Pensacola, Escambia County, in the extreme western Panhandle of Florida (Map 1). Carpenter’s Creek drains into the extreme northern end of Bayou Texar. The bayou is approximately 6 kilometers long in a north south direction and its width varies from 30 meters in the south to 400 meters in its mid section and 40 meters in the north. The Bayou has a surface area of approximately 157 hectares. The maximum depth is reached in the narrow channel located in the southern section and is approximately 5 m deep. Stratification of the bayou's water column is common and a saltwater wedge can be detected up to the northern end of the bayou (Stone and Morgan, 1990a; b). Fresh water inputs come from Carpenter’s Creek in the north and overland flow along the banks of the bayou via stormwater outfalls, surface flow, and groundwater discharge. Saline waters enter the bayou from Pensacola Bay in the south. Bottom water salinity in past studies has been measured at a range of five to 20 parts per thousand (ppt). Surface salinities are highest downstream and decrease as one proceeds upstream (Hannah, 1972; Hannah et al., 1973). The bayou is flushed through tidal exchange with Pensacola Bay. Water movement in the bayou is affected by diurnal tides (one high tide and one low tide per day). Normal tidal range in the bayou averaged 42 cm in 1989 and seldom exceeded 60 cm, however strong winds can noticeably diminish or augment tidal effects (Stone and Morgan, 1990a; b).

The combined Carpenter's Creek/Bayou Texar watershed is approximately 4,452 hectares (17.2 mile^2) in size. The Bayou Texar basin comprises 55% of the total watershed and is about 2460 hectares (9.5 mile^2) in size (Dames & Moore, 2000). The land use in the drainage basin of the Bayou is predominantly residential and commercial. Heavy industrial activities are not present in the basin. Urban development in the basin, however, has been very rapid during the last 50 years. Currently, the banks of the bayou in most locales have lawns running to the water's edge and the bayou is impoverished in native terrestrial and aquatic vegetation. Many stormwater outfalls also enter the bayou. Carpenter’s Creek, Bayou Texar’s only surface tributary, flows for about 8 km upstream from Bayou Texar. The creek drains suburban neighborhoods to the north of downtown Pensacola and is located in the eastern portion of the City of Pensacola with its northernmost portion extending from the city into Escambia County (Map 1). There are still substantial undeveloped areas in the creek’s watershed. The Carpenter's Creek basin is about 1994 hectares (7.7 mile^2) in size and drains into the Creek through 24 identified City storm sewer systems, an unknown number of Escambia County or privately owned storm sewer systems, and direct surface runoff. The creek then discharges to the northern end of the bayou at 12th Avenue (Dames & Moore, 2000; Baskerville et al., 2003.)

The bayou lies in the coastal plain province, a major physiographic division of the United States. Geologically the region consists principally of unconsolidated sands, silts, and clays deposited before the shoreline of the continental mainland reached its present position. The drainage basin of the bayou is underlain in the north by soils that are sandy near the top but clayey at depth. In the south of the basin the soils are sandy throughout. The region has a humid, warm-temperate climate. Summers are long and warm, and winters are short and mild. The average summer temperature at Pensacola is slightly more than 26.7 C; the average winter temperature is 12.8 C. The annual rainfall is fairly high at nearly 157.5 cm (62 inches) on the average. Rainfall is well distributed throughout the year with a peak in July and August and often falls as heavy afternoon thunderstorms.

2.2 Clean Water Act Classification

Bayou Texar has been classified under the provision of the Clean Water Act as a Class III body of water by the State of Florida. The USEPA Watershed Assessment Tracking & Environmental Results System 2000 305(b) Lists/Assessment Unit Information obtained from the State of Florida classifies Bayou Texar as suitable for recreational uses and as suitable for the propagation of fish, shellfish, and wildlife. This system of classification is not based on the chemical composition or toxicity of the sediments.

3. ENVIRONMENTAL HISTORY OF BAYOU TEXAR

3.1 Pre 1900

Human activities have likely impacted Bayou Texar from the time that the first humans entered what are now Escambia and Santa Rosa counties. The impacts of the pre-European human activities upon the environment have not been assessed. Undocumented adverse impacts probably occurred upon arrival of European settlers due to initial land clearing for agricultural and logging activities. The Bayou Texar drainage area during the age of exploration has been under the dominion of the Spanish, French, and English colonial regimes prior to passing to control of the American government during the 19th century. Deforestation impacts in the 18th century by logging in the bayou/creek drainage are suggested by the construction of a saw mill by the British in 1767 on Carpenter's Creek (Pensacola Historical Society, 2004). Logs and lumber were presumably transported on bayou and creek waters either as rafts or in vessels. There was possibly some commercial shipping activity during the 19th century because during the 1880s there were 16 wharves over a 5 km stretch from Bayou Texar to Bayou Chico (Port of Pensacola, 2004).

3.2 20th Century

Extensive residential development and recreational impacts occurred during the 20th century. Problems in Bayou Texar were numerous and became increasingly pronounced over the past hundred years probably because of real estate development within the watershed. The continuing increasing population and related real estate development has resulted in greater transport of sediments via erosion into the bayou and creek. Sedimentation in Bayou Texar has been adversely affected by the construction of bridges and resulting alterations upon tidal flow and sediment transport. The railroad track right of way and bridge at the southern end of the bayou have been hypothesized to be a significant cause of sediment quality degradation in the bayou (Dames & Moore, 2000). The construction of the other bridges (12th Ave and Cervantes Street Bridges) may have magnified these sedimentary transport impacts. The 12th Ave Bridge appears to have contributed to the loss via sedimentation of an estimated 600 ft of bayou north of the bridge. This former portion of the bayou is now considered to be part of the creek (Cason, 1978).

By the 1950's governmental entities within the State of Florida were aware that environmental problems existed in the Pensacola Bay System and its bayous. Sustained historic degradation due to urban stormwater runoff and other non-point sources, as well as point sources, were identified in the Escambia and Pensacola Bay basins, including Bayou Chico, Bayou Texar, Mulatto Bayou, and tributaries such as Jones and Carpenter's Creek (Thorpe et al., 1997). Hannah et al. (1973) reported that nutrient loading and siltation were converting the bayou into a shallow eutrophic system unsuitable for recreational and aesthetic utilization.

Sediments in Bayou Texar were identified as being enriched from stormwater runoff and sewage contamination (Collard, 1991; Thorpe et al., 1997).

Bayou Texar's deteriorated state received increased attention during the period of the late 1960s and early 1970s because of the numerous fish kills that occurred in Bayou Texar. During the 1970s, Bayou Texar experienced significant eutrophication with resultant fish kills (Moshiri et al., 1981). In August and September 1972, 2 ¼ tons of fish were reported dying each day in Bayou Texar (Thorpe et al., 1997). Somewhat more recent figures for fish kills were provided by Al Garza, the City of Pensacola Public Works Director: in 1987 there were 64,000 lbs dead fish recovered, 1988 there is no data, 1989 was 60,100 lbs, 1990 was 103,540 lbs, 1991 was 160,340 lbs, 1992 was 151,160, and 1993 was only 140 lbs. These figures were for fish actually removed by City of Pensacola workers from the bayou. Dredging was carried out between 1993 and 1995.

Investigators attributed the observed eutrophication to sources of inorganic nutrients from excessive stormwater runoff from urbanization of the watershed, and to effluent from sewage lift stations (Hannah et al., 1973). There was also significant sediment loading contributing to siltation of the bayou during the 1970s and 1980s (Stone and Morgan, 1990a; b). According to Stone and Morgan (1990a; b), the leading causes of impacts were construction of roads and bridges, overloading of wastewater and treatment facilities, major alterations of the watershed, increasing stormwater runoff, and direct inputs coming from fertilizer applied to residential lawns.

The environmental health of Bayou Texar was likely severely impacted years in advance of the fish kills reported in 1970's and 80's. The occurrence of fish kills is not necessarily an absolute indicator of an environment degraded by pollution. Fish kills do occur in pristine environments due to environmental extremes such as: very low or high temperatures, anoxic conditions, high import of nutrients coupled with low dissolved oxygen. The fish kills commonly reported from the 1970's till the early 1990's are no longer commonplace. In an environmentally healthy system the fish populations will be expected to recover to pre-fish kill levels after a die off. The most highly degraded environments seldom have mass fish kills that may be for the simple reason that the low populations of vulnerable fishes available for die offs are not sufficiently numerous to participate in the events that precipitate a fish kill (Collard, 1991). We have not found any current source of information on fish populations for Bayou Texar. Recent field observations made during the present study observed mullet commonly jumping, and the presence of fishing birds including wading and swimming birds. This does indicate that there are fish populations, but does not prove in itself that the original species diversity and total populations originally present are now present or that there has been a satisfactory recovery.

3.3 Bathymetry and Sedimentation of the Bayou/Creek System

Prior to 1885 there was no development within the drainage basin of the bayou/creek system (Henningson et al., 1975). Accounts by older residents claim that in the 1920's porpoises from the Gulf of Mexico entered the Bayou Texar to feed on freshwater bass. There were shrimp populations that were sustained by "grass" growing everywhere on the bottom and that speckled trout, black snapper, mullet, and flounder were present. The water was said to be crystal clear. It is not possible to know with certainty what the conditions were 80 years ago, but with increased residential land use it is quite likely that conditions in the bayou deteriorated due to sedimentation. Starting in the 1950's real estate development noticeably accelerated. The largest single historic development of land in the bayou's watershed was for the municipal airport that in

1975 covered 660 acres. Other more recent large developments have included shopping malls and parks.

Sediment accumulation in the bayou in the past has necessitated dredging of the bayou for navigational purposes. The last major dredging of Bayou Texar took place in the 1990's and removed sediments from the region of the 12th Ave. Bridge to 200 yards to the south, and also from the narrow entrance channel by the bay. The decision to dredge was based upon findings by investigators at the ICER (The Institute for Coastal and Estuarine Research at the University of West Florida). A summary of this work on Bayou Texar completed in 1990 by Stone et al. (1990) advised dredging and states that between 1977 and 1988 approximately 171,000 m^3 of sediments accumulated in Bayou Texar giving a sedimentation rate of 15,550 m^3 annually. The calculated life expectancy of the bayou was two hundred years. During this same period both the entrance to the bayou south of the CSX railroad trestle and the section between the trestle and the Cervantes Street Bridge each accumulated about 12,500 m^3 or 7% of the total infill volume of the bayou. In order to extend the life expectancy of the bayou it will be necessary to resort to periodic dredging and to reduce the sediment input from Carpenter's Creek and from storm drains, road ends, and culverts. Stone et al. (1990) recommended that the bayou mouth be dredged to increase flushing efficiency and that a jetty be constructed to reduce introduction of new sediment from Pensacola Bay into its mouth. A jetty was constructed in 1991 and dredging occurred. Continuing sedimentation in the bayou was found to reducing the flushing potential of the system. Flushing is also significantly impeded beneath the CSX railroad trestle where a 25% reduction in cross sectional area has occurred between 1977 and 1990. The cross sectional area beneath the trestle is only 43% of the average cross sectional along the lower reach of the bayou. Construction beneath the trestle, when combined with very low tidal ranges, significantly increases the flushing time and reduces the volumetric exchange of water between the bayou and Pensacola Bay. During periods when bayou waters are warm, low in salinity and tidal exchange capacity conditions combine to invoke significant environmental stress on the bayou which may result in fish kills (Stone et al., 1990).

A major contention from the above conclusions for sediment accumulation in Bayou Texar has been the narrowness of the entrance channel and the presence of the railroad trestle that appears to have additionally impeded the movements of the tide into and out of the bayou. Sedimentation of the bayou is a natural process that is greatly accelerated by urban development. Would dredging and removing points of constriction reverse the process of sedimentation that is occurring in Bayou Texar? This question has been studied over the years by several investigators. The earliest report on bayou flushing that we encountered was that of Cason (1978). He did a historic review of basin changes for Bayou Texar based on U.S. Coast and Geodetic Maps dating from 1879, 1893, and 1901. The purpose was to verify if changes in the entrance channel of the bayou could be correlated with increased sedimentation and degradation of the bayou. In his review of these maps Cason (1978) found that the narrowness of the bayou's mouth existed prior to the construction of the railroad bridge over the bayou based on an 1879 map of the bayou's mouth. Cason (1978) suggests that, while narrowing of the channel may have been a factor in reducing flushing, it was development that resulted in bayou sedimentation. His conclusion was that the bayou was always constricted and therefore constriction was not the primary cause of bayou degradation. A more detailed examination of the historical record suggests that constriction of the channel observed in the 1879 map could be human made. A 1768 chart of Pensacola by Gauld, that Cason (1978) did not review, does not show for Bayou Texar the extreme degree of narrowing of the channel that it now exhibits where the railroad trestle bridge is located. The exact scale of this 1768 map can not be established, but the map strongly suggests the constriction at the mouth of the bayou was not always present. A bridge that is perhaps the current railroad bridge appears to have been constructed sometime between 1879 and 1893 across a narrow spit of land near the present mouth of the bayou, and may have lead Cason to believe the constriction at the mouth was natural. Historical records verify that a bridge may have been constructed at that time because they state that in 1882 the Pensacola and Atlantic Railroad (P&A) bridge was completed across Escambia Bay (Buckman, 2003). The P&A line to Chattahoochee was completed in August of that year finally giving Pensacola a rail route to the east. The 1893 maps show this line approaching Pensacola by following the present railroad line that crosses Bayou Texar. The year 1879 is not that far removed from 1882. It is possible that work around Bayou Texar was already in progress at the time the 1879 map was drawn and the observed narrowing could have been human made. The 1893 map also shows a bridge crossing in the vicinity of Cervantes Street. The 1893 map shows islands in the bayou in a pattern that is different from the single island shown in the 1768 Gauld chart and also from what appears today in aerial photos of the bayou. In any case the channel was constricted in 1879 and problems became apparent by or before the 1950's in association with development in the watershed and construction of bridges. Human made alterations of the channel have played a role in retaining sediments in the bayou, and without the increased sediment load from development the bayou would likely still be healthier.

What role dredging and sedimentation have played over the years on bayou/creek bathymetry is unknown. Dredging activities were carried out in the Pensacola region by the federal government in the 19th century with some of these activities extending to inland waters (Pearce, 1990). However, we have not encountered any specific reference to Bayou Texar for this period of time. Before the 1960's dredging was unregulated and some dredging activities may have gone unreported. Cason (1978) mentions that alteration of the bayou's bottom occurred when the former Cervantes Street Bridge was constructed and that the arm just south of the 12th Ave. bridge was enlarged sometime in the past. Significant changes in the bayou channel were observed to have occurred at the extreme northern end. The bayou appears to have in the recent past extended about 183 m (600 ft) north of where the 12th Ave bridge is with a water depth of five ft and an eight ft depth was present below the location of the 12th Ave bridge.

Evidence of increased erosion and sediment transport is present in changes that have occurred in Carpenter's Creek. The section of Carpenter's Creek between the bayou and 9th Ave was represented in older maps as being a discrete channel rather than the diffuse serpentine morphology that it exhibited in 1978, and also currently. Presently, portions of Carpenter's Creek between 9th Ave. and Davis Highway have been channalized by construction of stormwater structures. The area of the creek around Davis highway has been extensively engineered for flood control purposes. Prior to 1978 this part of the creek contained up to three feet of organic material on its bottom (Cason, 1978). Just above Davis Highway the creek has been dredged and widened and presently has a depth of 8 ft in that section. Some of the dredging activity probably occurred in the 1980's when houses were constructed on the bank. These houses are perched on pilings that appeared to have been built upon spoil placed upon the southern bank. Recently there has been new bridge construction over Davis Highway and the channel under the bridge is now filled with stone blocks. The spaces between the blocks have filled with sediment impeding the flow of the creek at this point. Residents state that the sediments are derived from runoff from ongoing construction of a stormwater structure on interstate I-110 which is just upstream, but this contention was not verified.

Cason (1978) postulated that the bayou in 1978 had greater water exchange with the bay than it did in the later part of the 19th century due to the 1969 dredging of a deepened navigation channel from the Cervantes Street Bridge to the bayou mouth. Raney (1980) analyzed tidal transport of sediments in Bayou Texar that included various alternatives that could augment tidal effect in Bayou Texar. The primary mechanism considered for improving water quality was to increase tidal flow by modification of the bayou's inlet and channel geometry. The base flow in Carpenter's Creek is small averaging 10-15 Cubic feet/second (cfs) limiting any significant flushing action of the bayou except during intense rain events. Dames & Moore (2000) state that two sets of data for creek flow give 18.5 and 28 cfs which is still an insufficient volume for flushing. At the bay the narrow restricted entrance to the bayou prevents much short period wave energy from entering the bayou from Pensacola Bay and the narrow meandering shape of the bayou restricts a buildup of wind wave action. Thus, in the absence of large rainfall events, the dominant mixing process in the bayou is tidal action. Direct tidal exchange between the bayou and bay occurs through the fairly restricted inlet. Tidal forces are relatively low and sediment which finds its way into the bayou tends to be deposited rather than being flushed from the bayou (Dames & Moore, 2000).

Raney (1980) stated that the most apparent problem associated with Bayou Texar from visual inspection was shoaling caused by sedimentation. The sedimentation takes place where surface water runoff enters the bayou from outfalls and the creek, and causes the formation of deltas. Raney (1980) in his work determined tidal ranges from three gauges: one in the bay near the bayou's mouth, a second gauge near Bayview Park, and a third gauge near the 12th Ave. Bridge. These gauges are no longer in place. Raney concluded that tidal force was not much diminished between the lower bayou and the upper reaches of the bayou. Tidal range was found to be diminished by an average of 1.2 cm from Pensacola Bay to the 12th Ave. Bridge. Raney's (1980) findings confirm visual observations made during the PERCH study of strong tidal influence in the upper bayou extending into what is now considered to be the lower part of the creek on the north side of the 12th Ave. Bridge. Raney (1980) made calculations for the existing geometry and for four alternative modifications that might increase tidal flow. Raney's (1980) conclusions based on modeling predicted that none of the alternative modifications would significantly alter tidal circulation north of the Cervantes Street Bridge. These calculations were based on the velocity needed to transport "sand-type sediment" that has been accumulating as deltas in front of outfalls and at the present mouth of the creek. What is not clear is the situation for the fine sediments that compose much of the bayou bottom. Raney's conclusion was to eliminate the transport of sediments to the bayou through improved stormwater management.

A more recent report (Dames & Moore, 2000) states that tidal transport could remove contaminated sediments from Bayou Texar. In the main channel south of the Cervantes Street Bridge the sediments are predominantly sand (Map 23) but tidal transport of fine sediment out to the bay that leaves coarser particles (sand) behind may not be the sole explanation for this. The tidal influx is also transporting sand into the bayou derived from the bottom of the Pensacola Bay System. There is no definitive data defining transport of fine particles other than that they are accumulating in the upper bayou away from the shoreline. These fine particles are the kinds of sediments that pollutants can bind to.

Dames & Moore (2000) considered 12 alternatives that would remediate the bayou sediments by either increased flushing of sediments or preventing sediments from entering the bayou. Dames & Moore (2000) applied estuarine modeling programs to study Bayou Texar tidal flushing. After an initial screening process five alternatives were selected for analyses. These programs were applied to the five screened alternatives and it was calculated that two of the alternatives would be most effective. Just removal of the railroad trestle was not a favored alternative. However, it would appear that at least one of these alternatives would involve dredging the channel as it passes under the railroad trestle possibly affecting this bridge during dredging. Past dredging of the bayou has seen the dredgers approaching the bridge with caution and only removing a minimal of sediment underneath the bridge. Currently plans to replace the bridge are being considered. If these plans are approved, spans between the new support columns will be more than twice what is spanned over the channel at present. This may increase options to widen or modify the channel under the bridge. However, projects to modify the channel under the bridge would have to consider channel geometry upstream and downstream of the bridge.

The two feasible alternatives both involved dredging portions of the bayou south of the Cervantes Street Bridge (Dames & Moore, 2000). The first alternative would involve straightening and improving almost 1 km along the entrance channel between the mouth of the bayou and the island area south of the Cervantes Street Bridge. The other feasible alternative is to improve the channel from the Cervantes Street Bridge to the island of which half would be removed by dredging. The maximum change in tidal volume is 4.2% and 30% contaminant removal for alternative 1, and changes of 2.5% and 33%, respectively, for alternative 2. An even better remediative result was predicted by combining both alternatives (Dames & Moore, 2000).

These two alternatives applied together would make the lower bayou more efficient in allowing tidal current to move accumulated sediments. Straightening, deepening, and widening a waterway to facilitate flow is a well established practice (Dames & Moore, 2000), however, provide little information that describes the details of results they expect from changed tidal influx. There are many questions that have not been answered regarding the effects of transportation of sediments from the hot zone to the lower bayou and then to the bay. The environmental effects need to be assessed as to what would happen to habitat in the southern regions of the bayou. The Dames & Moore (2000) study did not address the effects of bay sediments being flushed into the bayou and how long it would be prior to the lower channel silting up again after dredging. Prior to any decisions the modeling process needs to be reviewed. The only verified data that Dames & Moore (2000) possessed to input into the program would be bathymetric data, tidal heights, and particles size derived from 10 sample cores taken in the bayou. Information on actual particle movement in the bayou is crucial to evaluate remediation alternatives, but is currently not available. It is certainly possible that the predicted tidal flows are correct, but the overriding question is what velocities applied over what period of time are needed to effectively transport fine and coarse sediments from the bayou to the bay.

4. Current Public Works Activities

4.2.1 Sediments

Presently the City of Pensacola has no plans to dredge in the bayou north of the Cervantes Street Bridge but does plan to do some maintenance of the channel and shore of the bayou south of the Cervantes Street Bridge. A project to stabilize the shore of the channel at the mouth of Bayou Texar is to be reopened to bidding. When it was last bid the low bid was $365,000 and there was only $170,000 budgeted. More funding has since been secured. Hardening of the west shore for construction of a parking lot, the 17th Ave boat ramp, and other related structures have altered currents in the area resulting in an eddying of water flow such that there has been erosion on the east shore near the trestle and buildup of a spit projecting from the east. The spit has to be periodically removed or it will constrict the channel. In 2006-2007 there is a planned maintenance of the existing entrance channel from about 300 m south of the railroad trestle to the Cervantes Street Bridge. No other dredging is being planned.

It is commonly recognized that erosion and transport of sediments into the bayou can be improved by modern stormwater management systems that include treatment of stormwater prior to its release into the bayou. The governing responsibilities for the drainage basin of the bayou/creek system are multi-jurisdictional involving the City of Pensacola, Florida Department of Transportation (FDOT), and Escambia County. The City of Pensacola boundaries enclose the largest area that includes all of the Bayou watershed and large portions of the creek watershed. Approximately 40% of the creek watershed is located in the eastern portion of the City of Pensacola with the remaining portion being outside of the city. Most of the remaining area is the responsibility of Escambia County, Florida, with the exception of some portions associated with state-maintained highways and interstates. The state maintained roadways are under the jurisdiction of the FDOT. Carpenter’s Creek is of great importance and the erosion and presumably stormwater effects are greater for the Carpenter’s Creek than for Bayou Texar due largely to the impact of ongoing activities related to construction of new housing and highways.

Sediment originating from erosion in the drainage basin primarily enters the bayou/creek system via stormwater transport with some portion also entering from wave action on the bayou shoreline and streambed erosion in the creek. The importance of stormwater import of sediments into the bayou/creek has been recognized by the City of Pensacola and Escambia County Governments. Previously stormwater controls were mainly intended to stop flooding and control erosion. The most important feature of a long-term remediative plan for the bayou/creek system must include a major reduction of sediment import into the system. Existing stormwater structures must be retrofitted to adequately treat the runoff so sediments and other materials are removed. Stormwater plans have been formulated for the Bayou/Creek System and substantial work has already been accomplished for the bayou (Garza, 2004). For Bayou Texar to date the most important activities have been retrofit of existing stormwater systems with designed changes that remove most of the solids from the stormwater before it enters the bayou.

4.2.2 Stormwater

Local governments have made a strong commitment towards lessening the impact of stormwater on area waters. A Citizens Task Force on Urban Stormwater Runoff was created as a joint undertaking and cooperative effort among the Escambia County Commissioners, the City of Pensacola, and the Escambia County Utilities Authority. The Task Force formulated 10 priority areas of concern and recommended action be taken in these areas: The priority areas of concern are:

1. Funding: they have established a dedicated revenue source
2. Retrofit, fix existing problems
3. Pave Dirt Roads
4. Accountability: define responsible agencies
5. Education and Training
6. Direct Discharge: untreated discharges to be stopped
7. Runoff Treatment, treat stormwater before discharge
8. Street Sweeping
9. Worst Pollutants: start with largest discharges
10. Buffer Zones: protect existing waterways

These priority areas of concern are consistent with the findings of the present project, and if addressed appropriately would help improve the environmental quality of Bayou Texar. Actions to address these areas of concern are already being taken by local governments and it is recommended that the actions be continued in the Bayou Texar/Carpenter's Creek watershed on a long term basis. On October 24, 2000 the Pensacola City Council adopted the top 10 priority areas of concern as Stormwater Management Strategies. Stormwater utility fees or other dedicated funding sources have been identified and utilized to retrofit existing stormwater discharges. The average annual pollutant loads (basin wide) that would cause or contribute to violations of state water quality standards are to be reduced by 50% by the year 2012 and by 80% by the year 2020 with the goal of restoring each water body to its designated use. The City of Pensacola will coordinate with other local governments to discuss and develop any additional uniform, minimum, stormwater protection standards that may be required to ensure compliance with future TMDL regulations. Wet detention ponds with gently sloping littoral shelves, planted with native emergent vegetation for nutrient uptake, shall be encouraged where soil conditions and topography are suitable. Street sweeping will also continue. There will be a 4 week cycle for street sweeping within the Bayou Texar basin and a 6 week cycle throughout the balance of the city (Garza, 2004).

Escambia County has a "Carpenter's Creek/Bayou Texar Watershed - Water Quality Enhancement Management Plan" and is requesting funding through an FDEP Application for Water Project Funding (Kirschenfeld, 2005). The county is justifying this request in part because Carpenter's Creek Watershed is ranked as the highest priority watershed of the 41 watersheds in Escambia County for stormwater quality and quantity problems by the County's priority ranking matrix. The long-term goals of Escambia County Management Plan are to reduce stormwater runoff pollutants into Carpenter's Creek and enhance the overall water quality of the Carpenter's Creek/Bayou Texar System. The short-term goals are to compliment the City of Pensacola's projects by implementing stormwater treatment enhancement projects that provide treatment mechanisms for untreated drainage areas within the county limits of the watershed. These projects will provide stormwater treatment for approximately 141.6 developed hectares of land that currently discharge directly to Carpenter's Creek without any treatment mechanisms.

4.2.3 Shore Erosion

Field observations during the present study show that hardened structures are used in Bayou Texar to prevent wave erosion. These structures often transfer or deflect the energy of waves and currents resulting in erosion somewhere else. Planting of emergent vegetation is a remedial methodology to prevent erosion, loss of shoreline, and provide habitat for biota that could be implemented in Bayou Texar. The present study encourages this because planting of emergent vegetation is often successful in preventing shoreline erosion (Broome, 1981). The vegetation dissipates wave energy rather than directing it elsewhere and has the additional benefits of providing habitat for animal communities and of trapping fine sediment that often carries pollutants. Planting of emergent vegetation has to be done with some understanding of sedimentation, and misapplication could be detrimental to the bayou. For example, the growing sand spit below the railroad trestle that is constricting the channel should not be planted. The locations of all planting sites should be examined in reference to bayou flushing and sedimentation.

5. NATIONAL PRIORITIES LIST SITES

5.1 Public Perception of Superfund Site Impacts

A Superfund site is an area contaminated by hazardous substances that pose a threat to human health and the environment, where USEPA's Superfund program either funds the cleanup of the site, works with the state to clean up the site, or oversees cleanup by those responsible for the contamination. USEPA lists the hazardous waste sites that have priority for cleanup on its National Priorities List (NPL). Bayou Texar is approximately 2 km east of two Superfund Sites and other areas along Palafox Street where heavy industrial activities took place. These Superfund sites, and the Palafox corridor in general, have impacted the regional groundwater (Sand and Gravel Aquifer). There are no producing wells in this impacted region of the aquifer, but in adjacent areas this aquifer supplies drinking water for Escambia and Santa Rosa Counties. Emerald Coast Utilities Authority (ECUA) drinking water wells in the area have been closed due to pollution. Hydrological models and monitoring well data strongly suggest that groundwater originating at the two Superfund Sites is presently transporting contaminants towards the bayou where discharge of the contaminated ground water probably occurs (Map 2). The Pensacola News Journal has informed the local population about environmental and health threats to the bayou from the contaminated aquifer. The owners of the ACC site have been successfully sued over aquifer contamination by a local law firm and other legal activities are ongoing. In 1999 and 2004 locally convened grand juries investigated the environmental situation in Pensacola that included Bayou Texar (Special Grand Jury, 1999; 2004).

5.2 ACC and ETC National Priorities List Sites

Agrico Chemical Site Background: The ACC site located at 4400 Bayou Avenue in Pensacola includes about 14.2 hectares of flat land. A company that produced sulfuric acid from pyrite (iron sulfide) began operating at the site in 1889. Fertilizer was produced at the site since 1920 by several different companies, including Agrico Chemical Company which purchased the facility in 1972 and continued operations until 1975. Industrial wastewater was discharged to low-lying areas and ponded areas throughout the history of site operations. There were also significant releases of lead. Many if not all of the areas that received waste water discharge or disposed solids were not lined resulting in transport of contaminants into the underlying aquifer. A common misconception about the ACC is that only inorganic releases occurred. There also appears to have been release of dinitrotoluene (DNT) from contaminated sulfuric acid (Geraghty and Miller, 1992 &1993).

In 1989, USEPA listed the site on the National Priorities List (NPL). Conoco Inc. and Freeport McMoRan, Inc., the potentially responsible parties, entered into an Administrative Order on Consent in 1989 with USEPA. The September 1992 Record of Decision (ROD) for soil contamination in Operable Unit I was to excavate and consolidate impacted soils above 1,463 mg/kg of fluoride from three areas of the site into one landfill. Soils and sludge contaminated with lead above 780 mg/kg were to be excavated, solidified/stabilized, and consolidated into a landfill protected by a slurry wall with multimedia cover system. Groundwater quality monitoring, access, and deed restrictions were also included. This cleanup was started in March 1995 and was completed in the fall of 1997. The remedial action for contaminated groundwater in Operable Unit II was selected in a subsequent ROD in August 1994. This decision was to allow the ground water pollution to attenuate with the passage of time along with monitoring of the ground water. The remedy for Operable Unit II was implemented in the fall of 1999. The selected remedial action includes monitoring the deep and shallow zones of the Sand and Gravel aquifer for approximately 70 years to check natural attenuation; monitoring Bayou Texar surface water; installing two additional monitoring wells adjacent to the bayou; conducting a door-to-door irrigation well survey; instituting on-site deed restrictions and groundwater use restrictions; and requesting that private land owners allow the plugging and abandonment of impacted irrigation wells. In addition, this alternative utilizes an extensive groundwater monitoring plan for the Sand and Gravel Aquifer. If the ACC plume threatens nearby municipal water supply wells, a contingency remedy will be used that consists of water supply well replacement or wellhead treatment with filtration, reverse osmosis (RO) with RO reject evaporation pond, off-site disposal of RO reject sludge from pond; on-site deed restrictions, groundwater use restrictions; and groundwater monitoring. A Five Year Review of the Soil and Groundwater remedy was conducted by the U.S. Army Corps of Engineers and the final report that was tentatively scheduled for release in September 2004 has not yet been released to the public.

Escambia Wood Treating Company Site: The ETC site operated as a wood treating facility from 1942 to 1982. The facility is located in a mixed industrial and residential area of the City of Pensacola, Escambia County, Florida. During its operational period, the facility treated utility poles, foundation pilings, and lumber with creosote and pentachlorophenol (PCP). Facility operations resulted in extensive creosote, PCP, and dioxin contamination in soil and groundwater. To address the immediate threat posed by contamination at the site, USEPA initiated an extensive removal action at ETC in 1991, and completed the action in 1992. A 3.7 m (12 ft) fence to restrict unauthorized access was installed and approximately 194,960 m^3 (255,000 y^3) of contaminated soil was excavated and stockpiled under a geomembrane liner designed to last about 10 years. The liner consists of a layer of low density polyethylene (LDPE) sandwiched between two layers of high density polyethylene (HDPE) with a combined thickness of 60 mils. The HDPE provides UV and chemical resistance while the LDPE allows for stretching of the liner to prevent tearing. The stockpile itself sits on a 20-mil thick bottom liner, a portion of which is on concrete. Two large excavated areas, approximately 12.19 m (40 ft) deep remain adjacent to the stockpiled material. Several buildings were demolished as part of the USEPA removal effort. Concrete displaced as part of the removal effort was stockpiled in an unused area of the site, or adjacent to removal areas. Finally, prefabricated steel sheet piling was driven 16.76 m (55 ft) into the earth to shore the walls of the northeast pit excavation area. Removal activities also consisted of installation of a storm water runoff system for the soil stockpile, site storm water trenches, and erosion control measures (CDM Federal, 2000). The issues of the excavation pits and the soil stockpile have not been resolved. USEPA is still conducting the remedial investigation/feasibility study (RI/FS) portion of the superfund cleanup process for Operable Unit Two (OU 2) and has initiated a Phase III of the Remedial Investigation. (CDM Federal, 2003) to better define the PAH plume in the aquifer and to determine if it has crossed under the bayou.

6. CONTAMINANTS OF CONCERN, LITERATURE REVIEW

6.1 Sediments

Excessive sedimentation, primarily from stormwater, is an important environmental issue in Bayou Texar. On the basis of field observations sediments were stated to be accumulating in Bayou Texar at a rate of approximately 15,550 m^3 per year (Stone et al., 1991). The sediments deposited during the course of storm runoff from urban environments contain metals and nutrients (Liebens, 2001). Even when the sediments do not contain hazardous pollutants, they are not necessarily benign. In Collard's (1991) review he postulated that the sediments in the Pensacola Bay System may no longer be suitable for the support of the fauna and flora that originally thrived in the Pensacola Bay System and in Bayou Texar. This statement is based on considerations of grain size, chemical constituents, and oxygen demand of sediments that could have a profound effect on the quality of all benthic habitats, including those of microbes, seagrasses, invertebrates, and fishes.

By the 1950's it was recognized that sedimentation appeared to have been the major culprit in the Bayou's deterioration as suggested in a 1955 report (Murdock, 1955). In this report Murdock remarked, "New roads and development of the whole Pensacola area is resulting in a much greater drainage into the waters than formerly. This drainage brings with it sediments which are covering the bottom, particularly in such areas as Texar Bayou". Hannah et al. (1973) reported that nutrient loading and siltation was converting the bayou into a shallow eutrophic system unfit for recreational and aesthetic purposes. Without dredging Bayou Texar was predicted to have a ''life expectancy'' of approximately 200 years due to accumulating sediments (Stone et al., 1991). Between October 1994 and February 1995 approximately 22,800 m^3 of fluvially transported sediment were removed from the northern end of the Bayou (Lewis et al., 2001a). The city of Pensacola also dredged the channel of the lower end of the bayou and installed a jetty at the bayou's mouth to prevent sand deposition from blocking the channel. Spoils dredged from the lower portion of the bayou were placed upon the east bank just north of the bayou's mouth. At least some of the spoils from previous dredging activities appear to have been disposed in the lower creek and lower bayou onto spoil islands.

Sediment remediation and the complexity of studying sediment and related water quality issues in Bayou Texar are very challenging to city and county governments due to budgetary constraints and real estate development. Dames & Moore (2000) cite that the first bayou study and remedial plan in the 1940s was accepted but not implemented. The most recent sedimentation study of the bayou (Dames & Moore, 2000) proposed several remedies. Their Phase IV: Long-Term Bayou Dredging included five projects that were designed to develop the necessary infrastructure for operating the dredging program and an additional five projects for the actual dredging in five segments of Bayou Texar. Expected costs for Phase IV were as follows:

- Testing and Permitting $524,500
- Infrastructure Construction $13,874,500
- 5-Phase dredging Program $242,966,000
- Projected Total Cost: $257,365,000

Complete remediation may not be implementable. This alternative would completely dredge the bayou and dispose of the spoils.

6.2 Nutrients

Carpenter Creek has been identified as the primary source of ammonia, nitrate nitrogen and orthophosphates in the Bayou (Stone et al., 1990). Water column concentrations were observed to decrease southward, and nitrate plus nitrite concentrations decrease from surface to bottom. Nitrite and orthophosphate concentrations were highest during spring and lowest during summer and winter. Nitrate plus nitrite concentrations were not affected significantly by season. However, a significant portion of the water pollutants likely originate in the bayou's own watershed since 55% of surface water entering the bayou comes from bayou stormwater outfalls and direct runoff to the bayou. The influences of tidal effects such as dilution from tidal influx must also be considered (Dames & Moore, 2000).

6.3 Fluoride

Hydrological models and monitoring well data strongly suggest that ground water originating at ACC and ETC is presently transporting contaminants towards the bayou where discharge of the contaminated groundwater occurs. Surface water that originates at the ACC and ETC sites does not flow as stormwater over land to the bayou but does move towards Bayou Texar upon entering the aquifer (Geraghty and Miller, 1990, 1991, 1992, 1993; CDM Federal, 2000, 2002).

High fluoride concentrations occur in the main producing zone (MPZ) of the aquifer just west of Bayou Texar (Geraghty and Miller, 1990, 1991; URS, 2003). In test wells the MPZ fluoride concentration is above the USEPA National Primary Drinking Water Standard MCL of 4 mg/L. In 2002 one well (AC-35D) on the western shore of the Bayou reached a fluoride concentration of 170 mg/L. This well also has elevated zinc, copper and naphthalene concentrations (CDM Federal, 2002). From the analytical data for the monitoring wells a fluoride groundwater plume, emanating from the ACC site, was identified in the MPZ of the sand and gravel aquifer to the west of Bayou Texar (Geraghty and Miller, 1990; 1991). The plume widens to a northern and southern branch (Map 2) as it extends away from the ACC site. The horizontal extent of the plume extends from the west towards the bayou. A key question is whether the fluoride is flowing under the bayou towards the east. Analyzed samples taken during the 1990's from a monitoring well screened in the MPZ on the east side of the bayou did not detect fluoride. However, more recent monitoring data from this well is needed to see if any fluoride has since been transported under the bayou towards the east.

Fluoride was detected in porewater from sediment cores from the northern part of Bayou Texar (ENTRIX, 1993). The porewater in most sediment cores had low fluoride values and fluoride decreased with depth. A local surface input of fluoride was suggested for most of the bayou by ENTRIX (1993). Four cores near the edge of the northern branch of the horizontal extent of the fluoride groundwater plume showed elevated levels of porewater fluoride. The highest levels observed are two orders of magnitude higher than the Florida FDEP Maximum Contaminant Level for drinking water, which is 4 mg/L. Higher fluoride values were present in the deepest sample than in the shallowest sample of each core but total depths varied between cores. The increase in fluoride was not gradual and not consistent in magnitude between cores. According to ENTRIX (1993), this suggests a groundwater origin for the fluoride which, most likely, comes from the fluoride plume detected in the monitoring wells. The presence of a freshwater, i.e. groundwater, source under the Bayou is supported by decreasing chloride concentrations with depth (ENTRIX, 1993). Three of the cores with elevated fluoride levels are located in the channel; one is just east of the channel. ENTRIX (1993) did not take any core samples near the southern branch of the horizontal extent of the fluoride plume.

6.4 Radium

Radium (Ra) is a naturally occurring radioactive element that is present in varying amounts in rocks and soil within the earth's crust. Small quantities of radium derived from these sources can also be found in groundwater supplies and is found commonly in ground water of the Sand and Gravel aquifer in southern Escambia County, Florida (Emerald Coast Utilities Authority, 2003). Radium can be present in several forms (isotopes). The isotopes of concern are

Ra-226 and Ra-228. Ra-226 is commonly encountered around sites where production of phosphate fertilizer occurred that contain significant levels of uranium 238. The decay formation of radium-226 and radium-228 can be represented as uranium 238 decaying through a series of daughters to become Ra 226 and for thorium- 232 to decay via daughter radium-228.

Phosphate ore is enriched in naturally occurring uranium-238 and its decay series progeny. Compared to typical soils and rocks it is elevated in content of radium, polonium, and lead. Phosphogypsum composed of hydrated calcium sulfate is formed as a byproduct during the manufacture of phosphoric acid from phosphate ore by the phosphate fertilizer industry. For example, central Florida phosphogypsum contains about 25 pCi/g of radium while background soil levels of radium would contain only about 1 to 2 pCi/g. The most "visible" contaminants in phosphogypsum are the naturally-occurring radionuclides of the uranium decay series -notably radium-226 and its decay product - gaseous radon-222. Radium-228 is not an expected byproduct from fertilizer production (Florida Institute of Phosphate Research, 1993).

Radium in water may pose a hazard to human health when the water is used for drinking. Ingested radium is absorbed from the digestive tract and distributed throughout the body. Some absorbed radium is excreted in urine. The remaining radium behaves similarly to calcium and is deposited in the tissues of the body, especially bone. The radiation received externally through showering, washing, or other uses of radium containing water from natural sources is insignificant since the skin blocks the alpha and beta radiation that pose the greatest health risks when ingested. Internally deposited radium emits radiation that may damage tissues. Studies of workers exposed to high levels of radium for extended periods show that high levels of radium may cause depression of the immune system, anemia, cataracts, fractured teeth, and some types of cancer. Based upon our current knowledge, it is assumed that any radiation exposure from any source carries some degree of risk. The U.S. Environmental Protection Agency has established a maximum contaminant level (MCL) for radium in public water supplies of 5 pCi/L. Water containing elevated levels of radium may carry a correspondingly higher level of risk to health. The USEPA calculates the cancer mortality risk to a member of the general public from a lifetime intake of radium in drinking water at an MCL that limits the increased lifetime cancer risk to less than 2 in 10,000 (USEPA, 2004a). In the case of radium, by virtue of the high cost of compliance with a lower level and the minimal public health benefits to be gained by going lower, the USEPA chose to retain the combined radium MCL of 5 pCi/L. Under scenarios where radium is not ingested USEPA sets the cleanup guidelines at 5 pCi/g for surface terrestrial soils where gamma radiation assumes greater importance due to its ability to penetrate the body.

A number of methods are available to public water supplies to remove radium from water. Ion exchange, lime softening, and reverse osmosis are the most common and can remove up to 90% of the radium present. Ion exchange (i.e., water softeners) and reverse osmosis units are also available for home installation and can often remove 90% of the radium present along with hardness removal (Illinois Department of Health, 2005). The ECUA has also included the blending of water with high radioactivity with water of lesser radioactivity to meet USEPA and FDEP guidelines (Grand Jury, 2004).

Radium activity in the ACC fluoride groundwater plume was tracked in monitoring wells between 1992 and 2002 (Maps 3a - c) by URS (2003). Some wells were tested for radium for the first time in only 1997 or 1999. All mapped wells were screened in the main producing zone (MPZ). In the well nearest to the ACC site (well AC-2D) the radium level decreased irregularly from 9.8 to 3.1 pCi/L between 1992 and 2002, in the next nearest well (AC-3D) the radium level decreased only slightly (20.8 to 19.1 pCi/L) in the same period (Table 1). In the other wells the radium activity increased irregularly between 1992 or 1997, whichever was the first date tested, and 2002 (Maps 3a - 3c). A similar spatial pattern was observed for fluoride in monitoring wells (see above). Many of the levels exceed the USEPA and FDEP Maximum Contaminant Level (MCL) of 5 pCi/L, including in several wells just west of the bayou. The aquifer in this contaminated area presently contains no producing wells for drinking water (Grand Jury, 2004).

6.5 Semivolatile Compounds

6.5.1 Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons are composed of two or more aromatic (benzene) rings. PAHs may be divided into two groups, depending upon their mass: low-molecular-weight PAHs, containing three or fewer aromatic rings, and high-molecular-weight PAHs, containing more than three aromatic rings. There are more than 100 different PAH compounds. Presently there are only sediment guidelines for a small number of the PAH species that commonly occur in the environment. Aromatics (including PAHs) are considered to be the most acutely toxic component of petroleum products, and are also associated with chronic and carcinogenic effects. Sixteen of the common PAHs typically analyzed in standard contract laboratory scans have been listed by the Environmental Protection Agency among 129 priority pollutants. Five of them are also listed among the 25 hazardous substances thought to pose the most significant potential threat to human health at Superfund Sites (Van Mouwerik et al., 1997).

In principle, PAHs can enter Bayou Texar via groundwater discharge from the aquifer into the sediments, via stormwater, air deposition from forest fires and vehicle exhaust, and petroleum product spills directly into the bayou. PAHs tend to partition from water into sediments at ratios based on their molecular weight. Larger PAHs (3-5 rings) transported into the sediments of the bayou and creek by stormwater would tend to partition preferentially into sediments with relatively small concentrations of PAHs showing up in water due to their lower solubilities. After a spill on the ground the heavier PAHs upon entering an aquifer sink to the bottom of the aquifer to form Dense Non-Aqueous Phase Liquid (DNAPL). The lighter PAHs may float on water. They also tend to be more soluble such as naphthalene and enter the water column and then evaporate to the atmosphere or be transformed to alkyl forms (Van Mouwerik et al., 1997).

In the present study the focus upon PAHs in bayou/creek sediments was due to the nearby presence of the ETC Superfund Site that had in the past released PAHs of creosote and diesel origin to the environment along with dioxins and PCPs. Creosote produced from coal tars was dissolved in heated diesel and used under pressure to treat wood. Naphthalene, a PAH detected at the ETC site, is present in a plume located between the ETC and Bayou Texar (CDM Federal, 2002). Data from CDM Federal (2002) show that concentrations of naphthalene in this groundwater plume are an order of magnitude above the USEPA health reference level (HRL=140 µg/L) and two orders of magnitude above the USEPA health advisory level (HAL=20 µg/L). One well (NWD-4D) near the bayou has a naphthalene concentration of 1600 µg/L. CDM Federal (2000, 2002) modeled this plume, but its extent and precise location is controversial. In a reassessment of the data Dohms (2002) presented a different model. In both models the eastern horizontal extent of the plume is adjacent to the northern end of Bayou Texar and to Carpenter’s Creek just before it enters the Bayou (Map 2). Vertically, the plume is about 22.86 m (75 ft) below the bottom of the Bayou. The possible contribution of the groundwater plumes transport to PAHs in the bayou is not understood. Previous studies of the bayou sampled for PAHs only in surficial sediments. Analytical data collected in the bayou by USEPA and

NOAA personnel in the 1990's indicated elevated levels of PAH's in surface sediments (Lewis et al., 2001b; DeBusk et al., 2002). More recently Baskerville et al. (2003) and CDM Federal (2000) collected cores and surface sediment samples in Carpenter's Creek and also found PAHs to be present in the sediments. There is no knowledge of the presence or distribution of PAHs in deep sediments that would be expected to be impacted by discharge of groundwater containing PAHs.

6.5.2 Dinitrotoluene (DNT)

DNT, a nitroaromatic, is analyzed by GC-MS in the 8270 analysis along with the semivolatiles. There is presently no federal regulation under the Safe Drinking Water Act for 2,4-dinitrotoluene (Cas 121-14-2) and 2,6-dinitrotoluene (Cas 606-20-2) (USEPA, 2004b). Both isomers are known to cause cancer in laboratory animals. These substances have been found in at least 69 (2,4-DNT) and 53 (2,6-DNT) of the 1,467 National Priorities List sites identified by the USEPA. Workers who have been exposed to 2,4-DNT showed a higher than normal death rate from heart disease (ATSDR, 1999). The 2,4- and 2,6-DNT may also affect the nervous system and the blood of exposed workers. In animal studies, both 2,4- and 2,6-DNT caused liver cancer in rats. There are no studies on the effects of 2,4- and 2,6-DNT on people. The international Agency for Research on Cancer (IARC) has determined that 2,4- and 2,6-DNT are possible human carcinogens. However, exposure to high levels may affect the nervous system and the blood (ATSDR, 1998b).

6.5.3 Organochlorine Contaminants of Concern

Pentachlorophenol (PCP) is a manufactured chemical that does not occur naturally. The technical grade PCP that was routinely used at ETC is more toxic than pure PCP due to by-products produced during its manufacturing. By-product contaminants of PCP synthesis include various dioxins and furans. Technical grade PCP is the form that humans are most often exposed to. PCP was widely used as a pesticide and wood preservative. Since 1984, the purchase and use of PCP has been restricted to certified applicators. It is no longer available to the general public. It is still used industrially as a wood preservative for utility poles, railroad ties, and wharf pilings. PCP can be found in the air, water, and soil. It enters the environment through evaporation from treated wood surfaces, industrial spills, and disposal at uncontrolled hazardous waste sites. PCP is broken down by sunlight, other chemicals, and microorganisms to other chemicals within a couple of days to months (ATSDR, 2001). PCP has been found at a concentration of 5 μg/L in one monitoring well near Bayou Texar (CDM Federal, 2002), which is above the drinking water MCL.

Studies in workers show that exposure to high levels of PCP can cause the cells in the body to produce excess heat. When this occurs, a person may experience a very high fever, profuse sweating, and difficulty breathing. The body temperature can increase to dangerous levels, causing injury to various organs and tissues, and even death. Liver effects and damage to the immune system have also been observed in humans exposed to high levels of PCP for a long time. Some of the harmful effects of PCP are caused by the other chemicals present in technical grade PCP. The USEPA has determined that PCP is a probable human carcinogen and the International Agency for Cancer Research (IARC) considers it a possible human carcinogen. In drinking water the USEPA and FDEP MCL has been set at 1 part per billion (ppb or 1μg/L) (ATSDR, 2004; CDM Federal, 2002).

6.6 Dioxins

Dioxins are ubiquitously present as environmental contaminants. They are very stable against chemical and microbiological degradation and therefore persistent in the environment. They are fat-soluble and thus tend to bioaccumulate in tissue lipid and in the food chain. These factors increase their potential hazards to humans and animals. The major sources of dioxins are combustion processes, such as waste incineration and metal smelting and refining. However, recent studies have revealed a major problem at localized spots, due to the production and use of pentachlorophenol (PCP) at wood treating sites. In the most contaminated regions the concentration of dioxins in soil and sediments appears to be extremely high. An unpredictable source are old transformers and capacitors, each of which may contain several kilograms of PCBs and hundreds of milligrams of dioxins. Paper mills in the past produced dioxins (mainly 2,3,7,8-TCDD) during the chlorine bleaching process used by pulp and paper mills (ATSDR, 1998a). Food is the major source for human exposure to dioxins, especially fatty foods: dairy products (butter, cheese, and fatty milk), meat, eggs, and fish. Some subgroups within the society (e.g., nursing babies and people consuming large quantities of dairy products and fish) may be highly exposed to these compounds and are thus at greater risk.

Dioxins bring about a wide spectrum of biochemical and toxic effects in experimental animals. These effects depend on species, strain, gender, age and tissue. For the most part, the mechanisms of the impacts are still obscure. The fate of these chlorinated compounds in the body is unusual. Because they are fat-soluble and practically not at all water-soluble, they cannot be excreted in urine. Moreover, our body is not able to metabolize them. The excretion is so slow that their so called half-life is many years, which means that it takes years for the human body to get rid of 50 % of the compound. Because dioxins are mixtures, every compound has a different half-life, but as a rule of thumb one can say that an average half-life is ten years. This long half-life makes them highly cumulative compounds, i.e., they accumulate in the body over the decades even at a low exposure.

In humans, a wide variety of health effects have been linked to high exposure to dioxins, including mood alterations, reduced cognitive performance, diabetes, changes in white blood cells, dental defects, endometriosis, decreased male/female ratio of births and decreased testosterone and in neonates elevated thyroxin levels. Presently the effects have been proven only in the case of chloracne (skin disease with severe acne-like pimples). The effect that has caused the greatest public concern is cancer, and International Agency for Research on Cancer recently classified dioxin as a human carcinogen. Another concern in the society is the possible developmental effects.

6.6.1 Dioxins at ETC

In 1991 the USEPA sampled the groundwater, soil and air at the ETC site and found that soil and groundwater were contaminated with PAHs, PCP, and dioxins/furans (CDM Federal, 2002). The USEPA determined that removal of the contaminated soil was necessary to prevent further contamination of the groundwater. In October 1991, USEPA's Environmental Response Team began excavating contaminated soil and stockpiling it on-site under a secure high density polyethylene liner. The USEPA completed excavation work and secured the site in early 1992. Although exposure to contaminants in air and soil are also a concern at this site, USEPA determined that groundwater contamination alone was a sufficient potential public health threat that cleanup of the site would be necessary. As a result, USEPA proposed this site in August 1994 for inclusion in the National Priorities List (NPL) of Superfund sites (CDM Federal, 2002).

Thirty-two monitoring wells were installed during the Phase 1& 2 of the Source Soil Remedial Investigation for ETC under and around the perimeter of the site (CDM Federal, 2002). Sampling was conducted in 1996 and 1997 for dioxins and furans. Four of the wells tested positive for dioxin 2378 TCDD (tetrachlorodibenzo-p-dioxin) TEQ (dioxin toxic equivalents) with the highest value being 0.00087 ng/L. This concentration is well below the USEPA and FDEP MCL for dioxin of 0.03 ng/L for potable water. Apparently there has been no groundwater testing for dioxin in monitoring wells near Bayou Texar. PCP was detected at low quantities in monitoring well NWD-4D (CDM Federal, 2002), about 400 m northwest of the northern end of Bayou Texar, leaving open the possibility that dioxin may also be present in the well since it is an impurity that occurs during the manufacture of PCP and spills of technical grade PCP also contain dioxin/furans.

6.7 Polychlorinated Biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) are a family of 209 chemical compounds (known as congeners) for which there are no known natural sources. PCBs generally occur as mixtures of congeners; the most common commercial mixtures are called Aroclors. Aroclor names reflect the percent chlorine (by weight) of the mixture (e.g., Aroclor 1242 is 42% chlorine by weight), with the more chlorinated mixtures generally being the most persistent and toxic. PCBs are among the most stable organic compounds known. They are toxic and accumulate in animal tissues. Even though PCBs are no longer commercially produced in the United States, high levels of the chemicals remain in poultry and fish in various parts of the country. PCBs are highly soluble in lipids and are known to biomagnify in upper trophic levels. Congeners with higher chlorine contents tend to bioaccumulate the most and, depending on structure, metabolize the least. The toxicity is influenced by the presence or absence of chlorines ortho to the phenyl ring. Since congeners tend to bioaccumulate and biomagnify, evaluations of potential adverse effects to ecological receptors are generally focused on upper trophic level organisms. Because of the persistence of PCBs in environmental media, analyzing the presence and concentration of PCBs is important in conducting ecological risk assessments.

The data from previous studies of the bayou surface waters are in the Pensacola Bay System GIS Database (DeBusk et al., 2002). Lewis et al. (2001b) and Lewis (unpublished) analyzed selected short lists of the 209 PCB congeners but the lists were not identical. The majority of the total PCB concentrations did not exceed the FDEP sediments guidelines of 21.6 μg/kg and none exceeded the PEL of 189 μg/kg. Out of 16 total PCB samples 7 were above the TEL and none were above the PEL. Lewis (2001b) reported that for 12 sediment samples 75% of the samples were above the method detection limits for PCBs with the mean for total PCBs being 28.1 μg/g.

6.8 Pesticides

Organochlorine pesticides are man-made organic chemicals that are extremely persistent in the environment and in the human body. In recent years there has been a marked increase in concern over the presence of organochlorine pesticides in the environment and in our food supply. Organochlorine pesticides are toxic, chlorinated, hydrophobic compounds whose residues tend to bioconcentrate and bioaccumulate in wildlife. The organochlorines are pesticides that contain carbon (thus organo-), hydrogen, and chlorine. They are also known by other names: chlorinated hydrocarbons, chlorinated organics, chlorinated insecticides, and chlorinated synthetics. The oldest group of the organochlorines is the diphenyl aliphatics, which includes

DDT, DDD, dicofol, ethylan, chlorobenzilate, and methoxychlor. DDT was the first that was used on a large scale in the U.S. DDT is probably the best known and most notorious chemical of the 20th century. More than 4 billion pounds of DDT were used throughout the world, beginning in 1940, and in the U.S. ending essentially in 1973, when the USEPA canceled all uses. The remaining developed countries rapidly followed suit.

Lewis et al. (2001b) found that in surface waters the concentrations of most chlorinated pesticides were below the corresponding method detection limits. These compounds are not very soluble in water and have an affinity for sediment particles, which may explain the low levels encountered by Lewis et al. (2001b). Diazinon and atrazine were the more commonly detected pesticides, usually during the spring months. Diazinon concentrations averaged 0.06 µg/L in Bayou Texar. Atrazine concentrations averaged 0.21µg/L. A study of water from Carpenter’s Creek showed the presence of low concentrations of the Atrazine at 1.0 µg/L and Simazine at 0.051 µg/L (Butts, 1996). Atrazine is a commonly applied herbicide and Simazine is an active ingredient in aquarium algicides.

Organochlorine pesticides including Mirex have been detected in Bayou sediments by studies conducted by NOAA and USEPA (DeBusk et al., 2002; Lewis et al., 2001b). Some of the values were above the PEL for DDT and its degradation products. The FDEP TEL and PEL respectively for DDT and its breakdown products for µg/kg dry wt. are: p,p'-DDT, 1.19, 4.77; p,p'-DDD, 1.22, 7.81; and p,p'-DDE, 2.07, 374.

6.9 Heavy Metals

Heavy metal concentrations in monitoring wells between Bayou Texar and the Palafox corridor vary greatly spatially and in their divergence from the MCL's (CDM Federal, 2002). Barium was detected in all tested wells but at levels well below the MCL (Map 4). The highest barium concentrations occur in wells near the mouth of Carpenter’s Creek. Cadmium was detected in only three wells and had concentrations relatively close to the MCL (Map 5). Lead concentrations are highest near the ETC site and in one case exceed the MCL (Map 6). No high lead concentrations were found in water near the hot zone in the bayou where lead concentrations in sediments exceed the PEL. Copper concentrations remain below the MCL but are highest in the southern tier of wells (Map 7). Chromium concentrations are generally low or not detectable but approach and exceed the MCL in three wells near the northern part of the Bayou and the mouth of Carpenter’s Creek (Map 8). Zinc concentrations in monitoring wells are also highest near the bayou and in the southern tier of wells in general (Map 9). A MCL is not available for zinc but the Florida secondary drinking water standard is 5000 µg/L. This standard is not exceeded by any well. Zinc and copper concentrations for one well on the shore of the Bayou are much higher than in other wells.

At the end of the 1980's water column metals in Bayou Texar showed no temporal variation with the exception of manganese which was highest during spring and summer and lowest during the winter (Stone et al., 1990). In the early 1990's cadmium, copper and nickel in bayou water exceeded national chronic water quality criteria (Lewis et al., 2001b). In the same study cadmium, copper, lead and zinc in sediments were found to exceed their PEL. Carpenter’s Creek, stormwater outfalls, and recreational boating activities were suggested as contributors to the metal input to the Bayou (Lewis et al., 2001b).

6.10 Bacteria

Epidemiological studies of marine and fresh water bathing beaches have established a direct relationship between the density of *Enterococci* and *Escherichia coli* (E. coli) in water and the occurrence of swimming-associated gastroenteritis. Recognition of this relationship has led to the development of criteria that is used to establish recreational water standards. The Florida Department of Health Escambia County Health Department (ECHD) has monitored fecal coliform and *Enterococcus* counts on a monthly basis at multiple sites for Bayou Texar and Carpenter's Creek. Potential sources of bacterial contamination for the Bayou Texar/Carpenter's Creek are stormwater outfalls, septic tanks, sewers, and animals (water fowl, wild mammals, and domestic animals). In the past observers have blamed ECUA for releases from the lift stations and from aging sewer lines (Hannah, et al, 1973; Henningson et al., 1975). During heavy rainfall water may enter through the joints of older sewer pipes and overwhelm the pumps of a lift station resulting in release of raw sewage.

The bacteria counts obtained by the ECHD were analyzed statistically to determine whether they are influenced by precipitation (Florida Department of Health Escambia County Health Department, unpublished report). The analysis showed that the amount of rain has a statistically significant effect ($p < 0.01$) on the bacteria levels. The results for Bayou Texar and Carpenter's Creek were very similar. Rainfall amounts exceeding 0.75 inches were found to result in enterococci levels that exceed USEPA's recommended limit of 35 CFU/100 ml for marine water. Bacteria levels exceed the USEPA's limit of 35 CFU/100 ml for Enterococci regardless of the amount of rain in Carpenter's Creek. Personnel from ECHD used 61 CFU/100ml as an interim working guideline when the unpublished report was being drafted. Rainfall exceeding 1.50" is associated with geometric mean counts that exceed this limit in Bayou Texar. This limit is also exceeded in Carpenter's Creek regardless of the amount of rainfall. The geometric means for the Enterococci levels in Bayou Texar do not exceed the limit of 35 CFU/100 ml for any particular month. The geometric means for the enterococci level in Carpenter's Creek all exceed the limit of 35 CFU/100 ml for every month. Fecal coliform were highest in the months of July and August for Bayou Texar, and in June, July and August for Carpenter's Creek (Florida Department of Health Escambia County Health Department, unpublished report).

7. OBJECTIVES

This project was designed to contribute in the following areas:

- Compile all accessible information related to pollution of Bayou Texar/Carpenter's Creek and identify data gaps;
- Assess the impact of two superfund sites to water and sediment quality in Bayou Texar and indirectly to potentially exposed human populations;
- Characterize the pollution of water and sediments in Bayou Texar;
- Assess the relative contribution of potential sources of pollution;
- Establish relationships between pollution and sediment characteristics;
- Assess the sediments relative to dredging activities and disposal of the spoils.

8. METHODS

Accessible information was compiled through an exhaustive literature search. For this effort we drew in part upon another component of the PERCH Project, the construction of the PERCH Bibliography, a fully searchable database of bibliographical materials pertaining to the environment of Northwest Florida (http://fusionmx.lib.uwf.edu/perch/search.cfm). A GIS database of the spatially referenced data was constructed by manually entering and digitally importing the data and by converting them to common spatial parameters. The purpose of the data compilation was to assess what was known about Bayou Texar, how it was or might be impacted by superfund sites and other sources, and how the present project could further that knowledge.

Unlike most previous studies, the present study examined Bayou Texar and Carpenter's Creek as one system because they are intricately linked via the inflow that the creek provides to the bayou. Recently the ECHD has conducted studies of temperature, pH, salinity, DO, *Enterococcus*, fecal coliforms, BOD, NOx, total phosphate, and precipitation that included stations in the entire creek. These studies are very important to assessing acute health hazards to the community, pinpointing sources of fecal contamination, and nutrient levels. However, such studies are not directed towards detecting import of chemical pollutants or assessing their concentrations in the sediments.

To help identify optimal locations for the sampling sites the bathymetry of the Bayou was surveyed with an echosounder and differential GPS (DGPS). Because we worked only when weather conditions were very favorable and minimal wave action was present on the bayou we did not use a heave compensator to correct for vertical vessel movement. Depth and coordinates were collected for 9365 points and stored in the field by the DGPS receiver's data recorder. Accuracy of the echosounder in the given circumstances was 0.06 m as per the manufacturer's specifications (Odom, 2000). The accuracy of the DGPS based on our previous work in the area was 0.5 m (Liebens, 2000). The echosounder was calibrated each day with a bar check, and tide information was recorded at the beginning and end of each day. The tide information was used to post hoc correct the raw echosounder readings for tidal changes. In a GIS the corrected echosounder readings were converted into a bathymetric surface using kriging and a cell size of 15 m for the surface. Optimal sampling locations were identified by project personnel based on the bathymetry of the bayou, the general location within the bayou, and specific objectives of the sampling. These locations were marked on an overlay on the bathymetric map in the GIS. A GPS receiver connected to a laptop with the maps displayed in the GIS was used to navigate to the sampling locations.

The sampling was divided into two phases, roughly coinciding with the 2003 and 2004 calendar years. Appendix 4 shows photographs of Phase I sampling sites. A total of 32 vibracores were collected during the two phases of the project. Initially they were used to search for possible intrusion of PAHs and fluoride from contaminated ground water. Three-inch decontaminated aluminum thin walled irrigation pipe was clamped to a vibracore powered by a generator. The vibracore sediment was retained by a plastic core catcher at the bottom and a vacuum plug sealed the top upon retrieval of the coring pipe. Rinsate blanks were taken for quality control. Only decontaminated equipment was used for sampling. Coring sites were located near the pollution hotspot identified in the literature, near the southern lobe of the fluoride groundwater plume where a potential local increase in pollution had not been examined, and in the mid and lower sections of the Bayou to obtain reference data from presumably less polluted areas. In Phase 2 some cores were located in the channel and some in shallower areas because upwelling of fresh and potentially polluted groundwater may be affected by the bathymetry and because particle size, which has been shown to affect various types of pollutants in many occasions, also varies with the bathymetry. In the lab the cores were split lengthwise and the sediments were sampled in Phase 1 at irregular intervals for total fluoride, radium, metals, and semivolatiles (Most of these cores were sampled at the surface (0-30 cm), B = middle (B 56-86 cm), C= bottom (142-173 cm) of core). In Phase 2 the cores were sampled at 1m intervals for porewater fluoride, radium, and particle size analysis.

Porewater for fluoride analysis was extracted from the sediments by centrifugation modified from ENTRIX (1993). In this method approximately 190 g wet weight of sediment plus 30 ml of water were placed in a 250 gram centrifuge bottle and spun at 9900 RPM for 16 minutes. The resulting supernatant was removed and placed into sampling containers by careful pipetting. The centrifuge was maintained at 20 C and pipetting was conducted at 23 C. Samples were stored at 0-4 C prior to analyses.

Fluoride analysis of aqueous samples was by USEPA Drinking Water Method Fluoride 340.2 (Potentiometric, Ion Selective Electrode) and sediments by Fluoride (340.2-EXT). Salinity was by American Public Health Association (APHA), method 2520B and pH was by USEPA Drinking Water Method (150.1). Radium isotopes 226 & 228 in water were analyzed by USEPA Drinking Water Methods approved for radionuclides, Ra-226 was analyzed by 903.0 and Ra-228 by 904.0. For radium in sediments these same methods were employed with approved USEPA modification as Ra-226 by 903.0 Mod. and Ra-228 by 904 Mod. Total petroleum was analyzed by the FDEP FL-PRO method. The following methods are from USEPA SW-846 methods: industrial polychlorinated biphenyls (Aroclor PCBs) were analyzed by Method 8082, PAHs and other semivolatiles by Method 8270C, and organochlorine pesticides were analyzed with Method 8081A. Mercury was determined by Method 7471A for cold vapor atomic absorption. For all other metal determinations the samples were prepared according to SW-846 Method 6010B, Acid Digestion of Sediments, Sludges, and Soils. Per the method, arsenic, cadmium, chromium, and lead were prepared for graphite furnace atomic absorption spectrometry (GFAAS). The other metals were prepared for flame atomic absorption spectrometry (FLAAS). The digestates were analyzed according to Standard Method 3111 for FLAAS or USEPA Method 200.9 for GFAAS.

Forty-nine composite sediment samples were collected throughout the bayou with a ponar grab sampler in deep water or a spoon in shallow water. Typically in deep water the canoe was anchored and samples taken in separated grabs as the canoe drifted about the anchor. Five local grab samples were joined at each sampling site and mixed thoroughly prior to sampling. In Phase 1 the composite samples were placed into sampling containers and sent to the analytical laboratory for mercury, lead, copper, chromium, organochlorine pesticides, total petroleum, aroclor PCB, and semivolatiles analyses. In Phase 2 the samples were split into aliquots for radium, metal, and particle size analysis. Sampling equipment was cleaned with soapy water, rinsed with reagent grade solvents, and two rinses of HPLC grade water. The decontaminated equipment was tested with rinsate blanks and field splits for quality control were taken. Other analysis were done as described above.

In Phase 1 nine water grabs were collected for total radium, fluoride, pH, and salinity measurements. In Phase 2 bayou water was sampled near the bottom and co-located shallow (1 m) sediment cores were collected at 15 sites. Water samples were collected with a Van Dorn sampler and sediment cores were obtained with an in-house modified 1 m sludge sampler (sampled at 0-30 and 60-90 cm). The sites were located in shallow areas and in the channel throughout the Bayou but with a slightly higher density at the pollution hot zone in the northern part of the Bayou. Salinity of the bayou bottom water was measured in the field with a YSI

Model 85 multiparameter meter. In the lab, porewater was extracted from the sediments with the centrifugation technique described above. Bayou water and porewater were analyzed for fluoride, and sediments for particle size. Samples for metal analysis from Phase 1 were analyzed for copper, chromium, lead and mercury. Considering the results of Phase 1, Phase 2 metal samples were analyzed for antimony, arsenic, cadmium, copper, lead, thallium, mercury and zinc. Methods were as explained above.

Samples for particle size analysis were collected in dedicated containers in the field from the ponar grab and sludge sampler samples and in lab from the vibracores. The samples were manually mixed and homogenized in the lab while being air dried. Samples were manually crushed with a mortar and pestle to break up aggregates. Analyses were then performed by dry, Ro-tap, sieving for the sand fractions (2 mm - 0.063 mm) and by the pipette method for clays (procedure 3A1 of Soil Survey Staff (1992). We preferred to use the pipette method over the often employed hydrometer method because the pipette method is generally considered to be more accurate.

Chemical analysis were performed by Severn Trent Laboratories, Pensacola, FL, and radium activity counting was carried out at Severn Trent Laboratories, St. Louis, MO. Particle size analyses were performed at the sediments lab, Department of Environmental Studies, University of West Florida.

9. RESULTS AND DISCUSSION

9.1 Gaps in existing data

Available reports, journal articles and of the constructed GIS database were utilized to evaluate bayou/creek data and assess this information for data gaps. The earlier studies on Bayou Texar were primarily directed towards levels of oxygen, nutrients, floral and faunal communities, and sedimentation (Hannah et al., 1973; Moshiri and Elawad, 1990; Moshiri and Crumpton, 1978; Moshiri et al., 1978a; b; c; 1981; Cason, 1978; Olinger et al., 1975; Pasko, 2001; Stone and Morgan,1990a; b; and Wolfe et al., 1988). In the 1990's there were several studies of metals, PAHs, PCBs, pesticides, other compounds, and sedimentation in Bayou Texar (Moshiri and Elewad, 1990; Stone and Morgan, 1990a; b; Stone et al., 1990; 1991; 1993; and 1994). With the exception of the metals all of these studies were for surface grabs. The vibracore studies for the metals were restricted to specific locations in Bayou Texar with no sampling in Carpenter's Creek. The following data gaps were noted:

1. There was no updated bathymetric map of the bayou after the dredging in the 1990's.
2. There was little or no information for metals or organic pollutants in Carpenter's Creek.
3. The studies of sampling in Bayou Texar for organics were for surface samples only.
4. No studies of the origin of sediment PAHs.
5. There were some studies using vibracores for metals in specific locales within Bayou Texar, but data gaps remained for large regions of the bayou.
6. Fluoride in porewater levels were known for part of the bayou, but no data were available for sediment fluoride content or for porewaters in the remainder of the bayou.
7. Fluoride levels were not known in bayou and creek waters.
8. There was no radiological data for radium.

9. There was no systematic investigation to determine what effects if any the superfund sites could exert over the bayou. Fluoride was shown to be entering the bayou at one point, but there was no research effort directed towards organic constituents in the groundwater plumes flowing eastward from the superfund sites.
10. Almost all existing data was about 10 or more years old.

The research that PERCH carried out during this study was intended to obtain data to fill in these gaps.

9.2 Bathymetry

The bathymetric map shows that in general the bayou deepens from the north to the south (Map 10). The deepest spots (about 5 m deep) are located by the Cervantes Street bridge and in the channel between the bridge and Pensacola Bay. These deep spots most likely result from natural scour in the narrow channel and structure induced scour around the bridge pilings. In the mid section of the bayou the bathymetry reflects the meandering pattern of the channel which is usually located on the outside of the bends. The depth is less than 2 m in the northern section of the bayou but deepens to just over 3 m by the 12th Avenue bridge where Carpenter's Creek enters the bayou. At the north and south end of the bayou shallow dead arms are present. The relatively shallow depths in these dead arms are probably due to the absence of significant water flow and erosion. Locally along the banks the effect of outfalls on the bathymetry is evident as shallow deltas. The locations of the sampling sites were selected based on this bathymetric map and a priori knowledge (Maps 11 - 15, Table 2). To our knowledge, no other study has methodically considered the detailed bathymetry of the whole bayou to locate sampling sites.

9.3 Fluoride in Porewater

The first indication that polluted groundwater enters Bayou Texar was shown by locally high and downward-increasing fluoride concentrations in sediment porewater (ENTRIX, 1993). The increases were not gradual and not consistent in depth and magnitude between cores. In fact, when fluoride concentrations for three consistent depths are examined a downward increase is not apparent (Map 16). The observed increases in fluoride occurred in deep cores that reached a tan sand layer in the northern part of the bayou. Our results for porewater show that fluoride concentrations at all sampled depths (up to 3 meters) are low for the middle and lower section of the Bayou. Only in the northern part of the bayou are elevated levels observed (Map 17). The highest porewater fluoride level is observed in core TC-4 (112.7 mg/L, Table 3). The concentrations in this core and one auger sample (A-9) are comparable to the concentrations in the monitoring wells near the bayou (Table 3, Table 4, Map 18). All other fluoride concentration for porewater are much below those for the monitoring wells, most likely due to mixing with meteoric water.

Fluoride concentrations in porewater generally do not increase with depth but in three cores in the northern part of the bayou they do (TC-3, TC-4, TC-5). One of these three cores (TC-5) is deeper than all other cores and extends slightly over 5 m down. In that core the porewater fluoride concentration increases an order of magnitude between 3 m and 4 m depth. The increase coincides with a transition from a clayey to sandy sediment. In the two other cores (TC-3, TC-4) porewater fluoride increases between 2 and 3 m depth (Map 19). The increase takes place again at a transition from clayey to sandy sediments. Of the nine cores without an increase with depth in porewater fluoride only three reach the tan sand layer. However, the correlation between porewater fluoride and sand content in all our samples is not strong enough (r=0.5 for % sand and logF) to statistically demonstrate an effect of sediment particle size on porewater fluoride. Cores TC-4 and TC-5 are about 25 m from ENTRIX cores that had relatively low fluoride concentrations that did not increase with depth (cores 3A, 3C). TC-5 is deeper than the nearby ENTRIX core 3A and extends into sand, which can explain the different results for these two cores. However, core TC-4 is not deeper than the nearby ENTRIX core 3C and both reach the tan sand layer. This suggests that local variations in porewater fluoride are large. Both ENTRIX (1993) and the current study had three cores with relatively high and downward-increasing porewater fluoride concentrations in the northern part of the bayou. The three ENTRIX cores and 2 of the three current study's cores are located in the channel of the bayou and all cores in the channel between TC-3 in the south and TC-4/TC-5 in the north have an increase with depth of porewater fluoride. The bottoms of these cores do not systematically reach a greater depth than the bottoms of cores without a downward increasing trend. This indicates that the depth of the deepest sample does not affect results.

Our data are consistent with ENTRIX's contention that a source of freshwater containing elevated concentrations of fluoride affects porewaters in part of the northern section of the bayou. We will call this area the hot zone in the remainder of this report (Map 20). Our data also show that the fluoride concentrations at the hot zone greatly vary horizontally and vertically. Other deep-seated sources of fluoride are not likely to exist. Perhaps it could be argued that in the past some fluoride might have entered the bayou from stormwater transporting fertilizer or a release from industry and that these layers were buried by subsequent sedimentation. However, for fluoride to persist in porewater a continual input would be required since fluoride is a highly diffusible ion under aqueous conditions.

Because there was more than 10 years between the ENTRIX study (1993) and our project, we examined if the hot zone as identified by ENTRIX had changed in size. Our cores TC-5 and TC-4 are located between an ENTRIX core to the south that is part of the hot zone and ENTRIX cores to the north that are not part of the hot zone (Map 20). Our two cores therefore better define the extent of the hot zone near its northern edge but do not necessarily point to an expansion of the hot zone as our cores were not collected at the exact same location as the ENTRIX cores. Our core TC-3 is just south of the hot zone, as defined by ENTRIX, and has an increase in porewater fluoride at depth. It is about 100 m south of ENTRIX core 9B which also had a fluoride increase with depth but is surrounded by ENTRIX cores that do not show an increase with depth. This means, again, that our core better defines the extent of the hot zone but does not necessarily point to an expansion of the zone to the south. Results from our cores taken farther away from the hot zone show that a major expansion of the zone did not occur since ENTRIX’s study.

9.4 Fluoride in Sediments

The literature review showed that although fluoride had been studied in porewater no other study examined fluoride in sediments of the Bayou. Therefore, depth profiles of total fluoride concentrations in sediments were studied throughout the Bayou in both phases of the project. Total fluoride concentrations at all levels are generally low (Table 3, Table 5), except at the hot zone where concentrations are higher (Maps 21, 21’). One observed fluoride concentration in a surface sample at the hot zone (C6, Table 5) is higher than the Florida FDEP soil cleanup target level for residential areas (840 mg/kg) but far below the soil cleanup target level for commercial and industrial areas (130,000 mg/kg). These soil cleanup target levels do not apply to the aquatic sediments of Bayou Texar, they are only provided to put the observed concentrations in perspective. In depth profiles, the highest total fluoride concentrations are generally found near the water/sediment interface (Maps 21, 21’, 22). In one 2003 sample (TM2) the highest concentration was found in the deepest level at 2.10 m and in one 2004 sample (TC-4) the highest concentration was found at 1m depth. These two sites are located in the hot zone, and thus the downward-increasing trend of total fluoride at these two sites is consistent with findings for porewater fluoride. However, the downward increase in total fluoride in these cores also coincides with marked increases in clay content, and fluoride has been shown elsewhere to interact with clay (Bower and Hatcher, 1967; Flühler et al., 1982). Consequently, the downward-increasing trend of total fluoride at these two sites in the hot zone is consistent with but does not unequivocally support the contention that a localized fluoride source exists at depth. The higher fluoride concentrations near the surface of the sediment, as compared to deeper layers, are not related to a high clay content of the surface layer (Maps 21, 22, 23, 24). In fact, in Bayou Texar there is an inverse relationship between clay content in surface sediments and total fluoride concentration (r=-0.65). This suggests that the higher fluoride concentrations near the surface of the sediments, as compared to deeper levels, may be due to input of fluoride via the water column. The fluoride may enter the water at the hot zone, spread throughout the bayou by water movement and then enter the surface of the sediments. Alternatively, the fluoride may originate from marine water entering the bayou from the bay or from other sources. Other potential sources are aerial deposition from coal burning power plants and industrial activities that produce HF or fluoroethene. In principle the fluoride may also enter the sediments from below and accumulate near the surface due to immobilization in a different biogeochemical environment. Resolving the question of the origin of fluoride in surface sediments requires further study. Although interesting from a scientific perspective such study may be hard to justify from an environmental perspective considering the generally low levels of fluoride in the bayou.

9.5 Fluoride in Bayou Bottom Water

For any given section of the bayou, both fluoride and salinity of bayou bottomwater are higher for measurements made during Phase 1 than for Phase 2 (Table 4, Table 6). This difference is most likely due to differences in tides and tidal currents at the time the water samples were taken. For each phase, salinity decreases irregularly from the mouth of the Bayou in the south to its headwaters in the north as expected. Fluoride levels are naturally higher in saltwater than in freshwater, and thus can be expected to follow salinity trends in the absence of external sources of fluoride (Turekian, 1968). In Bayou Texar fluoride concentrations in bottomwater do not follow the salinity trend (Maps 25, 26), being highest in the lowest salinity waters, and slightly increase towards the headwaters of the Bayou (r for salinity and fluoride in bottomwater is -0.97 and -0.48 for Phase 1 and Phase 2 respectively). This suggests that there is a source of bottom water fluoride in the northern section of the bayou. A strong correlation exists between fluoride levels in the bayou bottomwater and in sediment porewater (r=0.65 and 0.47 for the 0 - 30 cm and 60 - 90 cm sediment layers respectively) (Table 4). This correlation indicates that there is an exchange of fluoride between the sediment porewater and the bayou water. The dominant exchange is most likely from the sediment porewater to the bayou bottom water because fluoride levels are higher in the porewater than in the bottom water and because there is evidence that fluoride enters the sediment porewater from a source below the bayou. The pore water containing higher levels of fluoride is likely under a head of pressure that sends it out of the sediments into the waters of bayou. This means that fluoride from the groundwater plume enters the water of Bayou Texar. The higher fluoride levels in the sediment porewater can potentially also be due to the presence of organic complexes (Windom, 1971). The fluoride concentrations in the water of Bayou Texar are well below the Florida FDEP water cleanup target levels for freshwater surface water (10 mg/L) and marine surface water (5 mg/L). The FDEP fluoride cleanup target levels for groundwater and surface water are based upon calculations using a lifetime excess cancer risk level of 1.0E-6; a hazard quotient of 1 or less; the best achievable detection limits; and nuisance, organoleptic, and aesthetic considerations for past industrial spills. These levels are not necessarily protective of the environment.

9.6 Existence of 2nd Fluoride Hot Zone

The hot zone coincides with the area where the northern branch of the fluoride contaminated groundwater plume reaches the bayou. In the area where the southern branch of the plume intersects the bayou one core taken by ENTRIX had relatively low but increasing-with-depth fluoride concentrations. We collected two vibracores (cores TC-6, TC-7) in the channel of the bayou near the southern branch of the groundwater plume to verify if a second hot zone exists. Sediment and porewater fluoride concentrations at all levels in these two cores are low and not above the background fluoride concentrations elsewhere in the bayou (Maps 17, 21'). The concentrations do not increase with depth and are below the reportable limit in the deepest sample of the cores. Large local variations in fluoride concentrations occur at the hot zone and, obviously, may be present in this area too. However, our current fluoride data suggest that the southern branch of the fluoride groundwater plume may not affect the bayou system.

9.7 Radium

9.7.1 Radium Activities

Previously radium had not been studied in the in the Bayou Texar/ Carpenter's Creek system. In the present study we present a systematic study of radium in the Bayou Texar/ Carpenter's Creek system. A public interest in radium due to concerns about the possible contamination of drinking water in the area prompted the present project to carry out a methodical investigation of radium in sediments and bottomwater in the bayou. For sediments and marine waters there does not appear to be any federal or state of Florida standards for radium. Drinking water standards for radionuclides are based upon the risk of cancer being caused in humans by ingestion of radium isotopes that release alpha and beta particles. For sediments we are using the USEPA surface soil cleanup level (SCL) of 5 pCi/g. This SCL does not officially apply to the aquatic sediments of Bayou Texar, it is only provided to put the observed concentrations in perspective. In lieu of any other standards we cite these as giving some general frame of reference to possible hazard of radium containing sediment to the environment. We are not aware of any general body of research that allows any better method to cite environmental risk and hazard for radium. For clean up of spills on land the standard is based upon exposure of humans to ionizing irradiation entering the body mainly through irradiation of the human body. Under these conditions the low energy alpha and beta particles of radium will not adversely impact human health. However, gamma rays can penetrate the skin to act upon internal tissues. The gamma component resulting from radium decay do not present a significant health risk for water ingestion due to the relatively lower concentrations of the 5 pCi/l MCL versus 5pCi/g (=5,000 pCi//kg) SCL for surface soils.

The radium activity for surface sediments in Bayou Texar is relatively low (Table 7, Table 8, Table 9, Map 27). Except for the surface sample from TC-11 (7.97 pCi/g), the activities are below the USEPA surface soil cleanup level (5 pCi/g). The lowest activities are observed south of the Cervantes Street bridge (< 1.4 pCi/g). The activities gradually increase towards the north and reach their highest levels at the hot zone (Map 27). Low activities south of the Cervantes Street bridge may be due to the low clay content of the sediments (Map 23) and, consequently the absence of exchange sites for adsorption of radium. The low activities may also be due to the higher salinity in the south. The increased competition with calcium cations for exchange sites in saline conditions lowers the adsorption rate of radium onto clay particles. Under those conditions more radium may remain in dissolution where it can complex with anions typically present in salt and brackish water and be transported elsewhere by tidal currents. In the hot zone, however, clay content is also low but radium activity is higher. This higher activity may be a result of the lower salinity in the hot zone which favors adsorption of radium, but the higher activities may also result from locally higher radium input into the bayou, particularly from aquifer discharge.

Depth trends of radium activity are not consistent but in three cores at the hot zone (TS-1, TS-2, TM-3) and in one core near the southern extension of the fluoride plume (TC-6) the highest radium activity was observed in the deepest level (Maps 28, 29, Table 7, Table 8). Elsewhere in the bayou the highest radium activity does not occur at the deepest level. Depth trends vary spatially and even reverse over short distances. (e.g. TS-2 and TC-11, Map 29). The downward increasing trends of radium near the northern and southern branch of the fluoride plume suggest that a source of radium exists under the bayou and that it locally moves towards the surface. For the northern branch of the plume this contention is consistent with results for fluoride but for the southern branch it is not corroborated by the fluoride results.

Bayou and creek waters were tested for radium, and activities were found to be low when compared to existing standards (Map 30). The highest activities occur in the northern part of the Bayou, just south of the 12th Avenue Bridge. These activities are an order of magnitude lower than in other ecosystems in the nation that are still deemed to be safe for wildlife (Ramirez, 1993, NYSDEC, 1996). There do not appear to be any studies of local levels of radium in sediments to establish background baseline values. In Central Florida Ra-226 radioactivity ranges from non-detect to 2.25 pCi/g in the deeper part (up to 80 cm) of cores taken in lake and marsh sediment (Brenner et al., 2004). These deeper levels most likely represent background levels. Farming practices in that area, i.e. use of phosphate fertilizers and use of irrigation water from the phosphate rich Floridan aquifer, appear to have increased radium in the more surficial levels of the sediments. The values observed by Brenner et al. (2004) are not dissimilar from the Ra-226 values that we observed in Bayou Texar sediments. In a marine environment the background was found to be lower by Vegeria et al. (2004) with averaged background values of 0.41 pCi/g and 0.43 pCi/g for radium-226 and 228 respectively. This is in agreement with our results from the lower part of the bayou. The samples taken closer to Pensacola Bay during the present study had lower radium activities than those nearer to the creek. There is no evidence in the present study to suggest that radium in the Bayou Texar/Carpenter's Creek system presents a hazard to human health under current conditions of recreational use. We are not aware of any federal or State of Florida guidelines that suggest an environmental or health risk from the encountered levels of radium activity.

9.7.2 Radium Origin in the ACC Aquifer

The predominant radium isotope resulting from phosphate fertilizer production is Ra-226 (Florida Institute of Phosphate Research, 1993) but in the case of the ACC Ra-226 was stated to have gone out with the finished product due to the processing techniques utilized (Geraghty and Miller, 1992; 1993) and did not remain on site. A determination of radium isotope ratios can indicate if Ra-226 is present at higher levels that suggest a release from phosphate fertilizer manufacturing activities. Natural radium in an aquifer comes from decay of minerals that contain uranium and/or thorium. These parent elements produce radium isotopes during radioactive decay and the isotopes can subsequently be released to the water by leaching. Alpha recoil during radioactive decay can eject radium from the lattice of a mineral directly into the water. Once in the water, radium is subjected to adsorption on aquifer mineral surfaces. Adsorption/desorption is related to chemistry of the groundwater with adsorption being stronger with increasing pH. At the low (< 5) pH range, an inverse correlation between radium level and pH, i.e., increased radium mobility, is expected (Tuckfield et al., 2004). Radium is more mobile at acidic conditions because the solubility of minerals that contain radium increases and adsorption of radium to soil decreases. The half-life of Ra-228 is 267 times shorter than that of Ra-226 and as a result Ra-228 concentrations will diminish if Ra-228 is not being replenished at a rate that is at least equal to that of decay. High levels of Ra-228 in an aquifer suggest that this isotope is constantly entering the aquifer.

The data in Table 10a include information from shallow and deep wells taken from laboratory analytical reports in the appendices of the URS (2003) report that were not cited elsewhere in that report. These data are sorted in ascending order according to pH for deep wells screened in the MPZ and this is repeated for shallow wells screened above the MPZ. The wells in Table 10a bearing the letter S in the Well ID are shallow wells, those with D are deep wells. The evidence shows that shallow wells tend to have higher pHs and less radium radioactivity. The pH for the deeper wells ranged from 3.8 to 4.5 and varied from 4.4 to 6.4 for the shallow wells. Also levels of radioactivity decline in the wells furthest away from the ACC plume including those adjacent to the bayou (Maps 3a, b, c). The low pH values (< 5) show that the acidic pH could cause the mobilization of radium leading to elevated radium concentrations in the aquifer. Lower pH also seems to be associated with elevated sulfate (SO_4) ions. It is not known what the relative amounts of uranium and thorium containing minerals are in the aquifer or if the minerals in the main producing zone contain greater quantities of radioactive materials than other aquifer regions. These data show that higher total radium concentrations in ground water tend to be associated with higher radioactivities for Ra-228 than for Ra-226 (Table 10a). This suggests a non-fertilizer manufacturing origin for these compounds. The ACC handled materials that are known to have contained Ra-226. However, unless it can be shown that ACC also handled materials containing Ra-228, then it must be concluded that the source for Ra-228 lies elsewhere. More comparative data from similar areas of the aquifer distant from ACC influence needs to be studied prior to making conclusions of the geochemistry of this aquifer. It appears that Ra-228 is entering the aquifer in greater quantities than Ra-226 and is originating from sources other than wastes derived from phosphate fertilizer manufacture.

The Sand and Gravel aquifer east and south of the ACC has a sulfate plume derived from the synthesis, regeneration, and release of sulfuric acid and its byproducts (Geraghty and Miller, 1992, 1993). In ACC groundwater sulfate ion concentrations were observed to be associated with acidic pH’s (Table 10a). However, it is not clear if sulfate is responsible for lowering the pH since there are many chemical possibilities. A lowering of pH can also result from direct dissolution of acid producing materials such as aluminum salts, oxidation of ferrous iron, or biodegradation of organic materials. No information is available for the Sand and Gravel aquifer to accept or reject these alternatives.

9.7.3 Radium in Bayou Sediments

The total radium (Ra-226 + Ra-228) in the aquifer west of Bayou Texar and Carpenter's Creek is generally above the USEPA 5pCi/L MCL due to an increase in the percentage of Ra-228 (Table 10a). However, these levels decrease in the wells nearer to the bayou (Maps 3a,b,c). The aquifer on the basis of fluoride transport appears capable of transporting materials to Bayou Texar. Chemically both radiums react similarly and should interact identically with the sediments and porewaters of the bayou. It seems safe to assume that both radium isotopes upon transport to bayou sediments should accumulate according to their relative concentrations in the groundwater. However, the radium radioactivity of Bayou Texar sediments does not consistently display high Ra-228/226 ratios. Total radium activities are higher in the hot zone as are nearly all other pollutants examined. However, this is not reflected by a high Ra-228/226 ratio for sediments in the hot zone (Table 10b). The absence of a strongly defined trend for the radium ratio showing a higher percentage of Ra-228 suggests several alternatives:

1) The aquifer discharge to the bayou has resulted in radium not being deposited at a rate sufficient to maintain higher levels of Ra-228 versus its decay rate (half life 5.75 yrs).
2) Radium levels in the aquifer more strongly reflect sediment transport from surface sources.
3) The radium in the aquifer has not yet reached the bayou.

9.7.4 Bayou Texar Sediments and the Hagler Well

A recent Grand Jury Report (2004) researched ECUA records for radium and total alpha activities in production wells for drinking water. It was found that it was impossible to predict the health risk associated with the observed radium levels because it was not known how long ECUA customers were exposed to radioactivity in excess of the MCL. Until 1996, ECUA did not test individual wells for Ra-226+228. In 1996, pursuant to changes in Florida law, ECUA tested each well in its system for radionuclides and found that the Number 9 well exceeded the Maximum Contaminant Level (MCL) for gross alpha particles established under the Safe Drinking Water Act. The FDEP required ECUA to continue sampling the Number 9 well and to test for Ra-226+228. By May 1998, it was clear the well would not comply with standards for these radionuclides (Grand Jury Report, 2004). This well appears to no longer be producing since it is not listed as a producing well by ECUA (ECUA, 2003). The Number 9 well is located less than 3 km from the ACC. In November 1998, FDEP informed ECUA that the radium levels in the East and Hagler wells constituted an unreasonable risk to health and directed ECUA to give customer notice. Under the radionuclide rules it was then required to test Ra-226 levels to determine if 3 pCi/L levels are exceeded. Exceeding this value would have mandated that Ra-228 levels be tested. None of the wells exceeded 3 pCi/L for Ra-226, and, therefore, none were tested for Ra-228 at that time.

During a recent public meeting The Grand Jury Report of 2004 was presented by State Attorney Russell Edgar, prosecutor with the Office of State Attorney. Mr. Edgar stated that dredge spoils from Bayou Texar were placed in a pit near the Hagler Well. These spoils would have been from an area north and adjacent to the hot spot in the northern part of the bayou (Lewis et al., 2001a). These spoils likely contained some radium radioactivity that potentially could leach out and raise the radium levels in the aquifer. The levels of radium isotopes in these dredge spoils and total yards of spoil are not known. The presence of organic materials in the buried spoils could release CO_2 and lower the pH resulting in leaching of radium from the contaminated sediments. There is presently no confirmation that this spoil disposal site exists or any information derived from sampling and analysis. This should be done to assess what the radium levels are and if there could be a release of radium or other substances to the aquifer in sufficient amounts to effect contaminant levels in the water produced by this well. The most recent ECUA (2003) water quality report shows permissible levels (below 5.0 pCi/l) of radium-226+228 radioactivity in the Hagler Well.

9.8 Semivolatile Compounds

9.8.1 Distribution of Semivolatiles in Sediments

USEPA method 8270C employed in this study includes in its detection about 95 semivolatile compounds that include the common PAHs and DNTs (2,4-dinitrotoluene and 2,6-dinitrotoluene), six phthalates, carbazole, and PCP (pentachlorophenol). Oxidation and alkylated products are not detected by this method (Van Mouwerik et al., 1997). DNTs and PCP were not detected during this study. Phthalates and the following PAH compounds were detected during the 8270C analyses of Bayou Texar/Carpenter's Creek sediment samples: Anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, fluoranthene, indeno(1,2,3-cd)pyrene, phenanthrene, and pyrene. Carbazole, a nitrogen heterocyclic PAH, was also detected. The PAH analyses did not report any detections for naphthalene or 2-methylnaphthalene, the predominant PAH components of the contaminated groundwater plume from ETC (CDM Federal, 2000; 2002). In sediment cores PAHs were only found in the upper 30 cm of bayou sediments, with the exception of two locations that appeared to have been disturbed by dredging and/or recent deposition of silt. The general absence of PAHs in deeper sediment layers suggests a recent surficial origin for these PAHs. It is also possible that PAH in the deeper (older) sediments have had more time to degrade, but the general lack of any detections in the intermediate layers cast doubt upon this hypothesis. The PAH values for the surface sediments are relatively low in the middle and southern portions of the Bayou but are above the TEL (1,684 μg/kg) and in some cases approach the PEL (16,770 μg/kg) in the northern part of the Bayou (Maps 31, 32).

Previous studies have detected higher levels of PAHs than were observed in the present study. Total PAH values up to three times higher than those observed by the present study were encountered in 1994-1995 (Lewis, unpublished data). What is particularly interesting is that over the course of the Lewis study the total PAH concentrations increased for four of five sites that had been sampled at least twice over a nine month period. At one of these sites (TE10) naphthalene went from nondetect, to 674, 12,249, and 27,000 μg/kg over a nine month period. Site TE10 appears to be near the fluoride hotspot, however the precise coordinates are not known. DeBusk et al. (2002) lists PAH data obtained during NOAA sampling in Bayou Texar for naphthalene and other PAHs. Naphthalene values of 250 and 800 μg/kg were reported well to the south of TE10. The data from the 1990's shows that the naphthalene levels and total PAHs levels were previously much higher in the bayou and have declined. The presence of naphthalene is important since it is a major component of the ETC PAH plume. In these unpublished data naphthalene exhibited the highest concentration of all of the detected PAHs. The origin of these PAHs is probably input from a surface source(s). Because all of these samples were from surface sediments it can not be established with certainty that the ETC contaminated plume in the aquifer did or did not contribute. However, an accumulation of 27,000 μg/kg naphthalene seems very high for a volatile compound that never is above 2000 μg/L in the aquifer monitoring wells that lie adjacent to the bayou. The most plausible explanation is that there was a spill(s) of petroleum products in the Bayou Texar/ Carpenter's Creek Watershed during this time frame. Butts (2005) of the FDEP reported that there was a diesel fuel spill into Carpenter's Creek occurring on Feb. 06, 1996. The FDEP sampled later that month, some 20 days after the fact. Butts reported that: "Even so, the sediment reeked with diesel odor and visual sheens." The time frame of this spill does not explain the naphthalene levels found by Lewis (unpublished data), however, and earlier spills cannot be ruled out.

9.8.2 Total Petroleum and PAHs

PAHs can have multiple origins with oil spills and combustion products being the most important sources in urban environments. Total petroleum hydrocarbon concentrations were obtained for surface sediments and surface waters from Bayou Texar and Carpenter's Creek (Table 11). No petroleum was detected in surface waters of the bayou or creek but was generally detected in most bayou/creek sediment samples. The highest concentration of 1,700 mg/kg was found in a blind arm of the bayou just below the 12th Ave Bridge. This area was also highest for total PAH. Oil present in the bayou likely originates from spills and runoff from parking lots. PAH releases in the form of diesel spills and a roofing sealant spill in 2003 in Carpenter's Creek have been recorded by FDEP (Butts, 2005) and it is certain that unrecorded releases have also occurred. Petroleum does contain PAHs and can be expected to contribute in some way to PAH concentrations and composition in the bayou/creek system. If petroleum was the dominant source for PAHs, similar ratios from sampling site to sampling site for PAH/petroleum would be expected assuming that total petroleum for each site contains and contributes the same percentage of PAH to the sediment. To assess this possible origin, PAH concentrations to total petroleum concentrations (carbon content: C8-C40) were obtained, calculated as ratios, and compared for sediment grab samples (Table 11). Assuming transport and degradation or biotransformation is constant there does not appear to be any discernable relationship of PAH/total petroleum ratios. The range and standard deviation of PAH and total petroleum is large with the standard deviation being greater than the mean. This suggests either that spills of petroleum product are not the main source for PAH or that petroleum products with widely varying PAH compositions are entering the bayou/creek system at differing locations.

9.8.3 PAH Ratios and PAH Origin

Ratios based on concentrations of specific PAHs have been employed to find the probable origin of environmental PAHs (Rostad and Pereira, 1987; Yunker et al., 2002). According to Rostad and Pereira (1987) typical coastal sediment PAHs are not of creosote origin and have less phenanthrene than fluoranthene or pyrene. We constructed tables using Rostad and Pereira's (1987) system of ratio comparison for PAH samples from the Bayou/Creek System and observed that the ratios were different from what is expected for PAHs of creosote origin. In the Bayou/Creek System, ratios of fluoranthene or pyrene to phenanthrene are above 100, the reverse of what would be expected for PAHs of creosote origin (Table 12).

Yunker et al. (2002) conducted a critical appraisal of PAH ratios as indicators of PAH source and listed four PAH ratio calculations for parent (non-alkylated) PAH compounds. Three of the four ratio calculations were applied to this study. The ratios could be correlated with one of three sources: petroleum release; combustion of petroleum products; and combustion of grass, wood, and/or coal. The ratios are general in application and may not apply to specific cases for some petroleum products or some other specific applications. For example crude oil can vary considerably in content from one oil field to the next and other products containing PAHs are variable. Table 13 lists the origin indicator ratios that were calculated from experimental data. These ratios are An/(Pn+An) [Anthracene/Anthracene+ Phenanthrene], Fl/(Fl+Py) [Fluoranthene/Fluoranthene+ Pyrene], and IP/(IP+Bghi) [Indeno(1,2,3-c,d) Pyrene/ Indeno(1,2,3- c,d)Pyrene+Benzo(g,h,i)Perylene].

We obtained these ratios when the PAHs required for the calculations were detected in the sample (Table 14). It appears that at least two of the ratios indicate a PAH origin from combustion and not from petroleum spills. The average for An/(Pn+An) may have little physical meaning since it was derived from only four samples. These four samples have divergent ratios and are located in different parts of the bayou. For two of these four samples the origin indicated by An/(Pn+An) is consistent with that indicated by the other two ratios. For one other sample An/(Pn+An) suggests a creosote origin and for one a petroleum release origin. Values just over 0.50 for Fl/(Fl+Py) suggest combustion of non-petroleum products such as grass, wood, and coal for most samples. Based on this ratio PAHs in sample SG-22 originated from combustion of petroleum products. Values between 0.20 and 0.50 for IP/(IP+Bghi) for all samples that the ratio could be determined for is consistent with a petroleum combustion origin. Overall the data indicates combustion as a major source for sediment PAHs without a clear distinction being made for the source of combustion. These ratios indicate that creosoted wood pilings present in bayou/creek docks or bridge pilings are not a likely source of the PAHs in the sediments.

9.8.4 Naphthalene Discharge to the Bayou

CDM Federal (2002) modeling studies predicted an average travel time for constituents in the groundwater plume of 90.9 years from the ETC site to Bayou Texar based on advection alone. The ETC started operations after 1942 and, thus, this model suggests that no PAH from the ETC should have made it to the bayou. Data from the aquifer that show the presence of high concentrations of PAHs in some monitoring wells suggest otherwise. In the CDM Federal (2002) study a monitoring well located just west of the northern part of the Bayou (well AC-35D), had 300 μg/L naphthalene, 3 μg/L phenanthrene, 24.5 μg/L, 2-methylnaphthalene, 2 μg/L acenaphthene, 5.5 μg/L dibenzofuran, 2 μg/L fluorene, and 188 μg/L of 2,4 & 2,6 dintrotoluene combined. Simlarly high values for groundwater were observed near the vicinity of Carpenter's Creek a little north of the 12th Ave. Bridge. Very high concentrations of naphthalene (1600 μg/L) were measured for adjacent monitoring well NWD4D (CDM Federal, 2002). There is obviously a high concentration of naphthalene in this part of the aquifer, but evidence to suggest where naphthalene might discharge to the creek or bayou does not currently exist.

Only testing of PAHs in porewater can verify if the plume is entering the bayou system via porewater transport. Sampling by CDM Federal (2000) of sediments and porewater from one site in the bayou and three in the creek did not report any naphthalene compounds. The present study did not analyze for PAHs in porewater because other studies are scheduled to examine this issue in detail (CDM Federal, 2003). The lack of naphthalene detections in our sediment samples could be due to naphthalene not being present or being present in sub-detectable quantities. The detection limits and reporting limits observed in the analytical results may have not been sufficiently low to detect minimal concentrations of naphthalene and alkylated products of naphthalene. Naphthalene is the predominant PAH of the plume and its concentration upon reaching the sediments can be diminished by volatilization to the atmosphere or altered by alkylation. Environmental parameters such as temperature, available nutrients, and oxygen supply limit the rate and extent of biodegradation of petroleum products including PAHs (Lepo et al., 2003). ENTRIX (1993) found from monitoring chloride and sulfate concentrations that aerobic conditions extended to greater than normal depths for estuarine sediments creating conditions that are more favorable to degradation (Lepo et al., 2003). This could account partially for the lack of naphthalene in the deeper sediments due to degradation being increased by aerobic conditions. These processes would also degrade other PAHs and oils. The present study used USEPA method 8270C that is intended for determining the concentration in soil and ground water for 16 to 18 parent PAHs (ie. PAHs without side chains, along with two alkylated forms (1-methyl-naphthalene and 2-methyl-naphthalene). The 8270C method that was employed is a full scan method for semivolatiles that includes non-PAHs such as phthalates, PCP, and DNT. In water it is easier to obtain lower detection limits and correspondingly lower reporting limits. Matrices such as contaminated, fine grained sediments pose difficulties in obtaining low detection/reporting limit levels due to interferences. CDM Federal (2000; 2002) in groundwater reported values as low as 2 μg/L in contrast to about 90 μg/kg for sediment values in the present study. Semivolatile analyses employing selected ion monitor mode (SIM) can lower detections limits to 0.1 μg/L and 5 μg/kg for ground water and soil, respectively. A solution is to use an analysis for an extended alkylated PAH list of analytes using SIM methodology for sediment and porewater samples. This will lower detection limits and also detect alkylated PAHs.

USEPA has planned a Phase III study for the Remedial Investigation for Operable Unit 2 for the ETC (CDM Federal, 2003). In the final Sampling and Analysis Plan for Phase III of the remedial investigation the overall objective is to further define the nature and extent of offsite groundwater contamination originating from the ETC. This also includes determining the impact upon Bayou Texar from ETC contaminated groundwater. This plan will include the installation of eight additional monitoring wells to better understand the location and movements of the ETC plume. The groundwater samples from the new wells and existing wells will be analyzed for USEPA TCL VOCs (target compound list volatile organic compounds), SVOCs (semivolatile organic compounds) and USEPA TAL(target analytes list) metals. A number of samples (approximately 50% of the total samples) will also be analyzed for dioxins to confirm that these contaminants are not present in the groundwater. Finally it is stated that because of the probable presence of dense non-aqueous phase liquids (DNAPL), confirmation of DNAPLs in wells and/or soil during drilling will be attempted by visual examination, use of probes, and field testing.

9.8.5 Dinitrotoluene (DNT), Phthalates, and Carbazole

Detectable levels of DNT were reported in the aquifer groundwater in nearby monitoring wells (Geraghty and Miller, 1992&1993; CDM Federal, 2002; URS 2003). There were no detections of dinitrotoluene (DNT) with sediments reporting limits typically ranging from < 450 to < 850 ug/kg. Phthalates are chemicals used to make plastics flexible and are ubiquitous in the environment due the omnipresence of plastic materials. Phthalates are also commonly found to be contaminants occurring during collecting and laboratory handling since plastic containing protective gloves are commonly employed. Several phthalates were detected in sediment samples analyzed during this study: bis(2-Ethylhexyl)phthalate, di-n-butylphthalate, and butylbenzylphthalate. In this study most of the detections occurred in the surface sediment from grab samples or from the 0-30 cm level from sediment cores (Table 15, Table 16). In sediment Cores C8-11, and C22 detections did occur for phthalates analytes at deeper levels. In the cases of sediment cores C8 -11 these detections could be due to collection or laboratory contamination since no PAHs were detected as co-contaminants in the deeper layers. In core C22 phthalates were detected in deeper sediment levels that were also associated with PAH detection in an area where sediments had previously been disturbed by dredging (Lewis et al., 2001a). The phthalates results are not that unexpected and appear to represent a mixture of true field values and artifacts.

Carbazole is an organic heterocyclic PAH containing a nitrogen atom in a dibenzopyrrole system. Carbazole is a ubiquitous compound in the environment and its detection in some samples is to be expected. Carbazole can be produced by combustion, during coal gasification and occurs in crude petroleum and asphalt products. It is used widely in synthesis of dyes, pharmaceuticals, and plastics and is a suspected carcinogen. The concentrations detected are shown in tables 17 and 18.

9.9 Polychlorinated Biphenyls (PCBs)

For PCBs analyses we employed USEPA gas chromatography Method 8082 to determine the concentrations of polychlorinated biphenyls (PCBs) as Aroclors-1016, -1221, -1232, -1242,-1248, 1254, and -1260. Method 8082 is used routinely when industrial pollution is possible. It is most useful for recent spills. Aroclors that have been subjected to environmental degradation ("weathering") or degradation by treatment technologies will not be readily detected by this assay. Such weathered multicomponent mixtures may have significant differences in peak patterns than those of Aroclor standards. Quantitation of PCBs as Aroclors is appropriate for many regulatory compliance determinations, but is particularly difficult when the Aroclors have been weathered by long exposure in the environment.

No Aroclors were reported from any of the analyses that were run for sediment grabs obtained during the summer of 2003 by the present project. Reporting limits were lowest for sandy sediments (< 19 μg/kg) and higher (to < 1100 μg/kg) for the contaminated regions of the bayou. Previous studies for individual PCB congeners have reported low levels of PCBs (Lewis, 2001b; Debusk et al., 2002) in Bayou Texar sediments (See Section 5.7). The lack of any reportable quantities by Method 8082 suggests that there have been no recent releases of industrial Aroclor PCBs.

9.10 Pesticides

The standard suite of organochlorine pesticides was analyzed for in 24 sediment surface grabs from Bayou Texar and Carpenter's Creek. Previous studies for pesticides in Bayou Texar have been reported by Lewis et al. (2001b) for 12 samples and by the DeBusk et al. (2002) database for NOAA and USEPA studies (9 samples). The DDT pesticide data reported by Lewis et al. (2001b) and the data listed in the DeBusk Database (Debusk et al., 2002) are higher. The frequency of detection is also greater with 25% showing DDT in 12 samples analyzed in the 1990's by Lewis et al. (2001b) as compared to 12.5% in 24 samples in the present study. It appears that the DDT concentrations are declining which is not unexpected in that it is no longer released to the environment and it is degraded by microorganisms (Nadeau et al., 1994; Hay et al., 1998; Quensenet et al., 1998). In the DeBusk et al. (2002) database for p,p'-DDD out of nine samples there were five detections of which three exceeded the PEL and one was only above the TEL. For p,p'-DDE there were 5 detections of which 2 exceeded the TEL. For p,p'-DDT there were four detections out of nine samples and three exceeded the PEL. PERCH Bayou Texar DDT values were well below the PEL and somewhat above the TEL of 1.19 μg/kg (mean for three values was 1.83 ug /kg and two of these were identical values from QC split samples). There was only one detection for DDE and it is slightly above the TEL. An examination of the pesticides (Table 19) shows a few other detections for pesticides, however these pesticides do not have any applicable FDEP sediment guidelines. The data suggests that some minimal deleterious environmental affects due to pesticides could be expected in Bayou Texar sediments from organochlorine pesticides.

9.11 Metals

Heavy metals have been studied several times in Bayou Texar (DeBusk et al., 2002) but to our knowledge no other study systematically examined metals in sediments at the water/sediment interface and at depth like we studied. The present study found that metal concentrations in surface sediments are low in Carpenter's Creek, intermediate in the mid and southern section of the bayou, and elevated at the hot zone near the northern end of the bayou (Maps 33 - 39, Table 20). The concentrations in the creek and the mid and southern section of the bayou are comparable to those observed in estuaries elsewhere in the world (Ramessur, 2004; Sarkar et al., 2004; Cave et al., 2005; Roach, 2005). The concentrations for Cu, Hg, and Zn in the hot zone, however, are considerably higher than those for some other estuaries, including the Hugli River estuary in India and the Humber estuary in the UK which have highly urbanized and industrialized catchments (Sarkar et al., 2004; Cave et al., 2005).

Trends in metal concentrations have been shown to be related to clay content due to adsorption effects (Sansalone and Buchberger, 1997; Sing et al., 1999) but in Bayou Texar the influence of clay content is not consistent (r between clay content and copper=0.2, lead =0.6, zinc=0.5, mercury=0.2) and spatial trends of metal concentrations and clay content do not coincide (Maps 33 - 39 and Map 23). This may be because some metals are present in other forms (e.g. organic compounds, carbonates, and/or metal fluorides) or because metal input is spatially highly variable. In the latter case metal input may locally be so high that concentrations in the nearby sediments are elevated in spite of the relatively low clay content. A similar explanation was used to explain a lack of correlation between heavy metals and clay content in the Hugli River estuary in India (Sarkar et al., 2004). For instance, copper and zinc concentrations are very high in a monitoring well just west of the hot zone which may point to a localized and strong source. Alternatively, diminished flushing of the bayou away from its mouth in the south may also cause the metal accumulation in the northern section of the bayou.

The respective PEL values are exceeded in surface sediments in the northern part of the bayou by lead, mercury, copper, and zinc. The concentrations for these metals decrease in the extreme north at the mouth of Carpenter’s Creek. Dredging of this area occurred between October 1994 and February 1995 (Lewis et al., 2001a) probably led to a reduction in the metal concentrations but this result indicates that the Creek recently has not been a major source for these metals. The PEL for lead and zinc are also locally exceeded in the midsection of the bayou. Existing information on arsenic concentrations in estuarine sediments is limited. Our data show that the PEL for arsenic is not exceeded in Bayou Texar (Map 39). This is somewhat surprising considering that sediments in some retention ponds and even natural soils in the area have high arsenic concentrations (Liebens, 2001). Throughout the bayou arsenic concentrations that are low, i.e., below threshold effect level (TEL) (MacDonald, 1994) and that are intermediate (between TEL and PEL) are interspersed. This may point to a multiple source origin for arsenic. Arsenic is highly correlated with clay content (r = 0.7), and thus the spatial variation in arsenic may reflect variations in grain size. Cadmium was detected only at three sites in the northern part of the bayou (Map 38). High concentrations of thallium and antimony have been observed in stormwater retention ponds and roadside swales in Pensacola (Liebens, 2001) but these metals are below reportable levels in the surface sediments of the bayou. Concentrations for all metals are below the TEL south of the Cervantes Street bridge.

Differences in metal concentrations between channel and nearby shallow sites are fairly consistent (Table 20). Our grab sample dataset has eight pairs of deep-shallow sites. In five pairs the highest metal concentration is observed at the deepest site and in one at the shallow site. In one pair that actually consists of 3 sites the highest concentrations occur at the intermediate depth site. This trend can be explained by the differences in clay content between sites as shallow sites have 12% clay on average and deep sites have 27% clay on average (P=0.03 for t-test for equality of means). The shallow site of three of the pairs was located by a stormwater outfall, but apparently this did not lead to high metal concentrations in sediments even though the metal input can be expected to be high at outfalls. The reason is most likely that sandy deltas form where outfalls enter the bayou (e.g.G-7, G-17, G-21 on Maps 14, 15). In previous work local sediment particle size also explained the relatively low metal concentrations at outfalls (Stone and Liebens, 1997).

The depth distribution of metals in sediments shows that concentrations for copper, lead and mercury are highest near the sediment surface (0 - 30 cm layer) (Maps 40 - 42). The absence of these metals in the deeper layers is most likely due to the absence of industrialization and urbanization in the bayou's watershed at the times these deeper layers were deposited. Lead concentrations are relatively high at the intermediate depth (56 - 58 cm) in the extreme northern part of the bayou at the mouth of Carpenter's Creek. This intermediate depth may represent a distinct geological layer, deposited by the Creek. Chromium concentrations do not consistently show a depth trend (Map 43). In the analysis total chromium, which includes the two oxidation states Cr III and Cr VI, was measured. Chromium III is relatively inert but Cr VI, which principally occurs in toxic chromate forms, is highly mobile. The absence of a depth trend in our data most likely results from a relatively high proportion of mobile Cr VI in the total chromium.

Although there is a strong spatial correlation between the metal concentrations and the radium and fluoride concentrations in sediments in the Bayou, a causal influence of the groundwater plume on metal concentrations is not apparent. Lead, copper, zinc and cadmium are elevated in surface sediments in the northern part of the bayou but only copper and zinc are elevated in nearby wells that reach the plume (Maps 5 - 9). Copper and lead concentrations decrease with depth in the sediments, which also suggests that sources other than the contaminated groundwater plume may dominate metal input into the bayou system. According to Stone and Morgan (1993) the major source of bayou sediments and presumably metals is Carpenter's Creek but results of the current project do not clearly support that assumption for metals. Other potential sources of metals include stormwater outfalls and non-point sources along the Bayou. A relatively large number of known outfalls are present along the western shore of the northern part of the bayou where metal concentrations are high. Diminished flushing of the bayou by tidal currents has been hypothesized to have played a role in increased sedimentation rates that could also explain the elevated metal concentrations in the northern part of the bayou. This is supported by earlier findings that the accumulation of sediments was greater as one approaches the northern end of the bayou due to increasing sedimentation rates (Stone and Morgan, 1990a; b).

9.12 Bacteria

Monthly sampling was conducted by the ECHD in Bayou Texar and Carpenter's Creek from December 1999 until December 2003. At each station, the geometric mean of *Enterococcus* CFU counts recorded (colonies per 100 ml sample; USEPA Method 1600) was calculated by the present project and plotted to determine the spatial patterns of fecal contamination into the system. These data (Map 44) clearly show the fecal loading predominantly coming from the Carpenter's Creek drainage system. A few stations within the tidal portion of the bayou have values higher than the regulatory limit of 35 colonies per 100 ml sample, but most of the samples taken in the main portion of the bayou show little additional material being added except what might be expected from attenuated downstream flow from Carpenter's Creek.

It is instructive to extract from the dataset the minimum and maximum recorded *Enterococcus* counts. High minimum recorded counts at any one station are indicative of chronic loading situations that are likely groundwater derived from a constant source, whether septic tank or leaking sewer mains/lift stations. Clearly there are problematic localized sites along Carpenter's Creek with high minimum loading values (Map 45). Maximum recorded values that indicate different stations as loading points than the minimum values, highlight episodic loadings, likely due to runoff from rain events. In this case the maximum recorded values (Map 46) do not correspond to any of the highest minimum records, and stations within the main part of the bayou are indicated as episodic loading points as well as stations within Carpenter's Creek. Surface runoff in areas mostly devoid of septic tanks likely would carry feces from pets and wildlife as opposed to human fecal contamination.

Limited sampling was conducted in the later half of 2004 by the ECHD, and the results indicate that, despite an aggressive septic tank abatement program, stations within Carpenter's Creek are persistent loading points for fecal contamination to the system (Table 21).

10. REMEDIAL CONSIDERATIONS

10.1 Erosion and Sedimentation

It is essential that prior to any future full scale remediative dredging of the bayou, stabilization of the soils and sediments in the watershed be achieved. Currently construction is not complete on I-10/I-110 segments going through the Carpenter's Creek Watershed. During road construction and construction of new residences large quantities of soil erode. A significant amount of undeveloped land is still present in the bayou's watershed that will someday be developed resulting in soil erosion and increased sedimentation of the bayou. Sediments will continue to accumulate in the bayou until adequate erosion control measures are implemented and treatment of stormwater to remove sediments is achieved. Presently it is calculated by Dames & Moore (2000) that 803,000 kg of total suspended solids a year could be transported into Bayou Texar. Some of the material may not be deposited in the bayou because of tidal transport. The tidal influx also transports sand into the bayou. Stone et al. (1990a; b) calculated that 15,550 m^3 was deposited into the bayou yearly. It is not clear how much of the imported material actually remains as sediment and what portion is removed by tidal transport. The present project recommends that a sediment transport study be carried out for the whole bayou to support the selection of remedial alternatives for Bayou Texar.

There are two motives for dredging Bayou Texar: 1) sedimentation is threatening to fill the bayou locally (i.e. at stormwater outfalls) to the point where some boating and related activities will not be possible; and 2) the soft clay-rich sediments in the middle and upper parts of the bayou (between the Cervantes and 12th Ave Bridges) do not provide a suitable substrate for many organisms and in some cases retain pollutants in toxic amounts. Dames & Moore (2000) estimated that there is approximately two meters of soft clayey sediment in the bayou that upon dredging would amount to almost 3 million m^3. The cost estimate was $257,000,000 for dredging and disposal by land filling of this material.

Results from the current study allow a characterization of sediments at various depths throughout Bayou Texar. The current study shows that elevated concentrations of most pollutants are present in surficial sediments only and in the northern section of the bayou specifically. This suggests that not all clayey surficial sediments may have to be disposed of as hazardous waste if the bayou is dredged and that possibly only the most contaminated surficial sediment rather than 2 meters of sediment has to be disposed of at hazardous waste disposal sites. However, spoil disposal requirements are different from those used for assessing TEL and PEL values in the current study. Further studies are needed to formulate disposal options.

Dredging requires that permits are issued at federal and state levels of governments. The US Army Corps of Engineers and the USEPA share federal responsibility for regulating the discharge of dredge material. The federal law includes the Clean Water Act (CWA) and the Marine Protection, Research, and Sanctuaries Act. The fundamental guidelines for testing sediments prior to dredging are organized into four tiers. The guidelines provide the substantive environmental criteria used in evaluating proposed discharges of dredged material into waters of the United States. Fundamental to these guidelines is the precept that dredged material should not be discharged into the aquatic ecosystem, unless it can be demonstrated that such a discharge will not have an unacceptable adverse impact either individually or in combination with known and/or probable impacts of other activities affecting the ecosystems of concern (USEPA and USACE, 1991). The characterization of sediments done through PERCH surface and vibracore samples helps greatly in the initial characterization of sediments. PERCH data show that most pollutants are confined to the upper 30 cm of the sediments. This information will prove valuable to making decisions for Tier 1 evaluation. One of the purposes of Tier 1 is to determine whether factual determinations can be made on the basis of existing information. The purpose of Tier I is to determine whether a decision on compliance with the limiting permissible concentration can be made on the basis of existing information. Tier I is a comprehensive analysis of all existing and readily available, assembled, and interpreted information on the proposed dredging project, including all previously collected physical, chemical, and biological data (USEPA and USACE, 1991).

10.2 Pollution Concerns

The hot zone is currently a discharge point for the portion of the Sand and Gravel Aquifer originating from the area about the ACC superfund site. There has been a Record of Decision for the ACC Operable Unit 2 based upon land filling of hazardous wastes at the ACC site to prevent leaching into the aquifer. This has been the predominant engineered form of remediation. For the material already in the aquifer USEPA states that “groundwater will be treated through monitored attenuation” (USEPA, 1994). The time predicted for the natural attenuation envisioned for this remedy is 70 years. USEPA (1994) stated: “A comprehensive, detailed ground-water flow and solute-transport modeling was conducted for the site. The modeling yielded information on the movement of dissolved chemical constituents in ground water and predicted the fate of contaminants emanating from the site. The modeling indicates that under existing flow conditions with no active remediation of ground water, natural attenuation of the site ground-water contamination will occur within 70 years”.

Data listed by URS (2003) show that fluoride concentrations fluctuate spatially and over time (Table 22). The highest fluoride concentration for the two wells nearest to the ACC site was measured in 1992. The next nearest well was not analyzed in 1992 but the available records show a maximum concentration in 1997 and 1999. For all other wells, which are further away from the ACC site and closer to the bayou, the highest fluoride concentration was observed on the most recent sampling date (2002). The data set is not extensive enough to draw firm conclusions about the existence of true temporal and/or spatial trends, but the observations that seem to suggest that there may be systematic variations in the fluoride concentrations warrant a continuation of the monitoring of these wells.

The question remains whether letting fluoride diffuse into bayou waters is free of significant impact to the environment and if this is an adequate remedy in respect to long term impacts upon the bayou. The present study was limited to determining concentrations of selected pollutants and relating these to sediment type and location in the bayou. The fluoride concentrations detected in bayou water by the present study were 1.8 mg/L. Fluoride in seawater is 1.3 mg/L on average. It is not known if the observed fluoride concentrations offer a major stress in brackish estuarine water like that of Bayou Texar. Continued monitoring of fluoride in the hot zone and in monitoring wells to the west of the bayou is recommended to verify if the hot zone changes in extent or magnitude. Monitoring of wells east of the bayou must also be conducted to verify if the plume crosses under the bayou towards active ECUA wells.

Pollutants in some sediments in the hot zone might have an impact on benthic communities. The sediments in the hot zone, and elsewhere in the upper bayou, are mostly devoid of macrofauna and submerged aquatic vegetation (Butts and Lewis, 2002). For sampling at one station Butts and Lewis (2002) were unable to calculate macroinvertebrate community composition indexes because of low species and individual numbers. The present project has found elevated levels of several contaminants in this part of the bayou. Future efforts to remediate and restore the bayou should take account of these pollutants present in the hot zone. It is recommended that further accumulation of pollutants be abated by a multipronged approach. In the vicinity of the bayou this approach should include local efforts such as planting of emergent vegetation as discussed above, and reduced production/release of pesticides and bacteria generating products. At the watershed scale the efforts should concentrate on reduction of sediments and sediment bound pollution in stormwater runoff.

It is recommended that bathymetric changes in the bayou be monitored on an annual basis to get a better understanding of current sedimentation and erosion rates throughout the bayou. This can be achieved with relatively minor expenses. It is further recommended that a study of sediment transport and flushing relative to tidal and other currents be conducted in the bayou to better understand the sedimentology of the bayou and the elevated levels of pollutants in the northern portion of the bayou. This type of study would also allow recommending remedies to improve the flushing, including an optimal dredging scenario. Any such study should examine the potential effect of improved flushing of the bayou on nearby sections of Pensacola Bay.

11. SUMMARY AND CONCLUSIONS

Bayou Texar is an urban water body that is impacted by a variety of pollutants and pollution sources. Studies by consulting firms doing superfund mandated studies indicate that a freshwater groundwater plume carrying fluoride enters the bayou system from below. Our results corroborate this finding as fluoride levels are highest and increase with depth in the northern part of the bayou where the groundwater aquifer intersects the bayou. For most of the bayou, fluoride levels are higher in surface sediments than in deeper sediments at the same location. The reason for this is not fully explained by the data from the present study. A possible scenario is that fluoride enters the water column in the northern section of the bayou, is dispersed by the water, and then enters the surface sediments elsewhere in the bayou. Sediment composition has been shown elsewhere to account for vertical differences in fluoride but in Bayou Texar that composition does not seem to affect fluoride levels. Fluoride is also higher in bayou bottom water in the northern section and appears to migrate there from the sediment and porewater into the bayou water. The fluoride concentrations in the waters of Bayou Texar are below Florida FDEP water cleanup levels.

Because there was local public concern about radium in drinking water the bayou system was tested for radium. It appears that the radium levels in MPZ between the ACC and the bayou have elevated levels due to an increase in Ra-228. The total radium activity is less in the shallow parts of the aquifer and radium in the MPZ appears to attenuate somewhat as it approaches the bayou. In general, radium activity is low both in sediments and water. More radium is present in the northern section of the bayou than in the mid and south sections. There is some evidence to suggest that the relatively high levels of radium in the aquifer just west of the bayou are contributing radium to the bayou system via upwelling of groundwater. However, the relative proportion of radium-226 to radium-228 in bayou sediments differs from what is observed in the nearby ACC aquifer

Heavy metals in Bayou Texar/Carpenter's Creek do not seem to come from the groundwater plume but point and non-point sources are more likely contributors of the metals. As is the case for all pollutants, metal concentrations are high in the northern section of the bayou and relatively low elsewhere. In surface sediments and water this spatial trend may be due to limited turnover of bayou water in the narrow northern section. In that northern section the PEL for lead, mercury, copper, and zinc are exceeded, indicating that there is a probable effect on biota that come in contact with the contaminated sediments.

PAHs were only detected in surface sediments, except in two samples, and did not contain naphthalene. Ratios of PAHs suggest that the detected PAHs were derived from a variety of sources including the combustion of petroleum and non-petroleum products. It is probable that some PAHs are also derived from petroleum spills (diesel, motor oil, etc.)The PAH values for the surface sediments are highest in the northern section of the bayou where they exceed the TEL but not the PEL. No evidence was found to demonstrate contamination of the sediments by contaminated groundwater from the ETC. However, more study of porewater is required to confirm this. Total petroleum hydrocarbons were determined by FL PRO that is designed to measure concentrations of petroleum hydrocarbons in water and soil in the alkane range of C8-C40. Petroleum was generally found at most bayou/creek sites which are to be expected for an urban bayou/creek system. There are presently no applicable sediment quality guidelines for this general range of hydrocarbons. Petroleum products at low levels in the presence of bacteria, nutrients, solar radiation, and oxygen will be expected degrade (Lepo et al., 2003).

Dredging has been discussed as an option to reduce pollution in the bayou. The current study shows for non-fluoride pollutants that only the upper 30 cm or less is polluted. It is likely that the only concerns with dredging of lower sediment layers will be issues of turbidity, and disposal problems will be minimal. Historical maps show that the mouth of the bayou at least at some times in the past was wider than it is now, and thus natural flushing of the bayou may have been better. It is recommended that studies focusing on improving the flushing of the bayou be undertaken to avoid repeated dredging.

Septic systems in proximity to Bayou Texar have been greatly reduced in recent years. Although this is a very important evolution, continued efforts are needed to identify sources of input and to further diminish bacteria loading to the bayou. Various other mitigation efforts are currently underway or are being considered. Planting submerged vegetation and measures recommended by the Citizens Task Force on Urban Stormwater Runoff (2003), if implemented properly in the Bayou Texar/Carpenter’s Creek watershed, have the potential to greatly improve the environmental quality of the bayou.

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APPENDIX 1
TABLES

Table 1: Total radium activity [pCi/L] in monitoring wells in ACC plume (URS, 2003).

year	AC-2D**	AC-3D	NWD-4D	AC-8D	AC-12D	AC-13D	AC-25D	AC-29D	AC-30D	AC-35D	AC-36D
1992	**9.8**[#]	**20.8**	-*	-	-	4.2	**7.9**	-	-	-	-
1997	0.6	16.81	2.4	<0.6	8.4	5.4	5.5	10.56	10.9	-	-
1999	<1.0	2.1	<1.0	**3.6**	<1.0	-	<1.0	10.4	12.0	<1.0	<1.0
2000	3.7	7.5	2.7	**3.6**	4.2	**7.9**	1.2	12.7	17.2	6.5	**5.0**
2001	3.5	5.8	1.4	3.5	4.9	5.6	1.5	15.4	12.7	9.1	**5.1**
2002	3.1	19.1	**10.2**	3.5	**10.5**	7.0	**8**	**18.2**	**15.9**	**10.5**	2.9

[*] -: No sample taken.
** D indicates well was screened in the MPZ (Main Producing Zone)
# bold: Highest activity for well.

Table 2: Coordinates for sampling locations [decimal degrees].

Phase 1 samples			Phase 2 samples		
sample ID	latitude	longitude	sample ID	latitude	longitude
Fl-1	30.45905	-87.20595	G-1	30.42463	-87.18718
Fl-2	30.46007	-87.20869	G-2	30.42195	-87.18664
Fl-3	30.45905	-87.20595	G-3	30.42517	-87.18772
Fl-4	30.45539	-87.20387	G-4	30.42775	-87.18853
Fl-5	30.45189	-87.19994	G-5	30.42952	-87.19121
Fl-6	30.44499	-87.18723	G-6	30.43056	-87.18986
Fl-7	30.43051	-87.18916	G-7	30.4307	-87.18605
Fl-8	30.42379	-87.18779	G-8	30.43155	-87.18568
Fl-9	30.41903	-87.19280	G-9	30.43454	-87.18343
Fl-10	30.46737	-87.21021	G-10	30.43666	-87.18504
TN-1	30.45752	-87.20502	G-11	30.44001	-87.18891
TN-2	30.45759	-87.20748	G-12	30.43971	-87.18979
TN-3	30.45756	-87.20444	G-13	30.4436	-87.18669
TM-1	30.45518	-87.20422	G-14	30.44497	-87.18726
TM-2	30.45535	-87.20396	G-15	30.44783	-87.19110
TM-3	30.45565	-87.20357	G-16	30.44721	-87.19183
TS-1	30.45466	-87.20363	G-17	30.4498	-87.19374
TS-2	30.45501	-87.20342	G-18	30.44956	-87.19492
TS-3	30.45528	-87.20295	G-19	30.4492	-87.19598
C1	30.45935	-87.20731	G-20	30.4516	-87.19878
C2	30.45900	-87.20578	G-21	30.45134	-87.20181
C3	30.45724	-87.20466	G-22	30.45406	-87.20249
C4	30.45599	-87.20479	G-23	30.4599	-87.20788
C5	30.45507	-87.20370	G-24	30.45988	-87.20854
C6	30.45539	-87.20413	G-25	30.41901	-87.19252
C7	30.45182	-87.20123	G-26	30.42143	-87.19008
C8	30.44900	-87.19597	G-27	30.45695	-87.20520
C9	30.44696	-87.19190	TC-1	30.45837	-87.20531
C10	30.44523	-87.18726	TC-2	30.45609	-87.20507
C11	30.43849	-87.18865	TC-3	30.45442	-87.20290
C12	30.43347	-87.18631	TC-4	30.45629	-87.20422
C13	30.42833	-87.19055	TC-5	30.45609	-87.20507
C14	30.45667	-87.20433	TC-6	30.45016	-87.19764
C15	30.45583	-87.20387	TC-7	30.44954	-87.19645
C16	30.45524	-87.20304	TC-8	30.43136	-87.18800
C17	30.45494	-87.20258	TC-9	30.44213	-87.18884
C18	30.45992	-87.20781	TC-10	30.45353	-87.20220
C21	30.45916	-87.20702	TC-11	30.45501	-87.20286
C22	30.46003	-87.20921	TC-12	30.44044	-87.19392

Table 2: Coordinates for sampling locations [decimal degrees] (continued).

Phase 2 samples		
sample ID	latitude	longitude
A-1	30.45745	-87.20466
A-2	30.45684	-87.20525
A-5	30.45575	-87.20421
A-6	30.45540	-87.20429
A-7	30.45041	-87.19840
A-9	30.45672	-87.20451
A-10	30.45055	-87.19669
A-12	30.44263	-87.18726
A-13	30.43495	-87.18550
A-14	30.42333	-87.18815
A-01	30.45595	-87.20412
A-02	30.45007	-87.19751
A-03	30.44278	-87.18844
A-04	30.43290	-87.18438
A-05	30.42177	-87.19074
A-07	30.45678	-87.20449
A-08	30.45585	-87.20400

Table 3: Depth distribution of fluoride in sediment and sediment porewater, 2004.

sample ID	sediment [mg/kg]				sediment porewater [mg/L]					
	0 m	1 m	2 m	3 m	0 m	1 m	2 m	3 m	4 m	5 m
TC-1	220	<8.2	<12	<8.0	7.84	2.02	0.70	0.89	n/a	n/a
TC-2	230	<9.1	<10	<8.7	2.99	1.89	0.97	<0.20	n/a	n/a
TC-3	100	<12	<13	13	4.2	1.02	<0.20	6.07	n/a	n/a
TC-4	200	800	73	39	14.17	112.74	11.05	111.11	n/a	n/a
TC-5	230	94	15	21	6.44	3.30	1.14	1.10	13.37	18.00
TC-6	36	14	<8.9	<5.2	0.96	2.11	2.03	<0.20	n/a	n/a
TC-7	<11	<9.1	<7.5	<4.7	0.42	<0.20	<0.20	<0.20	n/a	n/a
TC-8	11	<8.9	<9.5	<9.1	1.44	3.17	2.57	2.08	n/a	n/a
TC-9	<12	<8.9	<5.1	n/a*	1.23	0.66	<0.20	n/a	n/a	n/a
TC-10	33	<8.9	<11	<5.8	4.00	1.33	1.03	<0.20	n/a	n/a
TC-11	25	<11	<7.0	n/a	0.54	<0.20	<0.20	n/a	n/a	n/a
TC-12	<14	<5.6	<11	<6.3	<0.20	<0.20	<0.20	<0.20	n/a	n/a

* n/a: Sample could not be obtained with vibracore.

Table 4: Fluoride in bayou bottomwater and sediment porewater [mg/L], 2004.

sample ID	bayou water F	 salinity [ppt]	porewater 0-30 cm F	porewater 60-90 cm F
A-1	1.0	9.5	7.48	2.80
A-2	0.84	6.8	1.74	0.76
A-5	1.1	11.0	12.64	19.89
A-6	0.95	9.4	3.28	3.49
A-7	0.66	9.6	0.56	<0.20
A-9	1.5	8.2	61.69	62.78
A-10	0.55	9.0	<0.20	<0.20
A-12	0.43	9.8	0.96	<0.20
A-13	0.41	10.9	0.85	0.62
A-01	1.2	8.3	6.94	1.10
A-02	0.46	10.8	<0.20	<0.20
A-03	0.45	9.6	0.47	<0.20
A-04	0.63	16.7	1.06	1.14
A-05	0.42	15.7	0.98	0.63
A-07	1.2	7.7	9.57	19.8
A-08	1.8	8.2	4.4	0.88
A-14	0.62	10.9	0.61	0.59

Table 5: Depth distribution of fluoride in sediment [mg/kg], 2003.

sample ID	depth A*	depth B*	depth C*
C1	41	<7.3	n/a§
C2	82	<11	<5.3
C3	180	18	<19
C4	240	94	33
C5	240	9.8	<9.1
C6	930	280	170
C7	40	<8.5	<6.5
C8	30	14	<6.1
C9	23	18	14
C10	44	<8.3	<9.8
C11	13	<13	<7.8
C12	14	<6.1	-n/a
C13	13	<8.3	<5.9
C14	470	<9.3	<12
C15	54	<11	<10
C16	220	<6.3	<10
C17	33	<11	<9
C18	22	<4.2	n/a
C19	<5.1	<6.3	n/a
C21	<18	<7.4	<4.5
C22	6.1	<6.6	<6.2
TN-1	140	-#	<8.2 (107-130 cm)
TN-2	270	<12 (168-198 cm)	<6.7 (340-363 cm)
TN-3	94	-	<4.5 (223-246 cm)
TM-1	67	-	<14 (181-204 cm)
TM-2	260	515 (89-135 cm)	610 (201-224 cm)
TM-3	250	-	<5.6 (185-208 cm)
TS-1	32	-	<8.0 (193-216 cm)
TS-2	290	-	21 (201-224 cm)
TS-3	53	-	<4.4 (198-221 cm)

* : Depths are not consistent between cores, Cores C1-22 were A = surface (0-30 cm), B = middle (B 56-86 cm), C= bottom (142-173 cm) of core. Values for TN, TM, & TS for level A were 1-23 cm; for levels B&C depths are placed in parentheses next to fluoride mg/kg concentrations.

-: No sample taken.

§ n/a: Sample could not be obtained with vibracore.

Table 6: Characterization of bayou bottomwater, 2003.

sample ID	radium [pCi/L]	fluoride [mg/L]	salinity [ppt]	pH
Fl-2	1.66	<0.20	<2.0	6.1
Fl-3	1.76	0.84	8.1	6.7
Fl-4	1.41	0.84	7.9	6.9
Fl-5	1.43	0.8	13	7.3
Fl-6	0.736	0.73	17	7.7
Fl-7	0.744	0.75	14	7.7
Fl-8	0.687	0.74	18	7.8
Fl-9	0.516	0.71	21	8
Fl-10	1.39	<0.20	<2.0	6.6

Table 7: Depth distribution of total radium in sediment [pCi/g], 2003.

sample ID	depth A*	flag**	depth B*	Flag**	depth C*	flag**
TN-1	2.82		-#		1.44	Ra226-j & 228-u
TN-2	2.44		2.21		2.48	
TN-3	2.87		-		0.85	Ra-226-J & 228-u
TM-1	4.34		-		3.21	
TM-2	3.50		4.05		3.1	
TM-3	2.24	Ra- 228-j	-		2.70	
TS-1	3.76		-		4.61	
TS-2	3.93		-		5.38	
TS-3	3.56		-		1.27	Ra-226-j & 228-j

*: Depths are not consistent between cores, A = surface, B = middle, C= bottom of core.
-: No sample taken.
**: Flag for Ra-226/Ra-228: u-sample is less than the detection limit and j-sample is less than reporting limit but greater than the detection limit.

Table 8: Depth distribution of total radium in sediment [pCi/g], 2004.

sample ID	0 m	flag*	1 m	flag*	2 m	flag*	3 m	flag*
TC-1	2.70	J/	2.52	J/	2.28	J/	1.40	J/U
TC-2	4.86		2.88		3.54		3.59	
TC-3	2.56		1.83	J/J	2.23	/J	0.55	J/U
TC-4	3.29	J/	1.30	J/U	4.23		1.12	J/U
TC-5	2.86	J/	4.20		3.25		3.51	
TC-6	2.11	/J	2.06		2.45		2.65	/J
TC-7	2.95		4.46		1.54	J/J	1.01	J/U
TC-8	2.12		3.02		2.18		2.08	/J
TC-9	2.13	J/	2.05	/J	1.79	J/J	n/a#	
TC-10	2.70		1.39	J/J	2.09	J/	1.31	J/J
TC-11	7.97		3.65		3.07		n/a#	
TC-12	2.58		3.81		2.64		3.57	/J

*: Flag for Ra-226/Ra-228. U-sample is less than the detection limit and J-sample is less than reporting limit but greater than the detection limit.

n/a: Sample could not be obtained with vibracore.

Table 9: Total radium in surface sediments [pCi/g], 2004.

sample ID	radium	flag Ra-226/Ra-228*
G-1	0.84	J/U
G-2	0.60	J/U
G-3	0.61	J/U
G-4	2.14	J/
G-5	1.18	J/U
G-6	1.54	J/J
G-7	0.56	J/U
G-8	2.14	/U
G-9	2.04	J/
G-10	2.19	J/
G-11	1.61	J/J
G-12	1.46	J/
G-13	2.29	J/
G-14	2.83	
G-15	3.04	
G-16	2.35	J/
G-17	0.97	J/U
G-18	2.39	
G-19	2.71	
G-20	2.73	
G-21	1.77	J/J
G-22	2.23	J/
G-23	1.70	J/J
G-24	0.56	U/U
G-25	0.50	J/U
G-26	0.24	U/
G-27	2.09	J/U

*: Flag for Ra-226/Ra-228. U-sample is less than the detection limit and J-sample is less than reporting limit but greater than the detection limit.

Table 10a: Radium activity and related parameters for monitoring wells, 1992 (URS, 2003).

depth*	well ID	total Ra pCi/L	Ra-226 pCi/L	Ra-228 pCi/L	Ra 228/226 ratio	pH	SO4 mg/L	F mg/L
deep wells	AC-12D	10.5	1.9	8.6	4.5	3.8	310	11
	AC-29D	18.2	1.7	16.5	9.7	3.9	340	59
	AC-30D	15.9	2.8	13.1	4.7	3.9	250	61
	AC-35D	10.5	2	8.5	4.3	3.9	230	170
	AC-13D	7	1.3	5.7	4.4	4	250	6.7
	AC-25D	8	2.9	5.1	1.8	4.2	80	48
	AC-3D	19.1	1.3	17.8	13.7	4.2	380	46
	AC-2D	3.1	1.1	2	1.8	4.4	18	3.2
	AC-8D	3.5	1.5	2	1.3	4.4	<5.0	<0.2
	AC-36D	2.9	1	1.9	1.9	4.5	17	<0.2
	NWD-4D	10.2	3.7	6.5	1.8	4.5	29	<0.2
shallow wells	AC-24S	0.6	0.3	0.3	1	4.4	4.3	<0.2
	NWD-2S	1.8	0.7	1.1	1.6	4.4	28	3.1
	AC-26S	2.2	0.7	1.5	2.1	4.4	22	<0.2
	NWD-4S	1.7	0.6	1.1	1.8	4.8	<5.0	<0.2
	AC-5S	1.5	0.5	1	2	5	21	<0.2
	AC-2S	0.1	0.1	0	0	6	22	210
	AC-3S	1	0.4	0.6	1.5	6.4	13	<0.2

*: Deep wells are screened in the MPZ (main producing zone) and shallow wells are screened closer to the surface (above the MPZ).

Table 10b: Average ratios for Radium-228/2226 for sediment cores.

sediment level	Means* & st. dev.	total pCi/g	% Ratio Ra-228/Ra-226
surface	mean (n=9)	3.2	100.5
	st. dev.	±1.66	
subsurface	mean (n=13)	2.8	87.9
	st. dev.	±1.09	

*: Ra-228 & 226 from sediment core series TS, TM, TN were averaged and means were calculated.

Table 11: Ratios of total PAHs to total petroleum in surface sediments, 2003.

sample ID	total PAH μg/kg	total petroleum mg/kg	PAH to total petroleum ratio
SG-1	BRP*	BRP	
SG-2	BRP	23.0	
SG-3	0.913	290	0.003
SG-4	0.13	320	0.0004
SG-5	BRP	41.0	
SG-6	BRP	100.0	
SG-7	1.221	49	0.025
SG-8	12.06	340	0.035
SG-9	4.065	43	0.095
SG-10	7.515	180	0.042
SG-11	8.584	180	0.048
SG-12	13.51	1700	0.008
SG-13	3.91	220	0.018
SG-14	0.16	110	0.001
SG-15	2.78	340	0.008
SG-16	BRP	31.0	
SG-17	BRP	3.0	
SG-18	2.71	37	0.073
SG-19	BRP	40.0	
SG-20	5.59	400	0.014
SG-21	BRP	280	
SG-21Dup	BRP	250	
SG-22	1.17	130	0.009

*: BRP - Below Reporting Limit

Table 12: Ratios of PAHs in surface sediments, 2003.

Sample ID*	Fluoranthene#	Phenanthrene#	Pyrene#
SG-3	342	100	260
SG-7	423	100	310
SG-8	403	100	284
SG-9	200	100	137
SG-10	246	100	185
SG-11	250	100	181
SG-12	500	100	404
SG-13	304	100	231
SG-18	169	100	128
SG-22	235	100	250
C1-A	383	100	255
C3-A	458	100	407
C4-A	576	100	424
C12-A	204	100	161
C13-A	217	100	204
C14-A	628	100	488
C15-A	611	100	506
C16-A	757	100	649
C18-A	680	100	560

*: SG: Sediment grab sample; C: 0-30 cm level in vibracore.
#: Ratios are based on calculating Phenanthrene to 100 and calculating the relative percent difference to Fluoranthene and Pyrene, i.e. (100/µg Phenanthrene) x µg of Phenanthrene, Fluoranthene, or Pyrene.

Table 13: PAH origin indicator ratios.

PAH Ratio	Petroleum release	Vehicle, crude oil combustion	Combustion grass, wood, coal	Creosoted wood pilings
An/(Pn+An)*	<0.10	>0.10	>0.10	>0.18
Fl/(Fl+Py)#	<0.40	0.40-0.50	>0.50	>0.62
IP/(IP+Bghi) §	<0.20	0.20 to 0.50	>0.50	>0.62

*: An/(Pn+An) = Ratio of Anthracene/ Anthracene+ Phenanthrene
#: Fl/(Fl+Py) = Ratio of Fluoranthene/ Fluoranthene+ Pyrene
§: IP/(IP+Bghi) = Ratio of Indeno(1,2,3-c,d)Pyrene/ Indeno(1,2,3- c,d)Pyrene + Benzo(g,h,i)Perylene

Table 14: Ratios of PAHs for samples with detectable levels of required PAHs.

sample ID	An/(Pn+An)*	Fl/(Fl+Py)#	IP/(IP+Bghi) §
C1-A&		0.600	0.475
C3-A	0.181	0.529	0.466
C4-A		0.576	0.450
C5-A		0.556	
C6-A		0.563	0.485
C7-A		0.541	0.474
C12-A		0.560	0.457
C13-A		0.515	
C14-A		0.563	0.478
C15-A		0.547	0.475
C16-A		0.538	0.458
C18-A		0.548	0.462
C21-A		0.513	
C22-A		0.550	
C22-ADup		0.522	
SG-3		0.568	
SG-7		0.577	
SG-8		0.587	0.495
SG-9	0.156	0.594	0.484
SG-10	0.111	0.571	0.483
SG-11	0.070	0.581	0.479
SG-12		0.553	0.465
SG-13		0.568	0.444
SG-15		0.565	
SG-18		0.568	
SG-20		0.588	0.446
SG-22		0.485	
SG-22Dup		0.473	

*: An/(Pn+An)= Ratio of Anthracene/ Anthracene+ Phenanthrene
#: Fl/(Fl+Py) = Ratio of Fluoranthene/ Fluoranthene+ Pyrene
§: IP/(IP+Bghi) = Ratio of Indeno(1,2,3-c,d)Pyrene/ Indeno(1,2,3-c,d)Pyrene+Benzo(g,h,i)Perylene
&: C = sediment core sample; SG = sediment grab sample

Table 15: Phthalates in μg/kg from surface sediments, 2003.

sample ID	analytes	mg/kg
SG-1	All values are <RL[*]	<RL
SG-2	All values are <RL	<RL
SG-3	All values are <RL	<RL
SG-4	bis(2-Ethylhexyl)phthalate	160J[#]
SG-5	All values are <RL	<RL
SG-6	All values are <RL	<RL
SG-7	All values are <RL	<RL
SG-8	bis(2-Ethylhexyl)phthalate	230 J
SG-9	All values are <RL	<RL
SG-10	bis(2-Ethylhexyl)phthalate	110 J
SG-11	bis(2-Ethylhexyl)phthalate	170 J
SG-12	Di-n-butylphthalate	770J
SG-12	bis(2-Ethylhexyl)phthalate	950 J
SG-13	bis(2-Ethylhexyl)phthalate	220 J
SG-14	All values are <RL	<RL
SG-15	All values are <RL	<RL
SG-16	All values are <RL	<RL
SG-17	All values are <RL	<RL
SG-18	All values are <RL	<RL
SG-19	All values are <RL	<RL
SG-20	bis(2-Ethylhexyl)phthalate	560 J
SG-21A	All values are <RL	<RL
SG-21Dup	All values are <RL	<RL
SG-22	All values are <RL	<RL
SG-22-Dup	All values are <RL	<RL

[*] < RL: Below reporting limit.

[#] J: Estimated concentration; detected values below lowest limit for quantification.

Table 16. Phthalates in µg/kg from vibracores, 2003.

sample ID	analytes	depth A*	depth B*	depth C*
C1	bis(2-Ethylhexyl)phthalate	930	<RL[#]	-[ns]
C1	Butylbenzylphthalate	273 J[§]	<RL	-[ns]
C1	Di-n-butylphthalate	270J	<RL	<RL
C3	Di-n-butylphthalate	780 J	<RL	<RL
C3	bis(2-Ethylhexyl)phthalate	1000 J	<RL	<RL
C4	Di-n-butylphthalate	550 J	<RL	<RL
C4	bis(2-Ethylhexyl)phthalate	940 J	<RL	<RL
C5	All values are <RL[1]	<RL	<RL	<RL
C6	Di-n-butylphthalate	590 J	<RL	<RL
C6	bis(2-Ethylhexyl)phthalate	800 J	<RL	<RL
C7	bis(2-Ethylhexyl)phthalate	300 J	<RL	<RL
C8	Di-n-butylphthalate	540 J	260 J	130 J
C8	bis(2-Ethylhexyl)phthalate	340 J	170 J	<RL
C9	Di-n-butylphthalate	430 J	380 J	330 J
C9	bis(2-Ethylhexyl)phthalate	<RL	200 J	<RL
C10	bis(2-Ethylhexyl)phthalate	970 J	<RL	<RL
C10	Di-n-butylphthalate	1300 J	180 J	240 J
C11	Di-n-butylphthalate	430 J	330 J	210 J
C12	All values are <RL[1]	<RL	<RL	-[ns]
C13	All values are <RL[1]	<RL	<RL	<RL
C14	bis(2-Ethylhexyl)phthalate	1700 J	<RL	<RL
C15	bis(2-Ethylhexyl)phthalate	480 J	<RL	380 J
C16	bis(2-Ethylhexyl)phthalate	1100J	<RL	<RL
C17	All values are <RL[1]	<RL	<RL	<RL
C18	bis(2-Ethylhexyl)phthalate	440 J	<RL	-[ns]
C19	All values are <RL[1]	<RL	<RL	-[ns]
C21	All values are <RL[1]	<RL	<RL	<RL
C22	bis(2-Ethylhexyl)phthalate	<RL	200 J	<RL
C22Dup	bis(2-Ethylhexyl)phthalate	110 J	200 J	<RL

[*]: Depths are not consistent between cores were A = surface (0-30 cm), B = middle (B 56-86 cm), C= bottom (142-173 cm).

[#] <RL: Below reporting limit.

[§] J: Estimated concentration; values below lowest limit for quantification.

-[ns] : No sample taken at this level.

Table 17. Carbazole in μg/kg from surface sediments from grab samples.

sample ID	Carbazole
SG-1	<370
SG-2	<470
SG-3	<530
SG-4	<660
SG-5	<440
SG-6	<470
SG-7	<550
SG-8	160 J*
SG-9	<450
SG-10	90 J
SG-11	120 J
SG-12	<2200
SG-13	<540
SG-14	<720
SG-15	<1600
SG-16	<450
SG-17	<440
SG-18	<950
SG-19	<490
SG-20	<1700
SG-21A[#]	<1500
SG-21B[#]	<1600
SG-22A[#]	<1600
SG-22B[#]	<1500

* J: Estimated concentration; values below lowest limit for quantification.
[#]: Field duplicates.

Table 18. Carbazole in µg/kg from sediment from vibracores, 2003.

sample ID	depth A*	depth B*	depth C*
C1	<780	<600	-ns
C2	<1200	<880	<440
C3	450 J#	<1300	<1600
C4	950 J	<800	<920
C5	<1600	<740	<750
C6	<2800	<900	<720
C7	<1000	<700	<530
C8	<1000	<630	<500
C9	<1100	<850	<830
C10	<2800	<700	<810
C11	<1100	<1100	<640
C12	300 J	<490	-ns
C13	<970	<680	<480
C14	<2200	<770	<1000
C15	<1300	<580	<850
C16	<2200	<520	<870
C17	<1100	<900	<750
C18	<1100	<350	-ns
C19	<420	<510	-ns
C21	<730	<300	<370
C22	<490	<550	<510
C22Dup	<450	<570	<460

*: Depths are not consistent between cores were A = surface (0-30 cm), B = middle (B 56-86 cm), C= bottom (142-173 cm).

J: Estimated concentration; values below lowest limit for quantification.

-ns **:** No sample at this level.

Table 19: Pesticides in sediment grab samples [μg/kg], 2003.

Sample ID	Aldrin	alpha-BHC	alpha-Chlordane	gamma-Chlordane	DDD	beta-BHC	DDE	DDT	delta-BHC	Dieldrin	Endosulfan I	Endosulfan II
SG-1	<1.9**	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9
SG-2	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4
SG-3	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7
SG-4	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4
SG-5	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2
SG-6	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4
SG-7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7
SG-8	<4.4	<4.4	<4.4	<4.4	<4.4	3	<4.4	<4.4	<4.4	<4.4	3.1	<4.4
SG-9	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4
SG-10	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2
SG-11	<2.0	<2.0	<2.1	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	2.7	<2.0
SG-12	<110	<110	<110	<110	<110	<110	<110	<110	<110	<110	<110	<110
SG-13	<27	<27	<27	<27	<27	<27	<27	<27	<27	<27	<27	<27
SG-14	<17	<17	<17	<17	<17	<17	<17	<17	<17	<17	<17	<17
SG-15	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2
SG-16	<22	<22	<22	<22	<22	<22	<22	<22	<22	<22	<22	<22
SG-17	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3
SG-18	<48	<48	<48	<48	<48	<48	<48	<48	<48	<48	<48	70
SG-19	<26	<26	<26	<26	<26	<26	<26	<26	<26	<26	<26	61
SG-20	<83	<83	<83	<83	<83	<83	<83	<83	<83	<83	<83	<83
SG-21A*	<8.0	<8.0	<8.0	<8.0	<8.0	<8.0	<8.0	<8.0	<8.0	<8.0	<8.0	<8.0
SG-21B*	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	2.3	2.1	<8.2	<8.2	<8.2	<8.2
SG-22A*	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	1.7	<8.2	<8.2	<8.2	<8.2
SG-22B*	<7.6	<7.6	<7.6	<7.6	<7.6	<7.6	<7.6	1.7	<7.6	<7.6	<7.6	<7.6

*: Field duplicates.

**. Below reporting limits is indicated by <.

Table 19: Pesticides in sediment grab samples [μg/kg], 2003 (continued).

Sample ID	Endosulfan sulfate	Endrin	Endrin aldehyde	Endrin ketone	gamma-BHC (Lindane)	Heptachlor	Heptachlor epoxide	Methoxychlor	Toxaphene
SG-1	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<110	<1.10
SG-2	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<140
SG-3	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<160
SG-4	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	<200
SG-5	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<130
SG-6	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<140
SG-7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<2.7	<160
SG-8	<4.4	<4.4	<4.4	5.3	<4.4	<4.4	<4.4	<4.4	<260
SG-9	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<140
SG-10	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<130
SG-11	<2.0	<2.0	<2.0	<2.0	<2.0	0.56	<2.0	<2.0	<120
SG-12	<110	<110	<110	<110	<110	<110	<110	<110	<6600
SG-13	<27	<27	<27	<27	<27	<27	<27	<27	<1600
SG-14	<17	<17	<17	<17	<17	<17	<17	<17	<1000
SG-15	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	<480
SG-16	<22	<22	<22	<22	<22	<22	<22	<22	<130
SG-17	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<1302
SG-18	<48	<48	<48	<48	<48	<48	<48	<48	<2800
SG-19	<26	<26	<26	<26	<26	<26	<26	<26	<1500
SG-20	<83	<83	<83	<83	<83	<83	<83	<83	<4900
SG-21A*	<8.0	<8.0	<8.0	<8.0	<8.0	<8.0	<8.0	<8.0	<470
SG-21B*	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	<480
SG-22A*	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	<8.2	<480
SG-22B*	<7.6	<7.6	<7.6	<7.6	<7.6	<7.6	<7.6	<7.6	<450

*: Field duplicates.
**. Below reporting limits is indicated by <.

Table 20: Metals in sediment surface grab samples [mg/kg], 2004.

sample ID	bathymetric location	As	Cd	Cu	Pb	Sb	Th	Zn	Hg
G-1	shallow	<0.52	<0.52	<1.0	2.0	<5.2	<1.0	7.7	<0.0084
G-2	shallow	0.85	<0.51	2.6	4.8	<5.1	<1.0	19	0.017
G-3	deep	<0.65	<0.65	<1.3	2.1	<6.5	<1.3	5.6	<0.011
G-4	deep	24	<1.5	31	68	<15	<3.0	220	0.26
G-5	shallow	0.97	<0.52	4.6	18	<5.2	<1.0	30	0.013
G-6	deep	2.7	<0.52	4.6	13	<5.2	<1.0	38	0.052
G-7	shallow	<0.67	<0.67	3.9	5.4	<6.7	<1.3	15	<0.011
G-8	deep	21	<1.6	39	100	<16	<3.2	270	0.34
G-9	deep	18	<1.7	38	90	<17	<3.3	260	0.29
G-10	shallow	7.9	<0.62	17B*	39	<6.2	<1.2	120	0.14
G-11	deep	6.6	<0.53	8.8B	27	<5.3	<1.1	110	0.10
G-12	shallow	3.5	<1.0	24B	27	<10	<2.0	110	0.097
G-13	shallow	18	<1.8	53B	130	<18	<3.6	390	0.42
G-14	deep	5.8	<0.77	18B	43	<7.7	<1.5	130	0.14
G-15	shallow	7.4	<0.77	28B	64	<7.7	<1.5	200	0.21
G-16	deep	18	<2.1	68B	150	<21	<4.1	510	0.52
G-17	shallow	1.5	<0.60	6.7B	15	<6.0	<1.2	58	0.050
G-18	intermediate	12	<1.4	68B	140	<14	<2.8	490	0.53
G-19	deep	15	<1.3	46B	99	<13	<2.6	340	0.32
G-20	deep	11	1.4	80B	99	<13	<2.6	500	0.73
G-21	shallow	7.5	1.5	81B	110	<15	<2.9	470	0.43
G-22	deep	15	2.5	260B	170	<24	<4.8	960	1.6
G-23	shallow	6.8	<1.2	36	69	<12	<2.3	150	0.80
G-24		0.95	<0.45	2.8	8.4	<4.5	<0.91	16	0.063
G-25	deep	0.73	<0.41	0.95	2.8	<4.1	<0.83	5.8	<0.011
G-26	deep	1.1	<0.54	1.6	3.8	<5.4	<1.1	17	0.013
G-27A[#]		18	<2.8	210	190	<28	<5.6	720	1.5
G-27B[#]		14	<2.5	180	170	<25	<5.1	620	1.4
Min.		0.73	1.4	0.95	2			5.6	0.013
Max.		21	2.5	260	190			960	1.5
Mean		10			68			258	0.885

*. B flag denotes analyte was detected in the method blank and client's sample, but method blank values was less than one fifth of total value detected in field sample.

[#]: Field replicates.

Table 21. Geomeans of *Enterococcus* counts for Dec ‘99 - Dec ‘03 and Aug ‘04- Dec ‘04*.

station	‘99-‘03 geomean CFU/100 ml	‘04 geomean CFU/100 ml
Burgess Road	1340	338
Springhill	509	457
Walton/Davis	469	1081

*: Data collected by Florida Department of Health Escambia County Health Department.

Table 22: Fluoride concentrations [mg/L] in monitoring wells, URS (2003) data.

well ID*	1992	1997	1999	2000	2001	2002
AC-2D	**5.5**[#]	2.9	3.5	3.0	3.0	3.2
AC-3D	**80**	46	14	18	13	46
AC-29D	-[ns]	**65**	**65**	45	48	59
AC-30D	-[ns]	15	18	11	11	**61**
AC-25D	19	20	2.6	3.3	2.9	**48**
AC-35D	-[ns]	-[ns]	23	150	160	**170**
AC-12D	2.6	8.8	0.5	6.7	1.7	**11**
AC-13D	5.3	4.9	-[ns]	4.6	4.7	**6.7**

*: Wells are listed in order of increasing distance from ACC site. Distance from AC-35D to ACC is somewhat larger than distance from AC-12D but AC-12D and AC-13D are listed at bottom of table to indicate they are south of ACC Site and of other wells.
[#]: Bold print indicates highest concentration for given well.
-[ns]: No sample taken (URS, 2003).