

ENVIRONMENTAL CONTAMINANTS
EVALUATION
OF
ST. ANDREW BAY, FLORIDA

Volume 1

Publication No. PCFO-EC 98-01

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1998

TITLE: Environmental Contaminants Evaluation of St. Andrew Bay, Florida

ABSTRACT: Between 1985 and 1997, a general survey of St. Andrew Bay, Florida, was conducted to measure chemical contaminant concentrations in the sediments and selected biota. The Bay is a 27,900 hectare (69,000 acre) high-salinity estuary located in the northwest "panhandle" of the State. Sediment samples were collected at 105 locations within the Bay and analyzed for metals, organochlorine pesticides, polychlorinated biphenyls, polycyclic aromatic hydrocarbons, and aliphatic hydrocarbons. Sediment samples were evaluated using recently published sediment quality guidelines, scored for total chemical contamination, and ranked and categorized to allow comparison between sediment stations. Five sediment samples were also analyzed (1994 - 1997) for polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans.

Based on the evaluation of sediment samples, contamination of sediments has occurred in St. Andrew Bay. Both historic and contemporary human activities are responsible for this contamination. These activities include: urban stormwater runoff, municipal and industrial point source discharges, historic oil spillage, marina repair operations, and pollution associated with commercial vessels and recreational boats. While some sites in the open Bay have experienced varying degrees of contamination, the most acute impacts have occurred in some of the bayous of the Bay; notably Watson Bayou, Massalina Bayou, Martin Lake, and Shoal Point Bayou. Evaluation of invertebrate and fish samples collected in 1985 and 1986 revealed some moderate contamination in the tissues of the species tested. Effects of this contamination on species survival and reproduction are, to date, unknown.

Sediment samples analyzed for dioxin compounds at seven locations in St. Andrew Bay (including two locations sampled by the U.S. Army Corps of Engineers) had toxicity equivalent (TEQ) concentrations that ranged from 2 to 33 picograms/gram (ppt) dry weight.

KEYWORDS: St. Andrew Bay, sediment, metals, mercury, dioxin, dibenzofuran, aliphatic hydrocarbon, polycyclic aromatic hydrocarbon, PAH, polychlorinated biphenyl, PCB, blue crab, shrimp, spotted seatrout, sediment quality guidelines.

ACKNOWLEDGMENTS

The completion of this project would not have been possible without the dedicated assistance and support of many talented people. I am especially indebted to my Fish and Wildlife Service (Service) colleague, Waynon Johnson, for his encouragement and support in establishing an environmental contaminants program at the Panama City Field Office. I thank my Service colleagues Dr. Donald Schultz, Dr. Parley Winger, Jim Barkuloo, Gail Carmody, Dr. Charles Facemire and Jerry O'Neal for their continuous support of the program, and their many valuable technical/professional contributions.

Many people assisted in the field collection of sediment and biotic samples. For their assistance in "mud grabbing," I owe a debt of gratitude to Pledger Moon, Dr. Ed Keppner, Lisa Keppner, Waynon Johnson, Dr. Parley Winger, Dr. Wayne Isphording, Laura Jenkins, Shelly DuPuy, Kennard Watson, Bob Jarvis, Diane Bateman, and Lorna Patrick. For their help in the collection of biotic samples, I thank Lloyd Stith, John Foster, Jody Wood, and Ed and Lisa Keppner.

For support related to sample analyses, I thank Mr. John Moore (Patuxent Analytical Control Facility) and Dr. Wayne Isphording (University of South Alabama, Mobile).

Several people assisted in the preparation and review of this report. I thank Dr. Donald MacDonald (MacDonald Environmental Sciences, Ltd., British Columbia), Dr. Lisa Pratt (Indiana University), Mr. Fred Calder (Florida Department of Environmental Protection, Dr. Ed Keppner (National Marine Fisheries Service), and Lorna Patrick and Gail Carmody (Fish and Wildlife Service) for their critique of the report. I also appreciate the assistance in preparing this report that has been provided by Diane Bateman, Bob Jarvis, Kathy Hoffmaster, and Frank Finchum.

Finally, a special thanks to Dr. Ed Keppner for his particularly dedicated interest and never ending support of this work, and all scientific investigations, having to do with that valuable coastal resource we call St. Andrew Bay.

PREFACE

This work was accomplished and funded through the U.S. Fish and Wildlife Service's Division of Environmental Contaminants. Study cooperators included: Athens, Georgia Field Office of the Columbia National Fisheries Laboratory (now within the U.S. Geological Survey) and the Regional Office of the U.S. Fish and Wildlife Service, Atlanta, Georgia. Questions, comments and suggestions related to this report are encouraged. Written inquires should be directed to the Service at the following address:

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INTRODUCTION

St. Andrew Bay, located in northwest Florida (the panhandle), has a total surface area at mean high water of 27,973 hectares (69,120 acres) (Figure 1). Total volume of the Bay is approximately 1.02 billion cubic meters (828,541 acre feet) (McNulty *et al.* 1972). The major freshwater inflow source is Econfina Creek. The average discharge from the creek for a 55-year period is 538 cubic feet per second (cfs) (U.S. Geological Survey 1990). The total discharge of all surface freshwater sources, including Econfina Creek, is probably less than 1,000 cfs into this estuary. By comparison, Apalachicola Bay receives approximately 25,000 cfs of fresh water from the Apalachicola River. With minimal introduction of fresh water, and therefore minimal sediment loading, St. Andrew Bay has remained quite deep, since sea level rise flooded coastal creek valleys to create the Bay approximately 5,000 years ago. Without a sediment-laden river to cause turbidity, the waters in the Bay have remained relatively clear, allowing the growth of some 6,200 acres of submerged vegetation. The dominant species is turtle grass (*Thalassia testudinum*), but there are also extensive beds of shoal grass (*Halodule wrightii*) and manatee grass (*Syringodium filiforme*) (McNulty *et al.* 1972). Average salinities are high and salinities of bottom water often exceed 30 parts per thousand (ppt). All of these characteristics create a coastal habitat that allows the Bay to support an unusually high diversity of marine species. A recent inventory of species based on existing, credible records includes documentation of 133 zooplankton, 1,649 benthic and epibenthic invertebrates, 309 fishes, 7 reptiles, 80 birds, and 2 marine mammals (Keppner 1996).

The Bay and most of its watershed are in Bay County, Florida. The watershed covers approximately 1,100 square miles of pine flatwood forests, sandhills, lakes, wetlands and coastal beach sand dunes. Several municipalities are located adjacent or near the shoreline including Panama City, Lynn Haven, Callaway, Cedar Grove, Springfield, Panama City Beach and unincorporated, developed areas. The population of the County is approximately 135,000. The primary chemical contaminant inputs to St. Andrew Bay are urban stormwater runoff, municipal and industrial point source discharges, pollution from recreational boats and marinas, marine repair facilities, oil discharges from vessels or storage facilities, chemical spills from barges or vessels using the Gulf Intracoastal Waterway or the main ship channel, and atmospheric

deposition from industrial emissions, a public waste incinerator, or other remote sources of airborne chemicals.

This report primarily describes a general survey conducted over several years to determine what chemicals may be present in the sediments of the Bay, their locations, and concentrations. As a result of this survey, conducted between 1985 and 1997, 105 sediment stations have been established by the Fish and Wildlife Service (Service) in St. Andrew Bay. The purpose of the survey was also to estimate background chemical concentrations at uncontaminated sites, to identify sites that have been contaminated, to estimate the magnitude of that contamination, and to begin a sediment map for the Bay as an information source for future management decisions. St. Andrew Bay is actually a complex of four estuarine parts, Lower St. Andrew Bay, East Bay, North Bay, and West Bay. Each part has associated bayous, lagoons, tidal creeks and marshes. For the purposes of this report, each major section of the Bay will be discussed as an individual component. Because the bayous may be the most environmentally sensitive areas of the Bay, these smaller waterbodies are discussed in a separate section.

TRUST RESOURCES

The Service has responsibility for the protection and conservation of many trust-resource species which inhabit and use the St. Andrew Bay ecosystem. Trust resources include federally listed endangered and threatened species, migratory birds, some marine mammals, anadromous fishes (fish species living in marine waters and moving regularly to freshwater areas to spawn, rest, and feed), and interjurisdictional fishes (marine fish species being cooperatively managed across state boundaries).

In excess of 170 species of migratory birds have been documented within Bay County, Florida (¹ Florida Audubon Society; Appendix 1). Forty-seven percent apparently use the Bay's habitats in some way; feeding, nesting, and/or resting (Keppner 1996). All of the bird species

¹ All appendices are contained within Volume 3 of this report.

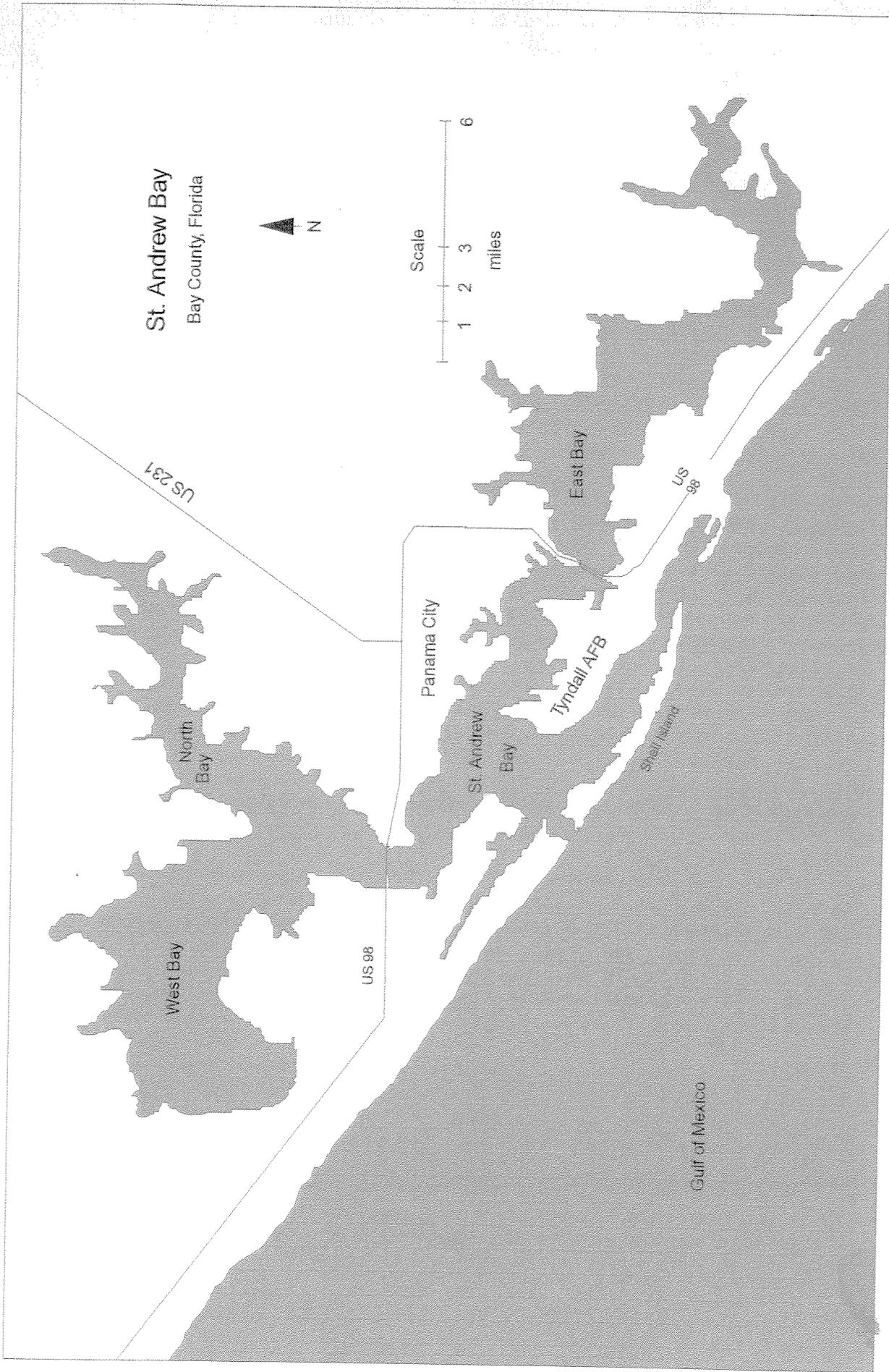


Figure 1. The St. Andrew Bay estuary in Bay County, Florida.

are protected under the Migratory Bird Treaty Act of 1918 (16 U.S.C. Sec 703-711). Important species associated with the Bay include wading birds, waterfowl, shorebirds, and raptors such as the osprey (*Pandion haliaetus*) and bald eagle (*Haliaeetus leucocephalus*). These species rely on quality habitats for their survival including open bay areas, tidal flats and beaches, salt and freshwater marshes, swamps, and even upland forested areas and grassed lands.

Federally listed endangered and threatened species (Endangered Species Act of 1973, as amended; 16 U.S.C. 1531 et seq.) are of particular concern, and include: the *endangered* green turtle (*Chelonia mydas*), leatherback turtle (*Dermochelys coriacea*), and Kemp's ridley turtle (*Lepidochelys kempi*); and the *threatened* bald eagle, loggerhead turtle (*Caretta caretta*), piping plover (*Charadrius melodus*), and Gulf sturgeon (*Acipenser oxyrinchus desotoi*). The Choctawhatchee beach mouse (*Peromyscus polionotus allophrys*), an endangered species, inhabits areas of Shell Island. On rare occasions, the endangered Florida manatee (*Trichechus manatus*) has been known to visit the Bay and utilize the resources it provides. Appendix 2 is a list of all endangered, threatened, and candidate species that are likely to occur in Bay County, and the natural communities with which they are usually associated.

The Service also has trust resource responsibilities for anadromous fishes under the Anadromous Fish Conservation Act of 1965 (16 U.S.C. Sec 757a-757g). Anadromous fishes include striped bass (*Morone saxatilis*) and Alabama shad (*Alosa alabamae*). Striped bass are rare in the Bay, but before the construction of Deer Point Dam, they inhabited North Bay, including Bear and Econfina creeks (Barkuloo 1995, personal communication). Alabama shad (n=51) were collected in St. Andrew Bay from January through March, and from November through December 1973, in monofilament gill nets (Pristas *et al.* 1978). The federally listed threatened Gulf sturgeon is a third anadromous fish that is known to use St. Andrew Bay. One sturgeon was caught and released in Watson Bayou by a Service biologist during this study. The specimen was 122 cm (48 in.) total length (U.S. Fish and Wildlife Service 1985).

Interjurisdictional fishes that use St. Andrew Bay are another group of trust resources. The Service is involved in their conservation and management via provisions of the Magnuson Fishery Conservation and Management Act of 1976 (16 U.S.C. § 1801 et seq.), and the Gulf States Marine Fisheries Compact (PL 81-66; 63 Stat. 70). Under these two laws, fishery management plans have been, and are being, developed. Their development is accomplished through the Gulf of Mexico Fishery Management Council for species in the offshore federal economic exclusion zone, and through the Gulf States Marine Fisheries Commission for species occupying state coastal waters. The Service also has responsibilities for interjurisdictional fishes under Executive Order 12962. Currently, management plans are being developed, or have been developed, for such species as: Gulf sturgeon, striped mullet (*Mugil cephalus*), Gulf menhaden (*Brevoortia patronus*), red drum (*Sciaenops ocellatus*), black drum (*Pogonia cromis*), striped bass, Spanish mackerel (*Scomberomorus maculatus*), spotted seatrout (*Cynoscion nebulosus*), flounder (*Paralichthys spp.*), blue crab (*Callinectes sapidus*), Gulf shrimp (*Panaeus spp.*), and oyster (*Crassostrea virginica*).

The Bay is also an important area for commercial and recreational fishing. The St. Andrew Bay ecosystem provides a variety of valuable habitats and myriad numbers of food chain organisms for all of the trust resource species cited above. The ecosystem is a highly diverse, productive and important natural area. Several years ago, the State of Florida designated parts of St. Andrew Bay as an Aquatic Preserve.

MATERIALS AND METHODS

The work performed in St. Andrew Bay is considered by the Service to be a "general survey investigation." Such investigations are designed to assess the chemical health of large and vitally important habitat areas, such as St. Andrew Bay. Usually little or no chemical data on these areas exist prior to commencement of such an investigation. Therefore, the Service collects samples from various locations within a study area including locations that, for one reason or another, may have experienced contamination because of human activities including agricultural

operations, industry air emissions, urban stormwater runoff, point source discharges, oil spills, etc. Because the investigations are not undertaken in contemplation of legal action, chain of custody procedures are not followed. This is in compliance with directives of the Service's Division of Environmental Contaminants for the Southeast Region. The Service does, however, adhere to standard operating procedures (SOP) to assure the quality of data that may ultimately be published as a Service report. In addition, during a general survey investigation, every field action is not recorded. Instead, the Service relies on instrument operation manuals, SOPs and other guidance, including State and Federal regulations, to govern its actions in the field.

A Definition for Chemical Contaminants

For this report, a definition of the term *chemical contaminant* is necessary. Many chemicals, such as copper and zinc, are natural components of the Bay ecosystem and are present in biologically acceptable amounts in water, sediments and biota. These chemicals can be referred to as *environmental chemicals*. However, human activities sometimes cause the release of additional quantities of these chemicals. When amounts of *environmental chemicals* (in water, sediments, or biota) become too great (because man's activities have added significantly to the naturally occurring amounts) the excess amounts are considered *chemical contaminants* because they become potentially harmful to living organisms when present in excessive quantities.

In addition, some chemicals (dioxin compounds, DDT, etc.) have never been parts of natural systems and these chemicals can exert toxic effects at extremely low concentrations. These chemicals are usually referred to as *xenobiotic chemicals* and are also defined as *chemical contaminants*, when present at any concentration.

Finally, *injury to biota* is another separate consideration. When appropriate, various tools (such as sediment quality guidelines, scientific toxicity tests, etc.) are used to estimate whether injury to resources may be occurring because of chemical contaminants present within habitats or organisms of the Bay.

Collection of Sediment Samples

A total of 128 sediment samples were collected from 105 sites (Figures 2-6) within the St. Andrew Bay estuary. Forty-nine sites were sampled in 1985 and 54 sites sampled in 1988. Some of the sites were sampled more than once. Volume 2 of this report contains information regarding latitude/longitude, Loran C coordinates, station names or other forms of identification, types of chemical analyses performed, and dates of analyses. Open bay sampling stations were randomly selected except for the concentration of stations in the area extending from the mouth of Massalina Bayou southeast to the Dupont Bridge, in the lower Bay (Figure 2). Those stations were selected to survey conditions near the point source discharge from the Bay County Military Point Treatment Lagoon. Also, 24 bayous were specifically selected to compare sediments in industrialized or developed areas with other locations having little development or human activity.

All sediment samples were composite samples consisting of five subsamples. Most samples were collected using a standard ponar 316 stainless steel grab. Depth of sediment samples collected by the grab depended on the type of sediment at each station; however, maximum depth in extensive silt locations was approximately 10 cm. Samples obtained in 1985 in Watson Bayou were collected using a manual coring device equipped with cellulose acetyl buturate (CAB) tubes, 4.7 cm (inside diameter), and 50.8 cm in length. The coring device sometimes compressed soft sediment within the collection tube such that the core consisted of samples taken to depths of as much as 1 meter. Samples collected in the field were immediately put into laboratory-certified, chemically clean, 1-liter glass jars with teflon-lined lids, and placed on ice in clean thermal field containers. Standard operating procedures for field collection of sediment samples (PCFO-EC SOP 004) are described in Appendix 3 of this report. Samples were temporarily stored at the Panama City Field Office in freezers at -23° C until shipment to analytical laboratories. Sediment samples were analyzed for organochlorine pesticides (OCs), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), aliphatic hydrocarbons (AHs), metals, dioxins, and furan compounds (Note: only five sediment samples were analyzed for dioxins and furans). Additional samples were analyzed for particle size and total organic carbon (TOC).

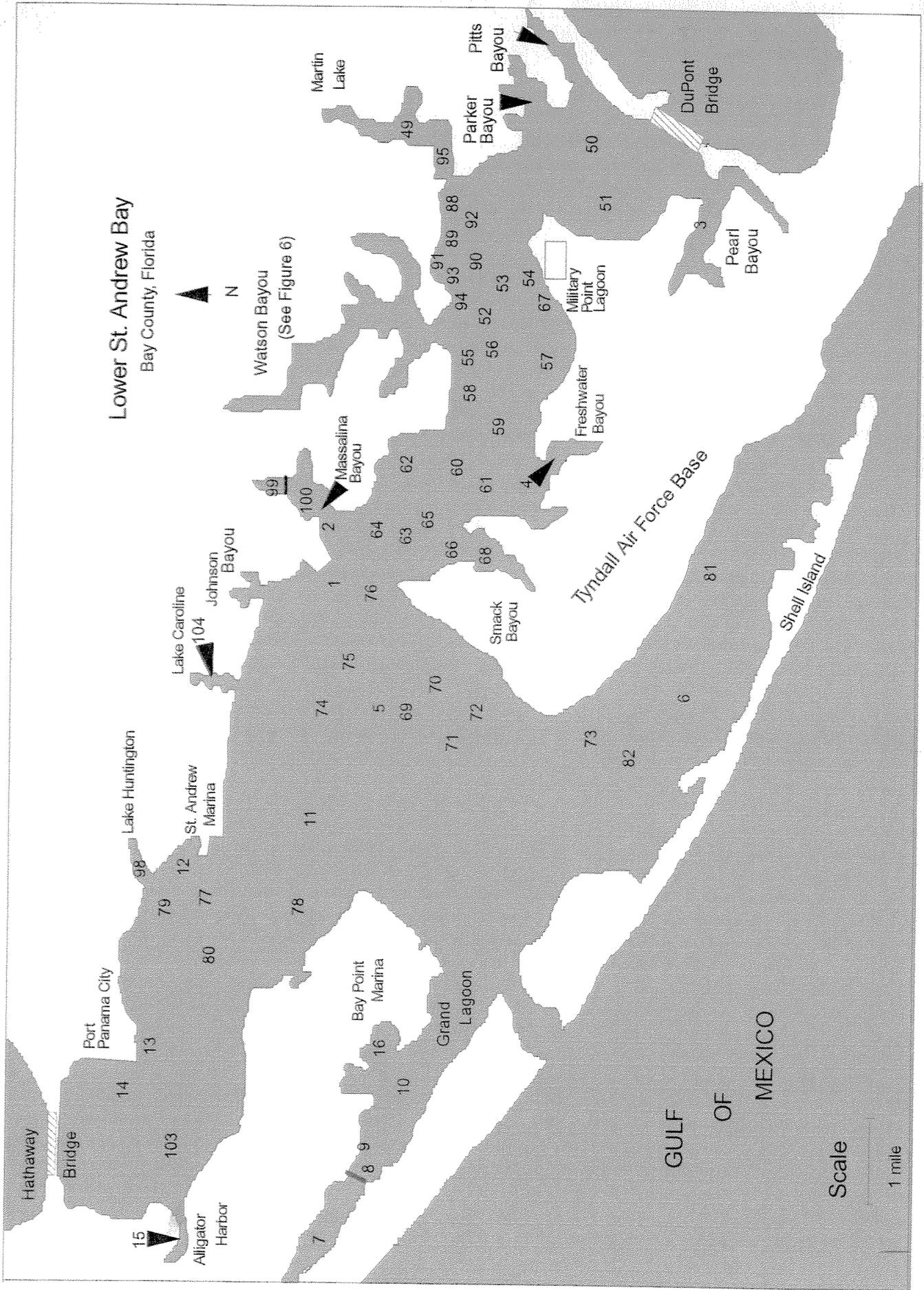


Figure 2. Lower St. Andrew Bay sediment stations.

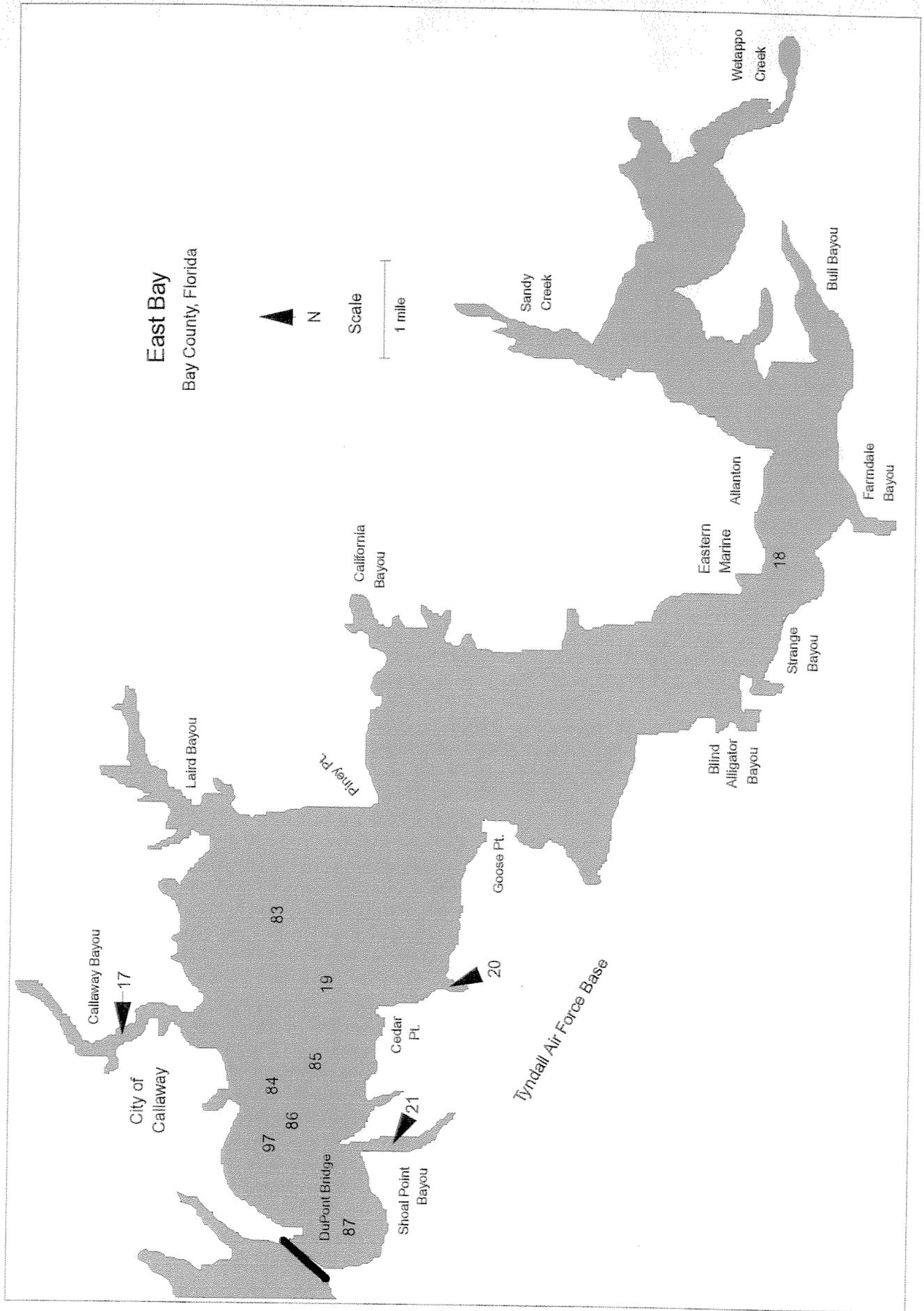


Figure 3. East Bay sediment stations.

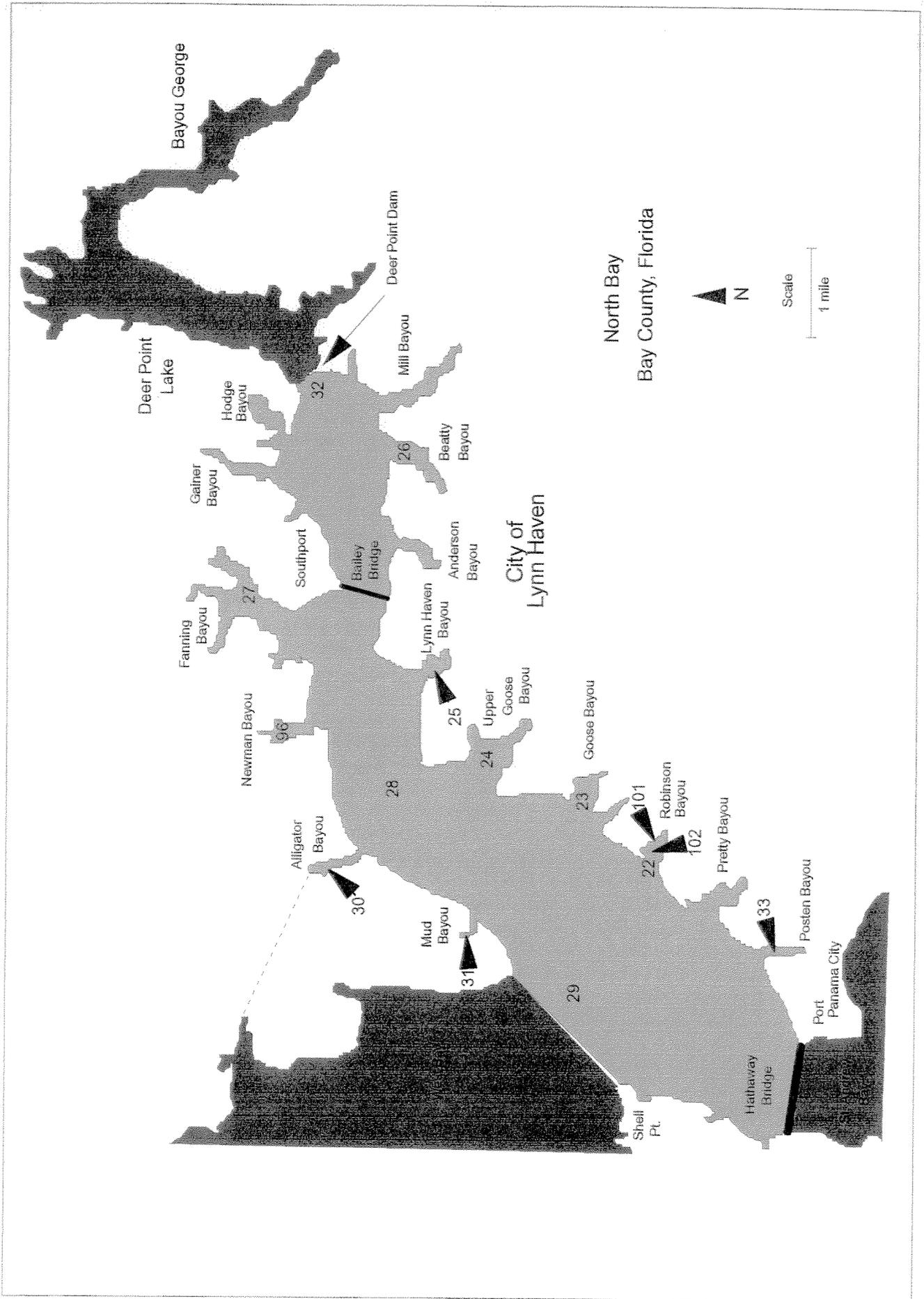


Figure 4. North Bay sediment stations.

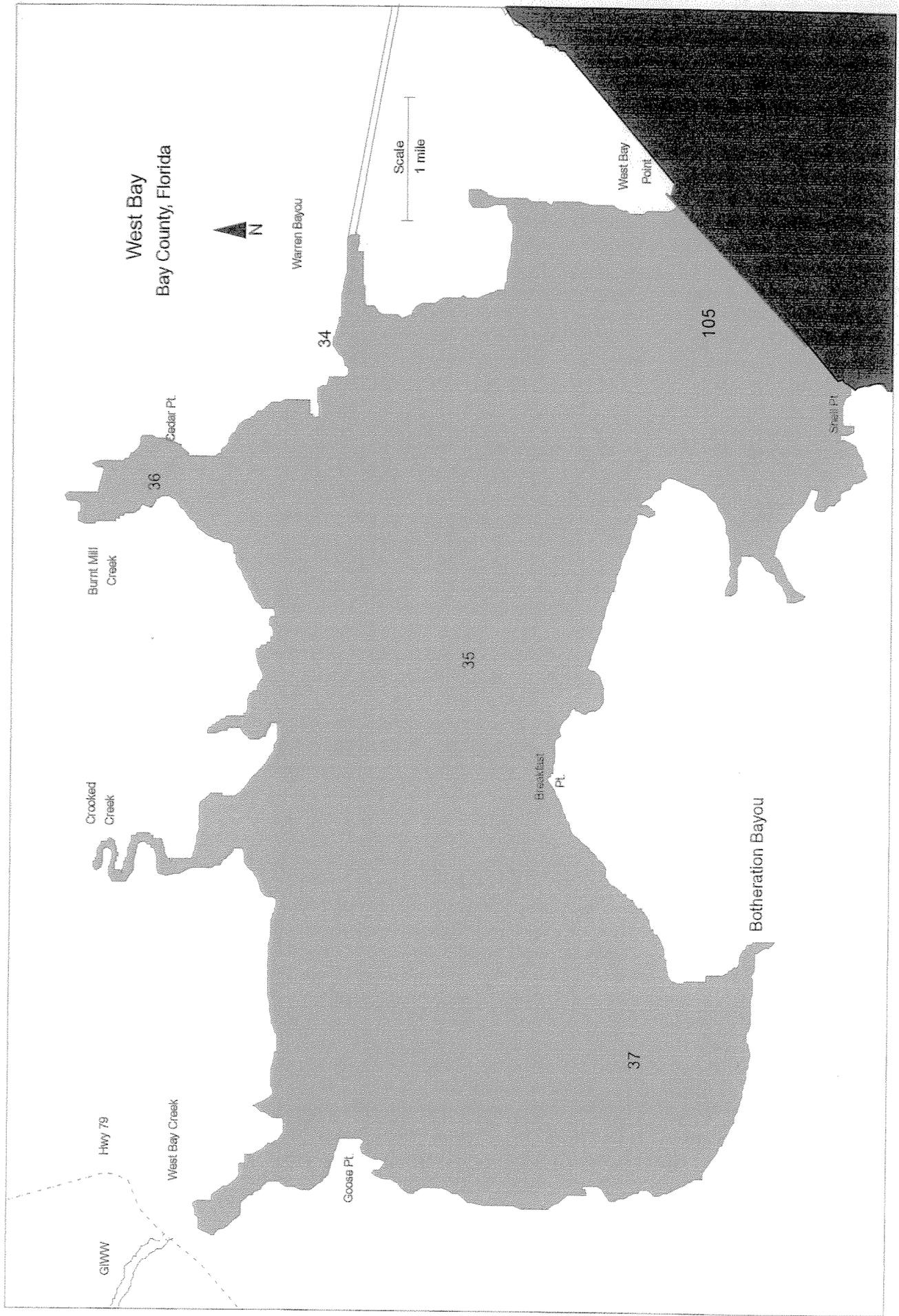


Figure 5. West Bay sediment stations.

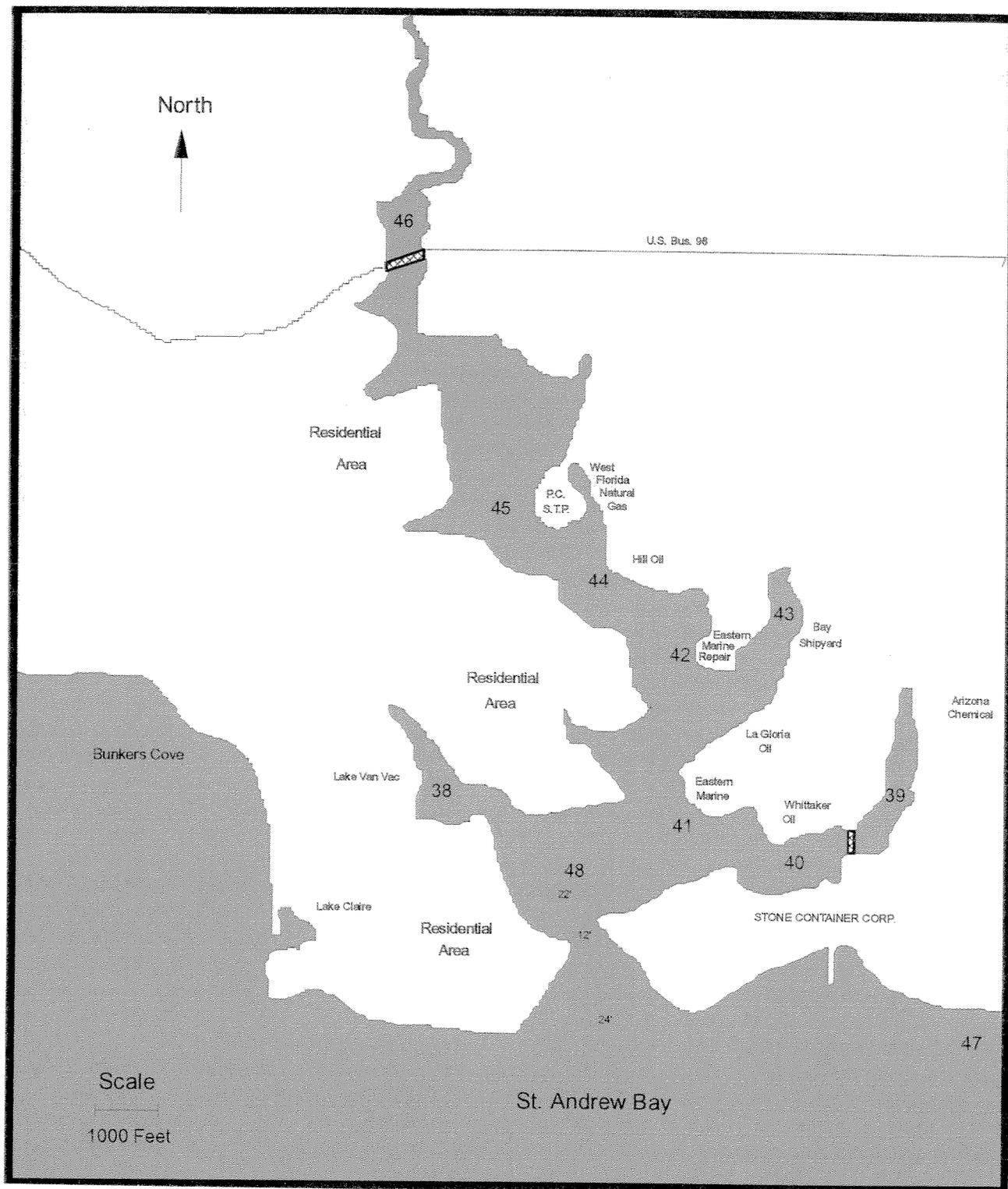


Figure 6. Watson Bayou sediment stations.

Collection of Biotic Samples

Thirty-seven biotic tissue samples from 14 species were collected in or near Watson Bayou during the summers of 1985 and 1986. Fish and invertebrate samples were collected with either a 16-foot otter trawl (with a cod-end liner of 1-cm square mesh) or variable-mesh monofilament gill net. Most analyses were run on composite, whole-body samples. However, spotted seatrout analyses were run on muscle (fillet), liver, reproductive tissues, and the offal (all remaining body parts). Samples were removed from collection gear, placed on ice in clean thermal field containers and transported to the Panama City field office laboratory for processing in accordance with the standard procedures (PCFO-EC SOP 001) for handling, storage and shipment of such samples (Appendix 4). Biotic samples were analyzed for OCs, PCBs, PAHs, AHs and metals. Tissue values are reported as wet weight (ww) concentrations.

Laboratory Analyses of Sediments and Biota

Sediment particle size, clay mineralogy, total organic carbon, and metal partitioning analyses were accomplished by Tierra Consulting Company, Mobile, Alabama. The sediment particle size was classified in accordance with the Standard Geological Soils Classification. Metal analyses were performed by Environmental Trace Substances Research Center, University of Missouri, Columbia, Missouri. Organic compounds analyses, other than dioxin, were performed at Mississippi State Chemical Laboratory, Mississippi State, Mississippi. Samples for analyses of dioxin compounds were shipped to Triangle Laboratories, Inc., Research Triangle Park, North Carolina, or to Geochemical and Environmental Research Group, Texas A&M University, College Station, Texas. Laboratory procedures and quality assurance/quality control information for all analyses are provided in Appendix 5. Laboratory analytical results are provided in four *Sediment and Chemical Databases (SCD)* found in Volume 2.

All metal concentrations for sediments in this report are dry weight values in units of micrograms/gram (parts per million; ppm). Each sediment sample was analyzed for 21 metals.

The laboratory analytical results for metals appears in the *Sediment and Chemical Database (SCD) for Metals*. The metals included for analysis are listed below.

aluminum	copper	nickel
arsenic	iron	selenium
barium	lead	silver
beryllium	magnesium	strontium
boron	manganese	thallium
cadmium	mercury	vanadium
chromium	molybdenum	zinc

Sediment samples were also analyzed for organochlorine pesticides (and polychlorinated biphenyls) (SCD for Organochlorine Compounds), polycyclic aromatic hydrocarbons (SCD for Polycyclic Aromatic Hydrocarbons). The 1985 samples were also analyzed for aliphatic hydrocarbons (SCD for Aliphatic Hydrocarbons); however, because these compounds were not detected at levels that could be defined as biologically harmful, AH analyses were not conducted in 1988. The specific compounds evaluated were as follows:

Pesticides

HCB (hexachlorobenzene)
 BHC (benzene hexachloride)
 oxychlordane
 heptachlor epoxide
 chlordane
 trans & cis nonachlor
 toxaphene
 total PCBs
 (polychlorinated biphenyl)
 DDT (dichloro diphenyl
 trichloroethane)
 dieldrin
 endrin
 mirex

PAHs

naphthalene
 fluorene
 phenanthrene
 anthracene
 fluoranthrene
 pyrene
 1,2-benzanthracene
 chrysene
 benzo(b)fluoranthrene
 benzo(k)fluoranthrene
 benzo(e)pyrene
 benzo(a)pyrene
 1,2,5,6-dibenzanthracene
 benzo(g,h,i)perylene

AHs

n-dodecane
 n-tridecane
 n-tetradecane
 octylcyclohexane
 n-pentadecane
 nonylcyclohexane
 n-hexadecane
 n-heptadecane
 pristane
 n-octadecane
 phytane
 n-nonadecane
 n-eicosane

Calculation of Toxicity Equivalents (TEQ values) of Dioxin Compounds

Toxicity equivalency (TEQ) was calculated using procedures developed by the Environmental Protection Agency (1989). In this report, all dioxin and furan toxicity is expressed as Toxicity Equivalents (i.e. total toxicity) of the seventeen 2,3,7,8-substituted dioxin and furan molecules in any sediment or tissue sample.

Toxicity is calculated by multiplying the absolute concentration of each isomer by a numeric factor that expresses the concentration in terms of the most toxic dioxin molecule, 2,3,7,8-TCDD, which is given a value of one. For example, a dioxin molecule with chlorine atoms at all eight available positions of attachment, called octochlorodibenzo-*p*-dioxin (OCDD) is only 1/1,000 as toxic as 2,3,7,8-TCDD. If the concentration of OCDD in a sample is 4,300 parts per trillion, the conversion to toxicity in terms of the most toxic form (2,3,7,8-TCDD) would be calculated by multiplying 4,300 by 0.001 which means that the OCDD in the sample has a Toxicity Equivalency of 4.3 TEQ. By multiplying the concentrations of the other remaining dioxin and furan compounds in a sample by each appropriate conversion factor, and then by adding up all the converted values, we can calculate the total toxicity of the sample (i.e., the TEQ) in terms of the most toxic form, 2,3,7,8-TCDD.

Sediment Quality Guidelines

Effects-based sediment quality guidelines were prepared by Long and Morgan (1990) for use by the National Oceanic and Atmospheric Administration (NOAA). Subsequently, the database with which these values were prepared was updated and expanded and the approach was refined (MacDonald 1993 for Florida; and Smith and MacDonald 1992). The sediment quality guidelines have been refined even further (Long *et al.* 1995) and these refined guidelines are used in this report to interpret much of the sediment data. It should be noted that these are interpretive guidelines only. The guidelines are based on two chemical concentration values, the ERL and ERM, which delineate three concentration ranges for a particular chemical. Concentrations below the ERL value represent a *minimal-effects* range; a range intended to estimate conditions in which biological adverse effects would be *rarely* observed.

Concentrations equal to and above the ERL, but below the ERM, represent a *possible-effects* range within which effects would *occasionally* occur. Finally, concentrations equivalent to and above the ERM value represent a *probable-effects* range within which effects would *frequently* occur (Long *et al.* 1995). The two values are therefore defined as follows:

ERL (Effects Range Low): The lower 10th percentile of the effects data for each chemical.

ERM (Effects Range Median): The median, or 50th percentile of the effects data for each chemical.

Sediment Station Ranking System

Evaluation of the data for each sediment sample included an estimate of the total potential biological effects resulting from the presence of many individual chemicals. For this report, sediment stations were ranked to compare relative amounts of chemicals at the different station locations. This was done only for those chemicals for which sediment quality guidelines exist, i.e., 9 trace metals, total PCBs, 2 pesticides, and 13 polynuclear aromatic hydrocarbons (Long *et al.* 1995). The system consisted of counting 1 point for each chemical concentration that exceeded the ERL value but fell below the ERM value (possible effects range), and counting 2 points for each concentration that was above the ERM value (probable effects range). The counts for all chemicals detected within the sample were then summed for each sample collected at each station. The station/samples were sorted in descending order from greatest probable effects to no effect. Some stations have multiple rankings for subsamples taken at Watson Bayou and several other stations.

Finally, to allow the use of some type of descriptors within the text, four groupings were used to describe the total number of chemicals in a sample having concentrations that exceeded the

ERL or ERM sediment quality guidelines. The groupings are as follows and range from no known biological effects to probable biological effects.

Level 1	=	Score of 0
Level 2	=	Score of 1 - 2
Level 3	=	Score of 3 - 4
Level 4	=	Score of 5 or above

Level 4 stations have concentrations of several chemicals exceeding sediment quality guidelines. Adverse biological effects probably occur frequently. Adverse biological effects are unlikely at Level 1 stations. The extent of probable biological effects at Level 2 and Level 3 stations are unknown. The groupings merely indicate some stratification between Level 1 and Level 4 stations.

RESULTS

Volume 2 contains all of the tables for this report. In addition, all the raw data are presented in the Sediment and Chemical Databases (SCD) found in Volume 2. The results of this study are reported below, as follows: a) the Bay-wide sediment evaluation, b) chemical analyses of fishes and invertebrates, and c) dioxin compounds evaluation.

BAY-WIDE SEDIMENT EVALUATION

Sediment samples were collected from 105 locations within the St. Andrew Bay estuarine system. Sediment samples at most sites (1988 samples and thereafter) were evaluated for their physical characteristics, i.e., sediment particle size and total organic carbon (TOC) content. Figure 7 is a preliminary sediment map for the Bay generated using those data. Particle sizes are defined as: sand (2000 - 62.5 microns); silt (62.5 - 4 microns); and clay (less than 4 microns). Figure 8 is the preliminary contour map for TOC concentrations.

The tables in Volume 2 present results and the scores for all sediment *samples*. When multiple sediment samples were taken at an individual station, that station number may appear two or three times under the column "Stat. #." At some stations, particularly within Watson Bayou, multiple sediment samples were collected and analyzed. Use of a descriptor (such as Level 3) to describe any "multiple-sample" station is based on an arithmetic average of the counts for each sample. For example, a station from which three samples were collected and analyzed may have had sample scores that fell within the ranges of three separate descriptors (Level 2, Level 3, and Level 4), but the average would have resulted in ranking that station as Level 3.

Total Chemical Loading

Table 1 (in Volume 2) presents the ranking of all stations for all chemicals. Of the 105 stations sampled, 28 percent (n=29) were Level 1; 27 percent (n=28) were Level 2; 18 percent (n=18) were Level 3; and 27 percent (n=27) were Level 4. Of the 27 Level 4 stations, 93 percent (n=25) were located in an area of the Bay extending eastward of an imaginary line drawn from the Panama City Marina to Redfish Point and running up the Bay to the U.S. Highway 98 Dupont Bridge. This area includes developed watersheds and shorelines such as Watson and Massalina bayous, Martin Lake, and an area of the Bay that has historically received, and is currently receiving, municipal and industrial effluent discharges and runoff.

Metals

Table 2 includes concentration ranges (minimum and maximum values) for the 21 metal analyses performed at all 105 sampling stations within the Bay. In addition, laboratory detection limits are provided for each metal analysis.

Table 3 is a ranking of all stations for metal concentrations using the sediment quality guidelines. Of the 105 stations sampled, 47 percent (n=48) were Level 1; 37 percent (n=38) were Level 2; 8 percent (n=8) were Level 3; and 8 percent (n=8) were Level 4. Sixteen of the 17 samples (94 percent) that ranked as Level 4 were collected from Watson and Massalina bayous, as were

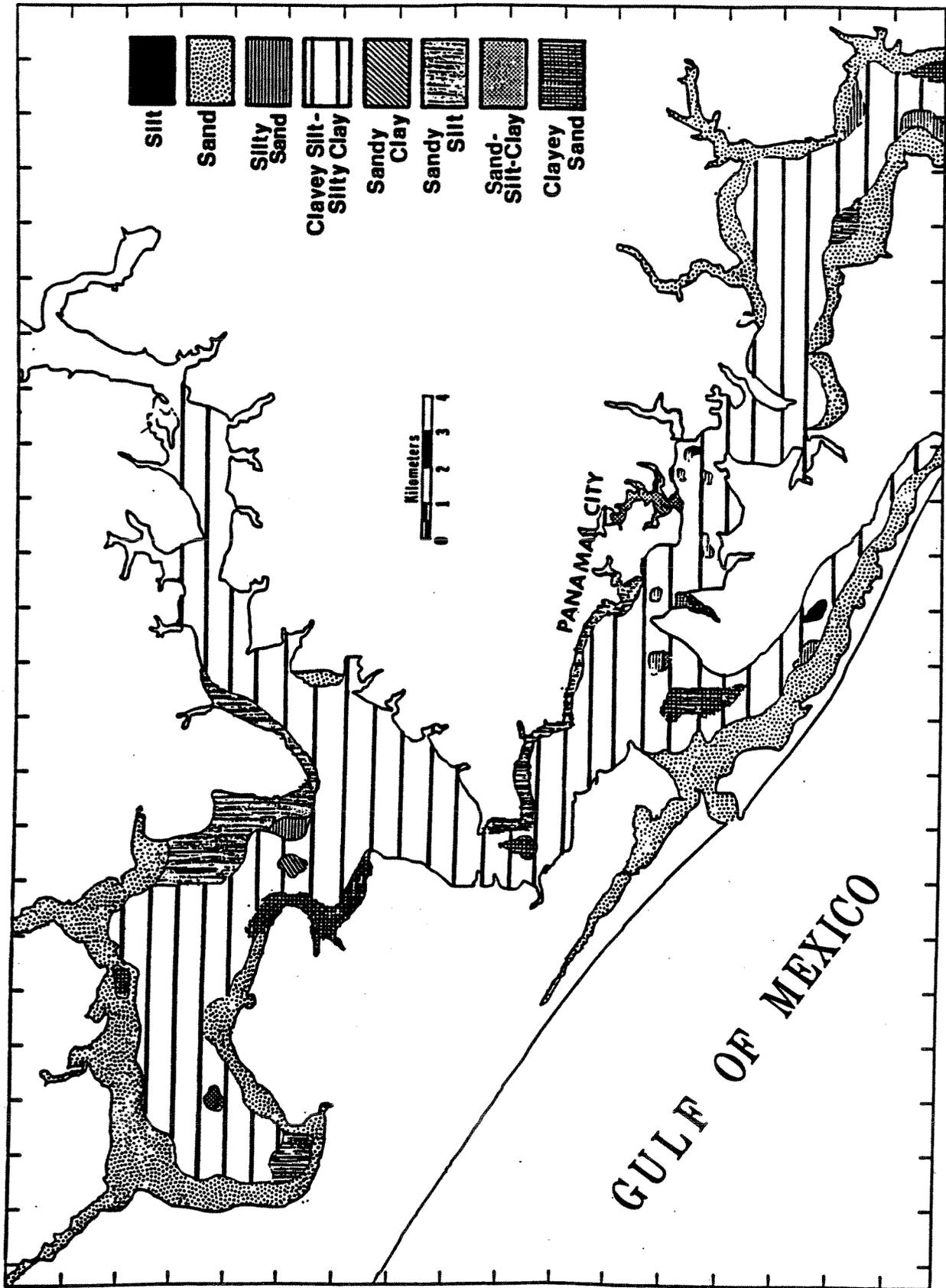


Figure 7. Preliminary St. Andrew Bay sediment map.

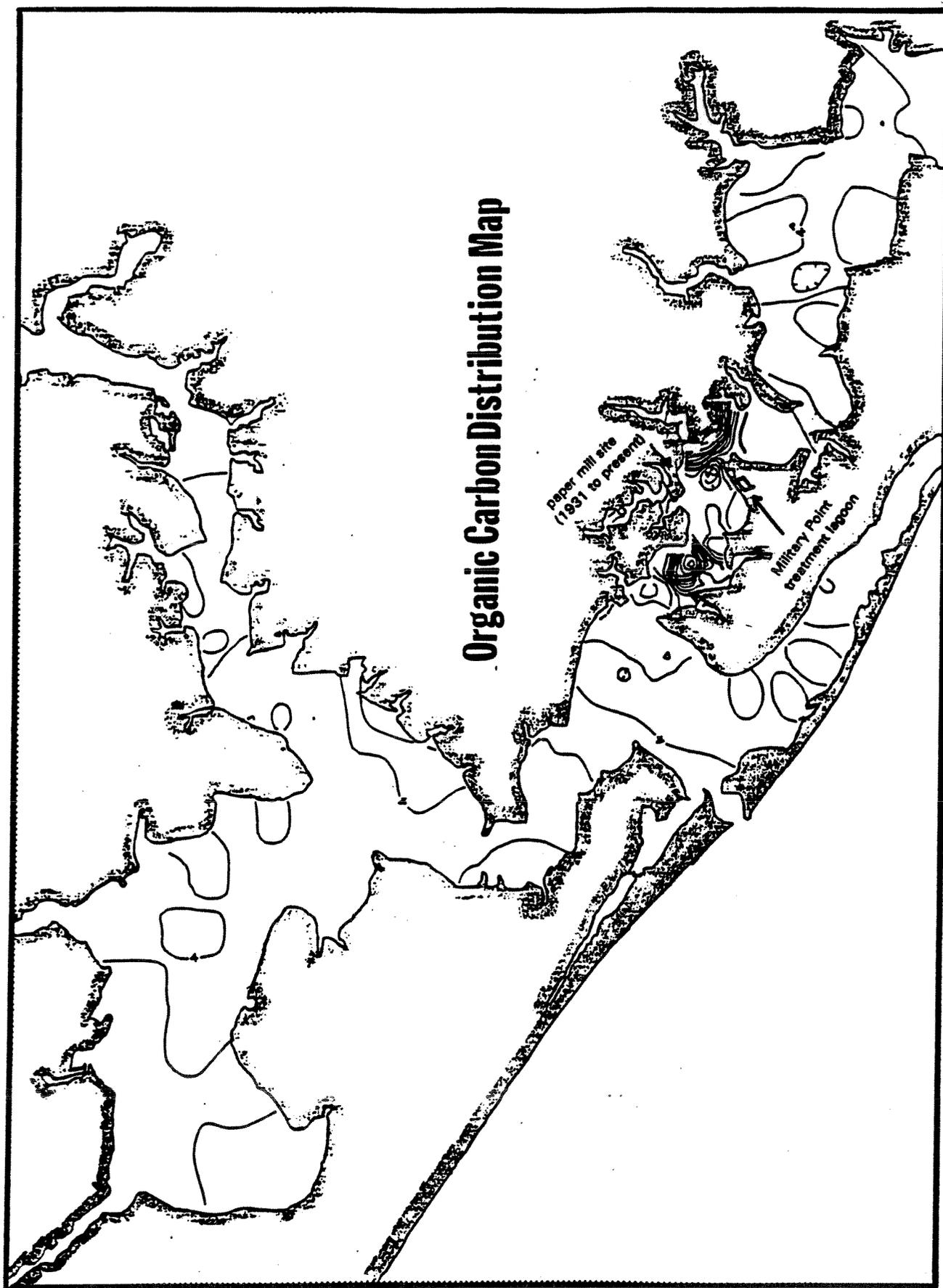


Figure 8. Preliminary map of St. Andrew Bay sediment organic carbon.

9 of the 14 samples (64 percent) that ranked as Level 3. It appears that most of the metal contamination within the St. Andrew Bay estuary is found within these two bayous. One sample from Martin Lake was Level 4; however, two other samples from the Lake were below the potential effects range.

Polycyclic Aromatic Hydrocarbons (PAHs)

Table 4 compares the concentration ranges (minimum and maximum values) for the 14 PAH analyses performed at all locations within the Bay. The Table also includes the laboratory detection limit for each PAH analysis. Ten of the 14 compounds were detected at over 50 percent of the Bay stations.

The most commonly detected compound was benzo(b)fluoranthrene which occurred at 82 percent of the stations. A sediment quality guideline does not yet exist for this compound; however, only 15 percent of the stations had concentrations 10 times, or greater, than the detection limit. Pyrene, benzo(a)pyrene, and benzo(g,h,i)perylene were each detected at 76 percent of the stations. However, pyrene concentrations only exceeded the ERL at 16 percent of the stations; and at no station was this compound detected above the ERM. Benzo(a)pyrene concentrations exceeded the ERL at only 12 percent of the stations; and this compound was never detected above the ERM. A sediment quality guideline does not yet exist for benzo(g,h,i)perylene; however, only 8 percent of the stations had concentrations at 10 times the detection limit.

Table 5 ranks all stations within the Bay for PAH concentrations based on dry weight (ppb). Of the 105 stations sampled, 70 percent (n=71) were Level 1; 10 percent (n=10) were Level 2; 4 percent (n=4) were Level 3; and 17 percent (n=17) were Level 4. Nine of the 17 samples (53 percent) that ranked as Level 4 were collected from Martin Lake and Watson and Massalina bayous. It appears that most of the PAH contamination within the St. Andrew Bay estuary is found within these three water bodies. Seven Level 4 sites were identified on the northern side of the Bay, between the entrance of Watson Bayou and the outflow from Martin Lake. The only

remaining station that was Level 4 was station #66 located in the Bay, NNW of the mouth of Smack Bayou. Two of the four stations that ranked as Level 3 were also in Watson Bayou.

Organochlorine Pesticides and PCBs

Table 6 includes the concentration ranges (minimum and maximum values) for the 22 organochlorine chemical analyses performed (and summation of Total DDT compounds) at all locations within the Bay. A number of pesticides were detected in Bay samples.

Table 7 is a ranking of all samples taken from 105 stations within the Bay for organochlorine chemical concentrations. Samples were ranked using the sediment quality guidelines that are available for three compounds; i.e. *p,p'*-DDE, Total DDT, and Total PCBs. Stations with multiple samples per station were averaged. Of the 105 stations sampled, 61 percent (n=62) were Level 1; 16 percent (n=16) were Level 2; 23 percent (n=23) were Level 3; and 1 percent (n=1) were Level 4. The Level 4 station is east of the mouth of Watson Bayou.

It should be noted that station 21, Shoal Point Bayou (also known as Fred Bayou), was ranked as Level 3 using the three organochlorine guidelines that are available. Other DDT compounds were detected in the Bayou, but sediment quality guidelines have not yet been developed for those compounds. The Bayou, part of Tyndall Air Force Base (AFB), is an Installation Restoration Project (IRP) and is listed as a superfund site on the federal National Priorities List, because of significant contamination with DDT compounds. If guidelines were available for other DDT compounds that are present in the Bayou, it may have ranked higher.

Aliphatic Hydrocarbons (AH)

Analyses of 13 alkane, aliphatic hydrocarbons were done for samples collected at stations 1 through 47, and 49 (n=48). Analyses included nine unbranched (n) saturated hydrocarbons (12-carbon to 20-carbon compounds), octylcyclo and nonylcyclo hexanes, pristane (2,3,10,12-tetramethylpentadecane) and phytane (2,6,10,14-tetramethyl hexadecane). These are light to

medium oil compounds and some are also common constituents in natural waxes on plant leaves.

Table 8 summarizes the results for AH compounds analyses. The most common compound was n-heptadecane which was detected at 85 percent (n=41) of the stations tested. Some form of aliphatic hydrocarbon was detected at 85 percent of the stations, with only 7 stations being non-detect for all AH compounds. Also, the most extensive accumulation of the compounds was found at station 49 (Martin Lake). Maximum concentrations for 9 of the 13 compounds occurred at that station. The source of these compounds is not known; however, the possibility of a natural plant source, as well as some anthropogenic contribution, cannot be eliminated.

Table 9 is the ranking of the data based on dry weight (ppb) for "total aliphatic hydrocarbons" for all samples collected, at the stations evaluated. Fourteen of the 48 stations (29 percent) had concentrations (in at least one sample) that exceeded 1,000 parts per billion (ppb), dry weight (dw). For the most part, these stations are located in, or near, Watson Bayou; or are sites with heavy boat and vessel traffic (marinas; station 13, Port Panama City). A second sample, taken from station 13, three years after the first sample, was non-detect for all AH compounds. Conditions may have changed at that site following maintenance dredging of the port that took place between the time the two samples were collected.

CHEMICAL ANALYSES OF FISH AND INVERTEBRATES

In 1985 and 1986, samples of invertebrates and fishes were collected for chemical analyses. A total of 14 species (2 invertebrates and 12 fishes) were evaluated (Table 10). Samples were either: a) whole-body composite samples, b) composite samples of tissues, or c) individual whole-body samples. Most of the samples (11 of the species) were whole-body composites consisting of several individuals of the same species. Tissues of spotted seatrout (*Cynoscion nebulosus*) were analyzed (fillet, liver, offal and gonads) as composites obtained from three samples (of five fish each). In addition, a single black drum (*Pogonias cromis*) and a single southern flounder (*Paralichthys lethostigma*) were analyzed (whole body).

Whole-Body Composite Samples of 11 Species

The results for most metals were within normal ranges for marine species (Table 11) (Hall et al, 1978). Cadmium was not detectable in any species group. Mercury was present in all species except the shrimp. The hardhead catfish and the gafftopsail catfish contained the greatest whole-body concentrations of mercury (range 0.32 - 0.44 ppm, ww). These amounts do not exceed State fish consumption advisory limits; however, concentrations of mercury in muscle tissue could be greater, since organic forms of mercury primarily partition in the edible portions of fish. Small amounts of lead were detected in 6 of the 11 species (range 0.2 - 1.2 ppm, ww).

Several organochlorine compounds (pesticides and PCBs) were detected (Table 12). The ranges of these chemicals (reported as ppb, ww) describe the general extent of contamination in the whole-body composite samples. Trans-nonachlor (range 10-90 ppb); p,p'-DDE (range 10-780 ppb); and p,p'-DDD (range 10-230 ppb) were detected in every species. Oxychlordan (range 10-20 ppb) was detected in only blue crabs and the catfishes. PCBs (range 50-1300 ppb) occurred in 10 of 11 species, and was highest in the two catfish species. Dieldren, cis-nonachlor, p,p'-DDT, and mirex occurred in low concentrations (range 10-40 ppb). Moderate levels of the organochlorine compounds and PCBs were common in many species at the time of this evaluation. The State of Florida currently has no advisory for PCBs for fish consumption (Environmental Protection Agency 1995; Atkeson, 1996, personal communication).

All PAHs analyzed for were detected except benzo(k)fluoranthrene (Table 13). Phenanthrene and fluorene were detected in most samples. PAH compounds are rapidly metabolically altered to other chemical forms by fishes (Statham *et al.* 1976; Varanasi *et al.* 1980; and Fabacher *et al.* 1985). Analyses were not run for these individual metabolites. Therefore, the data probably do not provide a complete picture of the degree of exposure to these chemicals. Watson Bayou sediments are extensively contaminated with PAHs.

While there was minimal accumulation (Table 14) of aliphatic hydrocarbon compounds by the invertebrates, the menhaden (a filter-feeding grazer), the hardhead catfish (primarily an omnivore) and the gafftopsail catfish (primarily a carnivore) had the greater concentrations.

Although the sediment data indicate the common occurrence of many of these compounds within the Bayou, it is unclear whether the catfish and menhaden acquired these compounds from the Bayou habitat. While little research has been conducted concerning potential toxic effects of aliphatic hydrocarbons, one study which focused on the winter flounder (*Pleuronectes americanus*), supported the hypothesis that the aliphatic component of complex hydrocarbon mixtures is relatively nontoxic (Payne *et al.* 1995).

Spotted Seatrout Samples

Spotted seatrout are known to reside primarily within their natal estuaries (Perret *et al.* 1980; Tabb 1966; Moffett 1961; Ingle *et al.* 1962; Topp 1963; Beaumariage 1964 and 1969; Beaumariage and Wittich 1966; and Rogillio 1975). For this reason, seatrout were selected for study because they are one of the common, top carnivores within the Bay. Seatrout often feed upon the same shallow water small forage fish that are fed upon by wading birds, terns, skimmers and pelicans.

Table 15 contains the dissection data for the 15 spotted seatrout that were analyzed. Table 16 contains the seatrout metals data. Lead was not detected in any samples. Cadmium was present at low concentrations in liver (.17-.21 ppm, dw) and reproductive tissue (.04-.19 ppm, dw). Mercury was present in liver (.67-.84 ppm, dw) and gonadal tissue (.17-.14 ppm, dw). The highest concentrations of mercury occurred in muscle tissue (1.8-2.1 ppm, dw). The mercury wet weight average for seatrout muscle tissue (about 0.45 ppm, ww) was slightly below the Florida limited consumption advisory level for fish tissue of 0.5 ppm, ww, (Florida Department of Health and Rehabilitative Services 1993).

The potential synergistic effects of cadmium and mercury in spotted seatrout is unknown. However, there may be some justification for concern because Vernberg *et al.* 1974 demonstrated reduced survival of fiddler crabs when both metals were present internally. These researchers observed an inability of the crabs to survive long periods of time when both

cadmium and mercury were taken up. They believed the decrease in survival was associated with an observed inability to transport mercury from the gills to the hepatopancreas when cadmium was also present.

PCBs were present in the three composite samples of seatrout liver (1,000, 1,500, 2,600 ppb, ww), reproductive tissue (NLD, 110-240) and in other body compartments (offal; 250, 430, 520) (Table 17). Only one muscle tissue sample had detectable PCBs (50 ppb). The hazards of PCBs to fish have been documented by Eisler (1986a). Also, the liver tissue contained DDT compounds (range 500-1,010); as did the reproductive tissue (range 60-190). DDT compounds were also present in other body compartments (offal; range 110-220). Trans-nonachlor was present in moderate amounts in both liver and gonads.

As noted above, PAHs are metabolically altered within fish systems. These metabolites, which can be harmful, are not detected by routine chemical analysis (Eisler 1987a). Therefore, the data (Table 18) probably do not accurately represent the internal concentrations of these chemicals (or their potentially toxic metabolites). However, the seatrout data do indicate that PAH compounds are being taken up from the environment. This is an undesirable situation, particularly in view of the uptake of metals, PCBs and pesticides already noted. Accumulation of PAHs has been observed in various fish species (Eisler 1987a). Direct comparisons between studies were not possible because of species differences. However, for total PAH concentrations in muscle tissue, the St. Andrew Bay seatrout values (range 20-40 ppb) exceeded the range for six Lake Ontario species (3-8 ppb) but did not exceed the range for three marine species (86-536 ppb) collected from the New York Bight and Long Island Sound (Eisler 1987a). In fishes, metabolites of PAHs can be cytotoxic, mutagenic, and carcinogenic, and Eisler (1987a) cites many research studies that are specific examples of these phenomena.

Finally, almost all of the aliphatic compounds that were tested for occurred in the seatrout tissues (Table 19). The data appear to indicate that the total body burden of aliphatic hydrocarbons (as a group of chemicals) generally increases throughout the life of an individual seatrout residing in and near Watson Bayou, the site of collection. Aliphatic hydrocarbons are

thought to be quite susceptible to metabolism (Payne *et al.* 1995) and some n-alkanes may even be converted to their corresponding fatty acids (Green and Selivonchick 1987). Because aliphatic hydrocarbons appear to be readily metabolized, most of the observed accumulation of these compounds is probably the result of chronic environmental exposures. The data may reflect continuous availability of these compounds.

The seatrout tissues evaluated in this study contained low concentrations of cadmium, mercury, PCBs, PAH compounds and aliphatic hydrocarbons. The synergistic effects to seatrout are unknown. In a discussion regarding the simultaneous exposure of several pollutants, Trahaut (1975) noted that "conditions in the biosphere are such that members of an ecosystem are not exposed to a single pollutant but to many." And, "interaction can potentiate toxic responses." Thresholds that may cause toxic responses are also unknown. However, the presence of these various chemicals, many of which are mutagenic, teratogenic, or carcinogenic, appear to have the potential to adversely affect the reproductive capacity of adults or long-term survival of fertilized eggs or embryos exposed to these chemicals, and thus research related to synergistic effects is needed.

Whole-Body Individual Samples of Two Species

Concentrations of most metals in the black drum and the southern flounder fell within normal ranges for marine fishes. None were high enough levels to exhibit toxicity in adult fishes (Eisler 1985, 1987, 1988). In the single black drum these metals were as follows (ppm): cadmium (0.01 ww, 0.06 dw), lead (0.24 ww, 1.0 dw), and mercury (0.16 ww, 0.67 dw). In the single southern flounder, the mercury concentration was (0.11 ww, 0.43 dw), while cadmium and lead values were below detection. Mercury concentrations were well below Florida consumption advisories. However, because the data are based on whole-body analyses, concentrations in muscle tissue could have been higher.

The black drum and flounder each had about equal levels of PCBs (100, 110 ppb, ww). Low levels of DDT compounds were also detected in these two specimens. These levels do not appear high enough to be problematic to the individual fish involved (Eisler 1986a).

al. 1993). The two sites sampled by the Corps were identified as stations PC-1 and PC-2. Station PC-1 is located just east of the mouth of Watson Bayou in 9.1 meters (30 feet) of water. Station PC-2 is located in mid-Bay, south of the mouth of Watson Bayou in 10.1 meters (33 feet) of water. Fifteen of the 17 dioxin compounds were detected in these samples (Tables 20 and 21). At station PC-1, 2,3,7,8-TCDD was detected at 0.86 ppt., and at PC-2 the 2,3,7,8-TCDD concentration was 1.45 ppt. The toxicity equivalent (TEQ) concentration at station PC-1 was 5.8 ppt. At station PC-2 the concentration was 6.2 ppt.

The third and fourth sediment samples were collected by the Service in 1994. One was collected from Watson Bayou (Station 48) and the second from Martin Lake (Station 49). Sixteen of the 17 dioxin compounds were detected in the Watson Bayou sediment sample (Table 22). The sample included 2.39 ppt 2,3,7,8-TCDD which accounted for about 16 percent of the toxicity equivalent (TEQ) total contained in the sample (14.8 ppt).

The Martin Lake sediment sample also contained 16 of the 17 dioxin compounds (Table 23). The same dioxin isomer that was not detected in the Watson Bayou sample (1,2,3,7,8,9-hexachlorodibenzofuran) was also not detected in the Martin Lake sample. 2,3,7,8-TCDD was detected at a concentration of 1.21 ppt, and accounted for about 5.6 percent of the TEQ total (21.4 ppt.).

In 1995, the Service collected a fifth sediment sample from St. Andrew Bay west of Beacon Beach (north of Shell Island) in 8.5 meters (28 feet) of water. This collection site is within the St. Andrew State Aquatic Preserve. For quality control purposes, both an initial analysis and a duplicate analysis were run on this sample by the laboratory. Eight dioxin compounds were detected in the initial analysis and the TEQ concentration was approximately 2 ppt (Table 24). The duplicate sample differed greatly from the initial sample. In the duplicate sample, 12 dioxin compounds were detected and the TEQ concentration of dioxin compounds was 7.2 ppt (Table 25). This value is similar to the values found in the two Corps of Engineer samples (5.8 and 6.2 ppt) further north in the Bay. The analytical laboratory report states that "the sample and the extracted duplicate of this sample did not meet relative percent difference (RPD) criteria for

some of the analytes. The differences are linear and therefore are likely to have been caused by *taking non-representative aliquots of sample* for the duplicates."

In 1997, the sixth and seventh sediment samples were collected by the Service from the Bay. The sixth sample was collected in East Bay about one-half mile east of the Dupont (Tyndall) Bay Bridge near the north shore in 29 feet of water. At this site, 2,3,7,8-TCDD was present at the greatest concentration found in any sample (6.5 ppt)(Table 26). This isomer accounts for 20 percent of the TEQ total of 33 ppt.

The seventh sample, collected from West Bay at a depth of 24 feet contained 15 of the 17 dioxin compounds (Table 27). 2, 3, 7, 8-TCDD was detected at a concentration of 1.4 ppt and accounted for 10 percent of the TEQ total of 14.4 ppt.

In summary, of the seven dioxin samples collected, the three from the lower bay averaged about 6 ng TEQ/kg of sediment (ppt). The four other samples collected from Watson Bayou, Martin Lake, West Bay, and East Bay were much higher; 15, 21, 15, and 33 ng TEQ/kg of sediment (ppt), respectively.

DISCUSSION

This report summarizes the Fish and Wildlife Service's evaluation of environmental chemical contaminants found in the St. Andrew Bay ecosystem. The data within the report cover sampling, analysis and testing between 1985 and 1997. Our objective has been to provide decision-makers with survey information from which to determine the need for additional monitoring and to develop management strategies. The ecosystem and the chemicals within St. Andrew Bay are discussed in two distinct ways. The first discussion is directed at each of the Potential Contaminants. The second discussion focuses on the relative importance of chemicals in specific geographic areas, and is entitled: Geographic View.

Potential Contaminants

Metals

Extensive sediment metal contamination was documented in Watson Bayou, Massalina Bayou, and the lower section of Martin Lake. Eighteen sediment samples from these waterbodies ranked Level 4, and an additional 14 samples ranked as Level 3. Our findings in Watson Bayou are consistent with those of the Environmental Protection Agency (1993) Environmental Monitoring and Assessment Program (EMAP). Based on the organically bound fractions present and the concentrations that exceed sediment quality guidelines, we believe significant quantities of metals are bioavailable. Almost all other areas of the St. Andrew Bay ecosystem were either Level 2 or Level 1. Little significant metal contamination was observed in open-bay areas.

Metals of primary concern include: **silver** - some contamination in Watson Bayou; **cadmium** - minimal contamination in Watson and Massalina bayous, and Martin Lake; **chromium** - Watson and Massalina bayous, and minimal contamination in Pearl and Freshwater bayous, also the small unnamed bayou southwest of Military Point Lagoon, and one site in Grand Lagoon; **copper** - highest in Massalina Bayou, high in Watson Bayou, and minimal in Robinson Bayou; **mercury** - high in Massalina Bayou and some parts of Watson Bayou, seven samples exceeded the ERM value; **nickel** - throughout Watson Bayou, also in Massalina Bayou, minimal contamination in Pearl and Freshwater bayous, and one site in Grand Lagoon; **lead** - highest in Massalina Bayou, high in most of Watson Bayou, moderate in Lake Huntington and Robinson Bayou; **zinc** - Massalina and Watson bayous, and lower Martin Lake.

Sources of these contaminants are probably primarily historic in nature. Such anthropogenic sources might include the application and removal of marine paints, lead from roadway runoff prior to the use of lead-free fuels, discharges from sewage treatment plants, the use of mercury compounds as slimicides by paper mills, and unidentified industrial operations no longer in existence. There are, however, contemporary sources of some metals and these sources should be identified and managed properly to prevent future contamination.

It is important to mention that the majority of the Service's sediment sampling in St. Andrew Bay was completed before the development of the aluminum/metal test (Schropp *et al.* 1990). The test is used to determine if metal concentrations are anthropogenically enriched in bed sediments. However, the test requires that sediment samples be subjected to *total digestion* using hydrofluoric acid. This digestion completely dissolves all of the silicates and measures all of the metals in the samples, including all aluminum present. Because the samples reported in the present study were analyzed prior to development of the aluminum/metal test, they were prepared by the laboratory using *strong acid digestion* in which mixtures of hydrochloric and nitric acids or nitric and perchloric acids are used to digest the samples. This type of digestion releases less than half of the aluminum that is present. Although we had hoped to apply the aluminum/metal normalization test, because the samples were not subjected to *total digestion*, the concentrations of the metals in samples could not be evaluated in that manner.

Because of the extensive sediment degradation in areas such as Watson and Massalina bayous, and Martin Lake (because so many metals exceeded the effects-based sediment quality guidelines (Long *et al.* 1995), it is probable that benthic productivity is depressed and that organisms surviving in those areas could provide a chemically contaminated food base for other species feeding upon them. However, individual metal concentrations in the tissues of the fish that were analyzed were relatively low. Metal contamination in fish may not be a problem unless synergistic effects of two or more metals are significant.

Organochlorine Pesticides

The only organochlorine pesticides of significance, detected in this study, within the ecosystem were DDT compounds. These persistent chemicals were detected at low levels at many sites. The most significant contamination was discovered in Shoal Point (Fred) Bayou, in 1985 (Brim 1990). Significant quantities of these compounds were historically stockpiled adjacent to the Bayou for use by Tyndall AFB. Additional assessment investigations were subsequently done (Rust Environment and Infrastructure 1994). The development of any necessary clean up

strategies are being addressed by Tyndall AFB to correct the contamination problem within Shoal Point Bayou. Access to the Bayou has been limited by the Air Force.

Levels of DDT found in Shoal Point sediments have been recorded as high as 12 ppm (range ND - 12 ppm). In addition, the ratio of DDT to its breakdown products (DDD and DDE) was high. This suggested the possibility of a recent release of DDT. Further investigations, in 1992, continued to demonstrate high DDT to break down product ratios which indicated that a renewable source of DDT may be present in the southern area of the Bayou (Rust Environment and Infrastructure 1994). Concentrations of DDT, DDD and DDE in Shoal Point Bayou have most probably adversely affected benthic productivity, and recent sampling has documented some bioaccumulation in marine fishes (Hunt, 1996, personal communication).

Sites with minimal DDT contamination include Watson Bayou and other bayous adjacent to residential areas. Biological effects would be expected to be minimal. Overall, the St. Andrew Bay ecosystem appears to have experienced very little contamination related to organochlorine pesticides. This is probably because of the limited amount of agricultural activities within the watershed. Organochlorine pesticides have been banned almost entirely for general use. Although they have been found to be extremely persistent in the environment, historic inputs will naturally diminish and eventually disappear. No appreciable amounts of DDT compounds have been detected in the limited sampling of fish and invertebrates conducted by the Service.

Polycyclic Aromatic Hydrocarbons (PAH)

The St. Andrew Bay ecosystem was surveyed for the 14 PAH compounds identified in the Materials and Methods section of this report. Sediment quality guidelines exist for ten of the compounds. PAHs consist of 6-carbon rings (benzene rings) with attached hydrogen atoms. There are thousands of PAH compounds and PAHs are ubiquitous in nature. Anthropogenic activities associated with significant production of PAHs include the iron and steel industry, heating and power generation, and petroleum refining. Aquatic environments may receive PAHs from accidental releases of petroleum and its products. PAHs have been observed to have

cytotoxic, mutagenic, and carcinogenic effects to wildlife, fishes, and invertebrates (Eisler 1987a).

PAH contamination was found at discreet locations within the Bay. The most commonly encountered compounds were fluorene, chrysene, anthracene, 1,2,5,6-dibenzanthracene, pyrene, 1,2-benzanthracene and phenanthrene. Martin Lake, Watson Bayou, Massalina Bayou, and the northern shore area of the Bay between the mouth of Watson Bayou and the outfall of Martin Lake ranked as Level 4. Robinson Bayou ranked Level 3 and Lake Huntington Level 2. The majority of sites sampled were uncontaminated with respect to PAH compounds, including the majority of open Bay sampling sites.

Because of the PAH contamination observed at Level 4 and Level 3 sites, a reduction in overall benthic productivity would be expected (Long *et al.* 1995). In addition, if food base benthic organisms have bioconcentrated PAHs, these compounds may be accumulated by foraging fishes, birds and other wildlife.

At the time this study was done, routine PAH analysis was limited to 14 compounds. It is now possible to analyze for 40 PAH compounds, including the alkylated forms, and it is desirable to survey particular sites within St. Andrew Bay for these additional PAH chemicals. The alkylated PAH compounds, such as 2-methyl naphthalene and 2,6-dimethyl naphthalene, have additional straight-chain carbon side branches. These compounds are of interest because there is evidence that increased alkylation of some PAH compounds increases their toxicity to aquatic organisms. For example, Ott (1978) exposed a marine amphipod (*Eurytemora affinis*) to naphthalene and various alkylated forms. The amounts required for lethal results to 50 percent of the test organisms *decreased* as alkylation *increased*. Concentrations required for LC50 results ($\mu\text{gm/L}$; ppb) were as follows: naphthalene (3,800); 2-methylnaphthalene (1,500); 2,6-dimethylnaphthalene (900); and 2,3,5-trimethylnaphthalene (300). It appears that much smaller quantities of alkylated naphthalenes are just as toxic as larger amounts of pure naphthalene. Alkylation might increase the toxicity of other PAHs as well.

Because of the carcinogenic nature and acute toxicity of some of the PAH compounds, all prudent management strategies for their control should be implemented. Regulatory control over the transport and storage of petroleum compounds has increased over the past decade. It is probable that most of the PAH compounds observed in St. Andrew Bay are either of a historic nature, originate from minor spills or vessel leaks, or enter the Bay via stormwater runoff. Continued careful operation of marina and oil storage facilities, continued improvement in shipping precautions, and implementation of adequate stormwater controls should help assure maintenance of clean conditions within the Bay.

Aliphatic Hydrocarbons

These straight chain petroleum compounds were encountered in very small quantities at most sites within the Bay. This was expected since alkanes are natural components of plants. Excessive quantities of alkane aliphatic compounds in sediments may reflect exposure of the site to large, anthropogenic sources of these materials such as oil spills or industrial discharges. Chlorinated aliphatic compounds are frequently found in municipal wastewater and certain types of industrial discharges (Moore and Ramamoorthy 1984). Alkanes can become halogenated, and chlorinated alkanes under the right physical or biological conditions could potentially form undesirable organochlorine compounds (for example, chloroform or carbon tetrachloride). To date, no sediment quality guidelines exist for aliphatic hydrocarbons. However, high amounts were observed in Watson Bayou and Martin Lake. These areas are known sites of oil storage facilities, marine repair yards, and/or industrial complexes.

Polychlorinated Biphenyls (PCBs)

Analysis for total PCBs was run on sediment samples collected in 1985 and 1988. The only sites contaminated with PCBs were found either in Watson Bayou or in St. Andrew Bay east of the mouth of the Bayou in deep water near the northern shore. The greatest PCB concentrations occurred at station #39 (a Level 4 site) within the southeastern arm of Watson Bayou. Lands adjacent to this station are heavily used by industry. All PCB values at that station exceeded the

ERM concentration level; therefore, at the time the sediment was collected, benthic productivity was probably significantly reduced at that site. It is not known whether natural degradation of PCBs has resulted in reduced levels at these sites over the last decade. The sites should be re-sampled for PCBs. However, over the great majority of the area of St. Andrew Bay, the sediments are primarily free of these industrial compounds. Fish collected in or near Watson Bayou and tested for PCBs had low concentrations of the compounds. Total PCB concentrations in spotted seatrout collected from St. Andrew Bay were low; muscle - ND to 0.5; gonads - ND to 0.24; offal - 0.25 to 0.52; and liver - 1.0 to 2.6 (ppm, wet weight). Whole body analyses of other fish species were also low (less than 1.5 ppm, wet weight).

Dioxin and Furan Compounds

The presence of dioxin compounds in St. Andrew Bay sediments could be a concern. Polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) are chemical byproducts occurring at low concentrations during the manufacture of other compounds. They can be found in trace amounts in certain industrial air emissions or liquid effluents carrying industrial wastes. Some sources of dioxin include the manufacture of chemical pesticides, the most important of which is the herbicide 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) (Eisler 1986).

Dioxin has its effect on living organisms at the cellular and subcellular levels. Dioxin causes cancer in laboratory animals (Gough 1987). Dioxin can also be "teratogenic" (causing defects to developing embryos) (Walker and Peterson 1992). Dioxin is an estrogenic compound that can have adverse effects upon the endocrine systems of some species, thereby affecting embryonic development and even behavioral patterns (Peterson *et al.* 1992).

Studies in the Great Lakes have demonstrated definite linkages between polychlorinated hydrocarbon compounds (PCDD, PCDF, PCB) and reproductive failures in fish (Ankley *et al.* 1991), birds (Tillitt *et al.* 1992; Kubiak *et al.* 1989), and mammals (Gilbertson 1988; Proulx *et*

al. 1987). Jones *et al.* (1993) demonstrated biomagnification in adult cormorants, ring-billed gulls and mergansers (range 104-356 pg/g, [ppt] TEQ) from habitat sites having sediment toxicity equivalents (range 6.3 - 14.0 pg/g, TEQ) comparable to those concentrations observed in St. Andrew Bay (2 - 33 pg/g TEQ). Morphimetric brain abnormalities in great blue heron hatchlings have been linked to polychlorinated dibenzodioxins (PCDDs) in British Columbia (Henshel 1993). In addition, dioxins and furans have been linked to reproductive impairment in wood ducks in central Arkansas (White 1993).

The State of Florida has not developed sediment quality guidelines for dioxin and furan compounds. EPA is currently reviewing potential sediment quality criteria for these contaminants. By the spring of 1999, Canada is scheduled to adopt the sediment quality guidelines for dioxin and furan compounds contained in the draft document *Proposed Canadian Environmental Quality Guidelines for PCDD and PCDF for Aquatic Ecosystems*.

The Canadian sediment quality guideline for the protection of aquatic life and wildlife in freshwater, estuarine and marine environments is proposed at under 1 ng/kg (ppt) for 2,3,7,8-TCDD, and under 1 ng TEQ/kg (ppt) for total 2,3,7,8-substituted PCDDs and PCDFs. The guidelines are normalized to a sediment sample with 1 percent organic carbon content.

In our survey, one site in particular, Martin Lake, had the second highest concentration of dioxin compounds (21.4 TEQ). This Lake, situated adjacent to the highly saline waters of the Bay, is a freshwater supply for migratory birds and other wildlife. It has also been considered as a candidate trophy fishing lake by the Florida Game and Fresh Water Fish Commission. The Lake is used by citizens as a recreational fishing site. If the Canadian sediment quality guideline is applied to the concentration of dioxin compounds found within Martin Lake, the amount of dioxin in the Lake far exceeds desirable levels. However, because only one sample has been evaluated from the Lake, more investigation is warranted to precisely define the concerns with respect to fish and wildlife resources. As noted above, sediment dioxin concentrations similar to the Martin Lake value resulted in biomagnification in the aquatic food chain (including bird life) in the Great Lakes (Jones *et al.* 1993; Jones *et al.* 1993a; Jones *et al.* 1994).

The origin of dioxin compounds in Martin Lake is unclear. The dam that separates the Lake from the Bay was installed in the 1950s. The Bay County Military Point Treatment Lagoon came on line in the early 1970s, ruling out effluent from the federally-permitted municipal outfall as a source. Also, the chlorine bleaching process at the mill did not commence until the mid-1960s (Mann 1996, personal communication). At that time, effluent from the mill was discharged directly into the Bay to the west, outside of the Martin Lake dam. The Corps of Engineers sediment station PC-1 is located in the Bay 1,100 meters (3,600 feet) due west of the dam. At this location dioxin has been measured at 6.15 ng TEQ/kg of sediment (ppt). Possible sources for the dioxin found within Martin Lake include industrial effluent released in the Lake's watershed, unidentified non-point source runoff, groundwater percolation from waste disposal areas, wind-blown particulate matter, or atmospheric deposition.

Many different isomers of the 2,3,7,8-substituted PCDD compounds were detected in significant concentrations at all seven sediment stations evaluated to date. The role of dioxin and furan compounds as potential contaminants to fish and wildlife in the St. Andrew Bay ecosystem remains undocumented; however, based on the presence of these compounds in the sediment samples, the potential does exist for some degree of harm to wildlife. Application of the Canadian Interim Sediment Quality Guideline (SQG) may provide a level of awareness, or define a degree of concern. For example, total organic carbon content of the open-bay sediment sample collected at Beacon Beach was 1.04 percent. Analytical results for the Beacon Beach sample were 1.98 ng TEQ/kg sediment (ppt) and 7.2 ppt (duplicate). Therefore, the sediment should not exceed 0.095 ng TEQ/kg of sediment (1.04 percent TOC x 0.091 SQG). Under the draft guideline, both reported concentrations greatly exceed the maximum concentration that would be protective of marine life. The applicability of these Canadian guidelines to southeastern U.S. freshwater lakes is unknown. However, because the guidelines appear to have a credible scientific foundation, they may be a useful tool to begin to assess potential biological risk related to dioxin compounds.

St. Andrew Bay sediment dioxin concentrations can be compared with other northwest Florida bays that the Service has sampled. All values are expressed as toxicity equivalents (TEQ). The

3 lower bay sediment stations within St. Andrew yield an arithmetic average of 6 TEQ (ppt). The St. Joseph Bay arithmetic average was 8 TEQ for six sediment samples. The West Bay sample (15 ppt) was similar in total TEQ concentration to two samples from upper and lower Perdido Bay (17 and 15 TEQ, respectively), and a single sample from Santa Rosa Sound (14 TEQ). A sample collected from St. George Sound was 0.5 TEQ. In more confined waters, Eleven Mile Creek (Perdido Bay) had sediment values from 25 to 78 TEQ, as compared to St. Andrew Bay's Watson Bayou (15 TEQ) and Martin Lake (21 TEQ). The East Bay-St. Andrew Bay sample (33 TEQ) stands out as the highest concentration found in an open-bay site. All the sediment data reported above have come from sample sites located near historic or contemporary industrial activity, except for the St. George Sound sample. Since the dioxin contamination in the Bay exceeds the proposed Canadian guideline, additional study to define the effect, if any, of these compounds on the Bay's fish and wildlife resources is warranted.

Geographic View

A *geographic subunit view* has been prepared because of the size of the Bay, its irregular configuration, and its complicated hydrologic dynamics. The Bay has been subdivided into four separate areas: St. Andrew Bay (i.e., lower bay), North Bay, East Bay, West Bay. In addition, the bayous have been addressed separately because they are characteristically different from the open bay areas, and are more susceptible to trapping contamination. Each area has different and varied adjacent upland activities, which are regulated by diverse government entities.

Lower St. Andrew Bay

Seventy-two sediment stations have been established in the lower bay and its associated bayous and backwaters. The bayous are discussed in a subsequent section of this report. Most of the upland development in the St. Andrew Bay watershed has taken place adjacent to lower St. Andrew Bay. It is here that federal dredging projects are located, vessel traffic is the most dense, two major effluent outfalls are located, and most of the urban stormwater runoff is generated. The lower bay also provides habitat for biological communities having very high

species diversity. Part of the lower bay is a Florida State Aquatic Preserve and is designated as an Outstanding Florida Water (OFW). State law provides that the water quality of OFWs shall not be degraded. This provision includes protection of the sediments that provide habitat for macrobenthic organisms.

Table 30 and Figure 10 summarize the scoring and ranking for all chemicals and all stations located in the lower bay, but not in bayous. About one-fourth (26 percent) of the stations (n=13) were Level 1; 43 percent (n=22) were Level 2; 16 percent (n=8) were Level 3; and 18 percent (n=9) were Level 4. All Level 4 stations are located near the industrial activity between the entrance to Watson Bayou and the point of outflow from Martin Lake. This contamination is probably reflective of historic rather than present day industrial activities. The majority of the Level 3 stations are associated with marinas and vessel activity. The contamination in the lower bay appears to be restricted to relatively small areas of intensive human activity, and most of the lower bay appears to be generally free of the contaminants for which analyses were run. Most of the contamination in the lower bay is attributable to the presence of PAH compounds, with lesser, but nearly equal, contributions from metals and organochlorine compounds.

Future protection of the natural resources of the lower bay is probably dependent upon the implementation of several management actions. First, because most of the land adjacent to the lower bay is already extensively developed, and remaining open lands will probably be developed, it is important that urban stormwater management takes place. This will require the integrated cooperation of Bay County, City of Panama City, Tyndall AFB, and the municipalities of Cedar Grove, Springfield, Parker, and Callaway. Equally important is the continued education of the citizens living adjacent the lower bay to assure proper application of fertilizers, herbicides and pesticides to residential property. Also, proper management of marinas, vessel painting and repair yards, and oil storage facilities is needed. Most vessel repair and painting facilities appear to have no containment controls for the discharge of paints, oils and greases. Materials may be windblown or transported by rain runoff into confined waters such as Massalina and Watson bayous. Best practicable technologies should be applied in the treatment

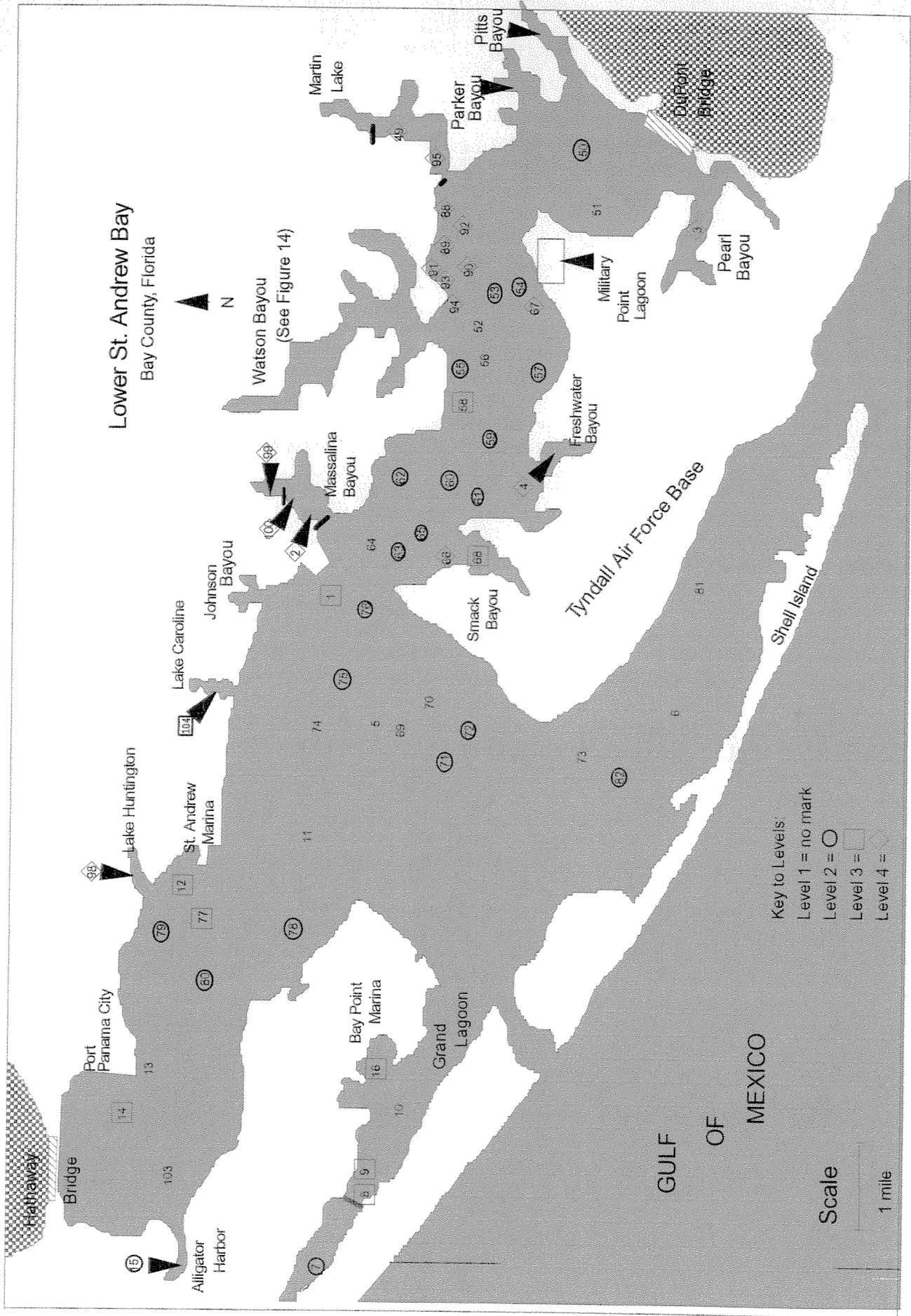


Figure 10 . Chemical quality of Lower St. Andrew Bay sediment stations.

of all effluents discharged as point sources to the Bay. The cumulative loading of all discharges (and stormwater runoff) need to be evaluated for the lower bay. Finally, local air emissions for all of Bay County should be carefully evaluated and controlled, as necessary. A study of local air emissions and potential loading of chemicals to land and water surfaces should be completed to assess this potential source of contaminant input to the St. Andrew Bay ecosystem.

East Bay

This section of St. Andrew Bay is a large area with moderately dense residential development along the western half of the northern shore. The southern shore is held almost exclusively by Tyndall AFB. East Bay has variable, moderate salinities. As such, it provides commercial oyster harvesting and a variety of fishing opportunities. Seven sediment stations are located in East Bay. In East Bay, 57 percent of the stations (n=4) ranked as Level 1 (Table 11 and Figure 11). Two stations had slightly higher concentrations of metals and PAHs and ranked as Level 2. Station 85 near the center of the Bay south of Callaway Bayou ranked Level 3. There were no Level 4 stations. Future concerns in East Bay will probably be associated with urban runoff, particularly related to residential development of the north shoreline from Laird Bayou east to Wetappo Creek. See the "Other Bayous" section for discussion of concerns at Shoal Point and Pearl bayous.

North Bay

North Bay is the most estuarine section of the St. Andrew Bay system. It receives significant volumes of freshwater from Deer Point Lake, the potable drinking water supply for much of Bay County. Prior to the early 1960s, North Bay extended far beyond the Deer Point Dam, covering 1,100 acres of what is now the Lake. Because of the brackish nature of North Bay, it is the primary oyster harvesting site within the ecosystem. Oyster bars provide an important habitat type that is used by dozens of other important species. North Bay provides prime habitat for numerous fishes, marine invertebrates, wading birds and waterfowl.

Only three sediment stations are presently located in the open waters of North Bay (Table 12). Two of those stations (stations 28 & 29) ranked as Level 1, and one station (32), below the Deer Point Dam ranked as Level 2 because of an arsenic concentration (11 ppm, dw) that slightly exceeded the ERL value (8.2 ppm, dw). However, based on the aluminum contained within the same sample, the arsenic that is present probably occurs naturally. The chemical quality of the North Bay sediment stations, excluding the associated bayous, is good (Figure 12). Urban stormwater runoff appears to be the major future contaminant threat to this area. Frequently, in the past, temporary increases in fecal coliform bacteria levels following heavy rains have resulted in the State temporarily closing the waters of the Bay to oyster harvesting. Future management objectives for North Bay include sustaining a viable, harvestable oyster fishery and an economically valuable recreational fishery, and conservation of saltmarsh wetlands, seagrass beds, and associated marine nursery areas. Requirements to maintain these socially important resources include: management of future residential development to minimize contaminated stormwater runoff and physical impacts to wetlands; recognition of the need for adequate amounts of freshwater inflow to North Bay to sustain natural brackish conditions; proper management of adjacent industrial facilities including the international airport, light industries, and boat manufacturing and repair yards. Future expansion of residential use of septic tanks should be minimized, and centralized sewage facilities considered to eliminate bacterial threats to oyster harvesting waters.

West Bay

West Bay is the least developed area of the St. Andrew Bay system. With little freshwater inflow, the Bay provides clean, moderate-salinity, estuarine habitat. Seagrass beds are numerous, and the south shore of the Bay provides the most extensive salt marsh area within the ecosystem. The Bay does, however, receive the treated municipal wastewater effluent from the City of Panama City Beach, and the thermal effluent from the Gulf Power Plant cooling system. The Gulf Intracoastal Waterway extends through West Bay and barge traffic is moderate.

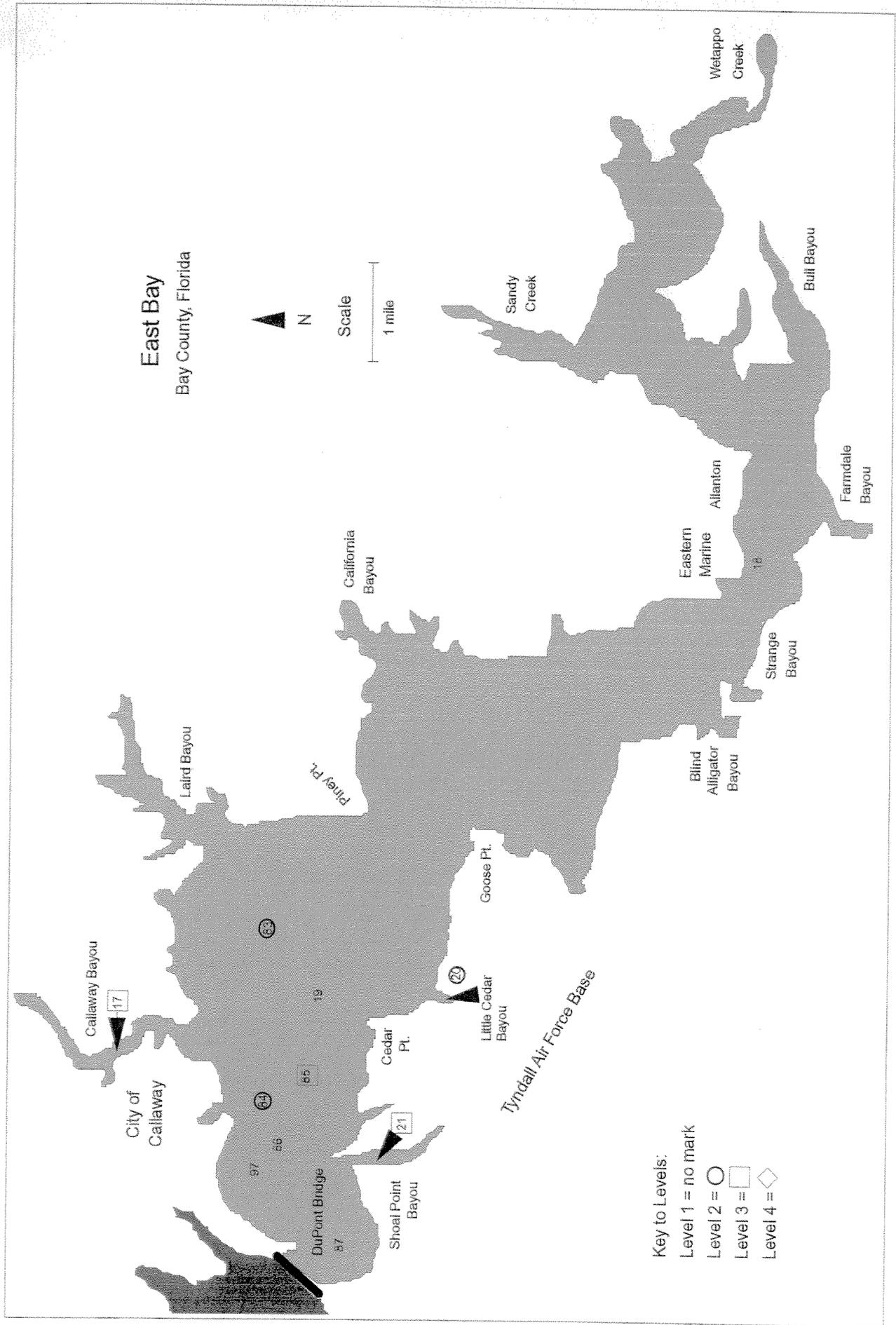


Figure 11 . Chemical quality of East Bay sediment stations.

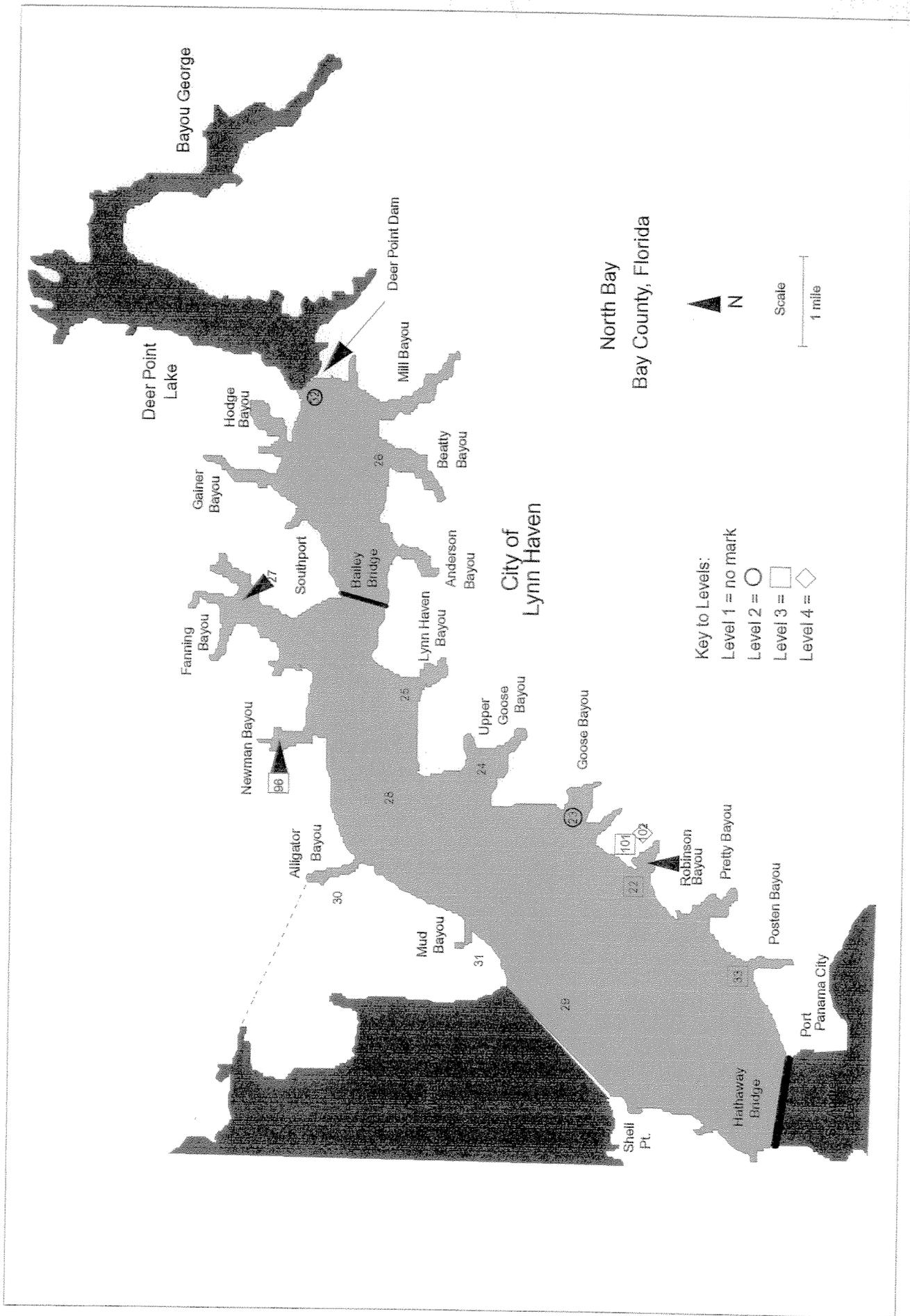


Figure 12 . Chemical quality of North Bay sediment stations.

Four open water sediment stations are located in West Bay (Figure 13). All stations ranked as Level 1 (Table 13). With proper management of uplands around the Bay, including control of stormwater runoff and conservation of wetlands, West Bay should remain a relatively pristine coastal embayment. Management strategies that should be considered include acquisition of large tracts of undeveloped areas to buffer impacts of development. Future development, particularly residential development and associated roadways, should be strategically planned to assure conservation of the Bay's resources. Additional evaluation of municipal effluent discharges associated with the growth of Panama City Beach is warranted. Assuming no change in existing water quality criteria requirements, significant increases in effluent discharges could exceed the Bay's capacity to assimilate pollutants. In addition, the impact of effluent suspended solids deposition on seagrasses needs to be evaluated.

The Bayous of St. Andrew Bay

There are 59 bayous within the St. Andrew Bay system. This study provides chemical sediment data on 22 (37 percent) of these bayous. The bayous constitute some of the most important habitat areas within the Bay. They serve as nursery areas for myriad numbers of larval and juvenile fishes and invertebrates. They are important feeding and resting areas for many species of water birds. Unfortunately, these waterbodies are also primary receptacles for stormwater runoff from the land. Unmanaged urban runoff can carry numerous chemicals such as pesticides, oils and greases (including AHs and PAHs), metals, and industrial compounds. Also carried in urban and rural stormwater are large quantities of silts and clays, and biological pathogens.

Bayous are nearly enclosed extensions of the Bay. Most were once incised valleys that were eroded by streams during the previously lower sea level and then flooded by the rising sea, which reached its current level approximately 5,000 years ago. Bayous have poor hydrologic flushing capacities and usually have no permanent streams flowing into them. The natural sediments within most bayous are usually rich in silts, clays, and organic matter; conditions that make them likely to retain toxic chemicals transported to the bayous by stormwater runoff.

Since the natural sedimentation rate within a bayou is minimal (Isphording 1995, personal communication), the contaminants often remain within 10 cm of the sediment surface where they are readily available for uptake by bottom dwelling organisms. The chemicals associated with the organic fraction or interstitial water of the sediments are the most available to biological organisms. Once a bayou becomes badly contaminated with chemicals, it may take literally years, or in some cases, even decades for such chemicals to break down or be carried out of the bayou. Human attempts to artificially restore or mechanically remove contaminated sediments from within bayous may or may not be feasible.

Estuarine fishes and invertebrates using contaminated bayou habitats may assimilate and even concentrate harmful chemicals within their bodies. Adverse effects can include reproductive impairment, injury to immune systems, and development of cancers. Proper management of St. Andrew Bay's bayous is an important factor upon which the welfare of the Bay is, to a significant degree, very dependent.

Of the 22 bayous evaluated (Tables 34, 35, and 36), 27 percent (n=6) ranked as Level 1; 14 percent (n=3) as Level 2; 23 percent (n=5) as Level 3; and 36 percent (n=8) as Level 4. Watson and Massalina bayous are among the 8 bayous contaminated to a Level 4 status. Because of the extent of contamination within these two bayous, they are discussed separately in this section.

In St. Andrew Bay, there is little doubt that some of the bayous have experienced contamination that is historic, rather than contemporary, in nature. For instance, today's Martin Lake was once Martin Bayou, and home to a number of industrial sites prior to construction of the dam that created the Lake and isolated it from St. Andrew Bay. James Watson had his saw mill west of the Bayou as early as 1836 (West 1922) and International Paper Corporation built a paper mill in 1931 on Watson's site. Arizona Chemical established its plant west of the Bayou in 1937 and expanded the facility in 1945 (Wong 1996, personal communication). Even a mast maker worked near Martin Bayou for a brief period (Womack 1996, personal communication). In the mid-1950s, the dam adjacent Highway 98 was constructed that converted Martin Bayou into the



Figure 13 . Chemical quality of West Bay sediment stations.

freshwater Martin Lake. Another example is Robinson Bayou, in North Bay, which has been the site of boat manufacturing for several years and has received extensive residential runoff for a number of years. Also, the southwest runway of the Panama City International Airport is within the Robinson Bayou watershed. Lake Huntington, located in the historic St. Andrews section of Panama City, has received residential urban runoff for many years. Decades ago, Smack Bayou (Tyndall AFB) was probably used as a safe harbor in which to clean the bottoms of the bay fishing boats (smacks) of a bygone era. Pearl and Freshwater bayous may both have been inadvertently contaminated by military activities and application of DDT compounds. Very significant levels of DDT were discovered in the latter 1980s at Shoal Point Bayou and are being addressed by Tyndall AFB. This situation is discussed in more detail below. Because of historic contamination problems, any additional chemical degradation of these vital bayou habitat areas should be avoided.

Watson Bayou

Watson Bayou is the largest of all the bayous within the St. Andrew Bay ecosystem. Before its shorelines were developed by man, and before its waters began to be used extensively by vessels, the Bayou probably provided prime estuarine habitat for many species of marine organisms.

Twenty-nine sediment samples from Watson Bayou that were chemically analyzed by the Service are reported here. In 1985, three sediment samples (A, B, & C) were collected from each of nine stations (n=27) within Watson Bayou. In 1988, a tenth station, 48 (WB-11), was added just inside the Bayou near the inlet and a single composite sample was analyzed. That same year, station #39 was re-sampled (single composite sample). All stations within the Bayou were subsequently re-numbered with a permanent, single number. All stations indicate that adverse biological effects are probably due to contaminants (Table 14 and Figure 14). Twenty-four samples (83 percent) ranked as Level 4 and have likely been biologically impaired. Two samples (7 percent) ranked as Level 3; 3 samples (10 percent) were Level 2; and none were Level 1.

The history of Watson Bayou has been one of industrial development to the east and residential development to the west. Development began as early as 1836, when James Watson acquired a large tract of land for the timber it held. He bought nearly all the pine land on the north shore of the Bay from Dyers Point (now the location of Port Panama City) to Long Point (Dupont Bridge, leading to Tyndall AFB and erected a sawmill on the Bayou that bears his name (West 1922). Commerce and industry flourished near the Bayou. Until the 1950s, most wastes and effluents were released into the Bayou in an untreated or poorly treated state. In 1953, the City of Panama City constructed its Millville Sewage Treatment Plant on a small island-like peninsula near the Bayou's center. In 1984, effluent discharge from the plant to Watson Bayou was terminated, and the treated effluent was piped to the Bay County Cherry Street Sewage Treatment Plant for additional treatment (Alsworth 1996, personal communication). A National Pollutant Discharge Elimination System permit was issued for the Millville facility on December 13, 1974 (Environmental Protection Agency 1975). For a period of 31 years, secondarily treated effluent was discharged from the plant into the Bayou. Although the effluent was treated, using the best technology of the period, some contaminants may have been released to the water and subsequently incorporated into Bayou sediments.

In 1931, International Paper Corporation built the first paper mill in Florida on what had been the former site of Watson's sawmill. The mill changed hands from International Paper Corporation to Southwest Forest Industries, and finally to Stone Container Corporation. The Panama City mill has never discharged to Watson Bayou, and in fact, the flow of groundwater at the mill site is away from Watson Bayou (Hurd, personal communication). In 1945, when Arizona Chemical Company located its plant between Watson Bayou and Martin Lake, the company began using industrial liquids from the paper mill for extraction or synthesis of commercial chemicals.

For many years, the Bayou has been the home for marine repair and construction facilities. These facilities use, or did use, sloping marine railways to move vessels onto the near shore.

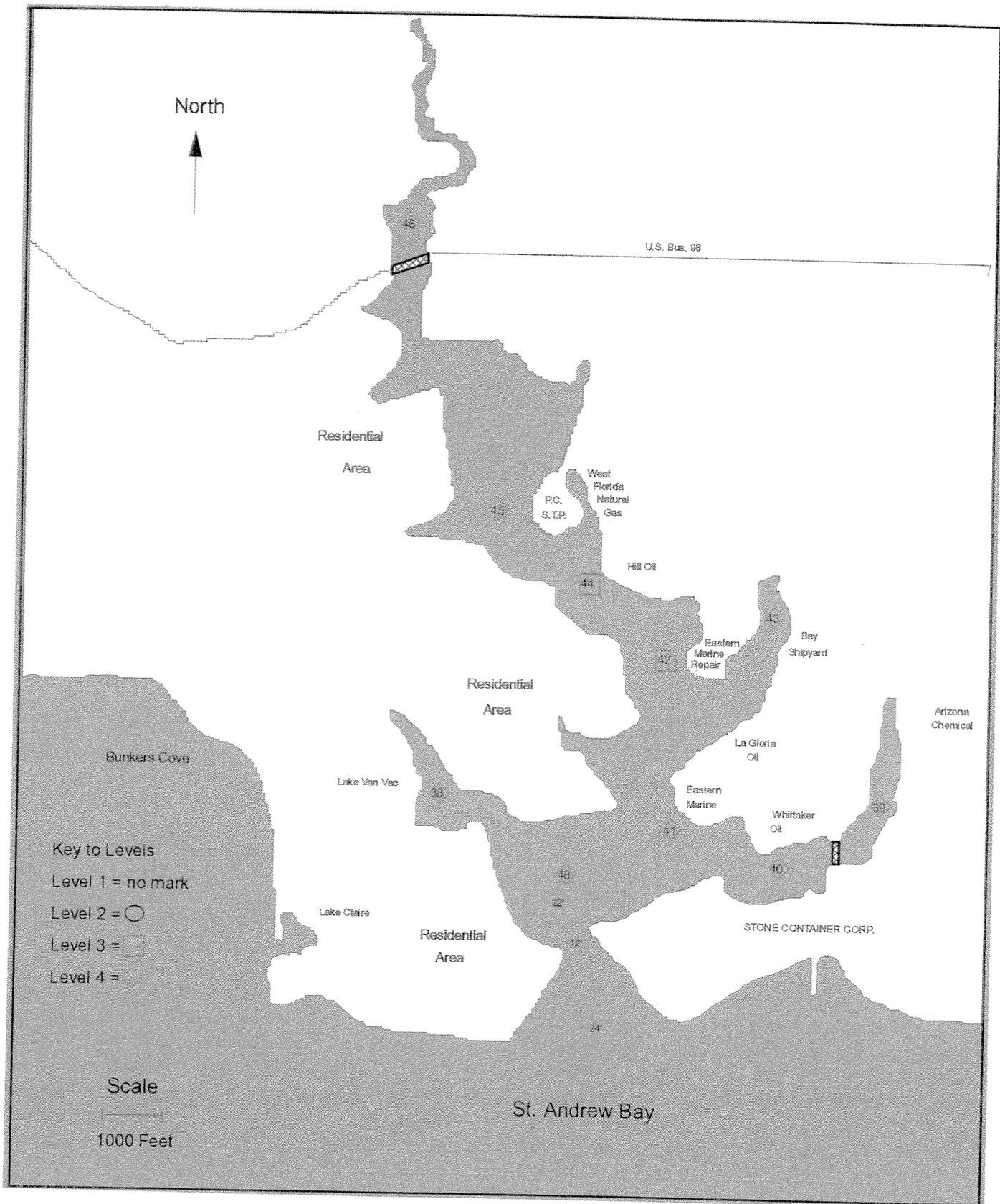


Figure 14 . Chemical quality of Watson Bayou sediment stations.

Numerous paints are removed and new paints and chemical compounds are applied to boats at these sites. Because air-borne particles (from sandblasting, etc.) and ground runoff is sometimes uncontrolled, contaminants may enter the Bayou as a result of these activities. Common metals currently or historically associated with vessel construction and/or repair include chromium, copper, lead, mercury, tin, and zinc.

Several oil storage facilities are also located on Watson Bayou. Spillage has occasionally occurred at such facilities. Each oil storage facility is now required by the EPA, under provisions of the Clean Water Act (33 U.S.C. § 1321) and federal regulation (40 CFR Part 112) to have a Spill Prevention, Control and Countermeasures (SPCC) plan; along with appropriate site construction and response equipment to implement the plan.

The steeply sloping live oak hammock that forms the western shoreline of the Bayou was established as a residential area decades ago. Normal yard maintenance since World War II has included the application of fertilizers, herbicides, and persistent organochlorine pesticides. For many years, upland storm runoff carried these chemicals into the Bayou.

Metals found in the sediment samples were a primary factor in the rankings. The elements of interest included arsenic, cadmium, chromium, copper, mercury, nickel, silver, and zinc. Metal contamination is common in the Bayou. Forty-one percent of the samples would have ranked as Level 4 based on metals alone. Metal "site partitioning" analyses (Isphording *et al.* 1985) were run at two stations for chromium, copper, lead, nickel, vanadium, and zinc (Figures 15 and 16). Unfortunately, the technical procedures in these analyses do not allow for evaluation of mercury.

Very little of each metal (less than 2 percent) was associated with the pore water. However, one-third to one-half of the amount of several metals was bound to the organic portion, and therefore readily available to biota inhabiting the sediment. While chromium, nickel, and vanadium occurred in significant amounts in the organic fraction, results varied highly for copper, lead, and zinc.

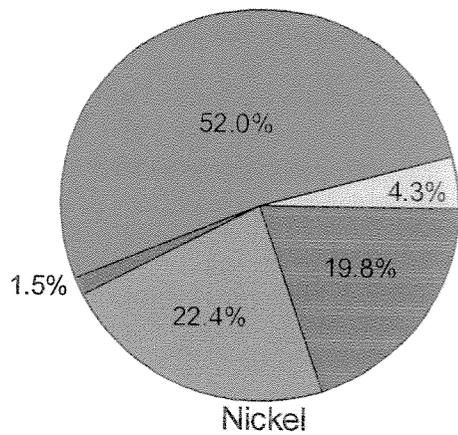
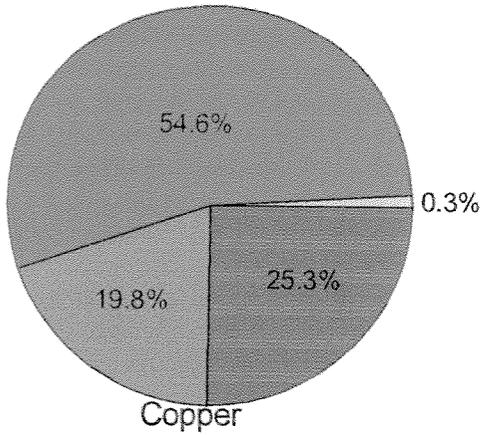
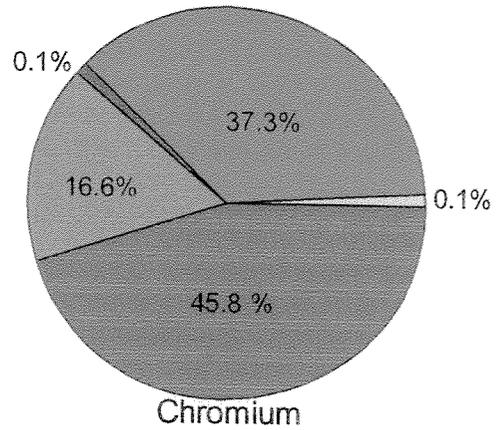
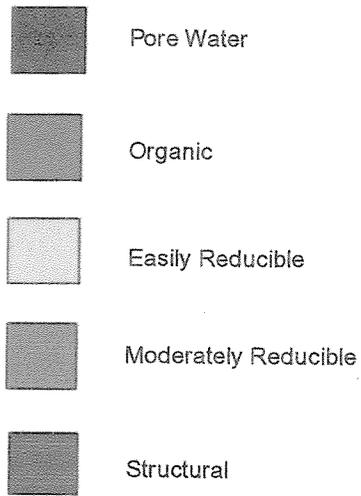
Levels of mercury exceeding the sediment ERL value were recorded throughout the Bayou. Almost all contamination observed is believed to be of historic origin. In the early years of paper mill operations, and up until 1965, wood pulp awaiting processing was treated with compounds to prevent growth of algae or slime. These slimicides were usually phenylmercuric compounds (D'Itri *et al.* 1977). Mills in various locations of the U.S. inadvertently contributed mercury to the environment (Lambou 1972). Mercury was also a component of anti-fouling paints (Eisler 1987; D'Itri *et al.* 1977) and the vessel repair facilities within the Bayou may have been sources of mercury. Four of the 11 Watson Bayou sediment stations exceeded the ERM value for mercury. The following maximum values for mercury were recorded at each station (ppm, dw): station 38, 0.75; station 39, 1.50; station 43, 0.76; and station 45, 0.80.

During the period of leaded gasoline, lead compounds from vehicles likely became a part of the runoff and concentrated lead at various points. Lead concentrations in the possible biological effects range were found in the upper sections of several arms of the Bayou (Stations 38, 39, 40, 43, and 46) and at mid-bayou stations 44 and 45.

PAHs are a major source of contamination within the Bayou and 34 percent of the samples, representing half of the Bayou stations, would have been ranked as Level 4 based on these chemicals alone. At these concentrations, adverse biological effects would probably occur. The PAH compounds that were detected at concentrations exceeding the ERM values, and the associated number of samples (n=) were as follows: chrysene [ERM = >2,800] (n=2, range 2,456-3,813 ppb); 1,2-benzanthracene [ERM = >1600] (n=2, range 2,456-3,813 ppb); and 1,2,5,6-dibenzanthracene [ERM = >260] (n=7, range 261-451 ppb). The remaining samples all exceeded the ERL values for PAHs. Historic oil leaks and small spills are the likely source of most PAHs in this Bayou.

Organochlorine compound contamination (pesticides and PCBs) was encountered at most stations within the Bayou. Two of the three sites in the Bay system that would rank as Level 4, based solely on organochlorine pesticides, are in the southernmost eastern arm of Watson Bayou.

Metal Site Partitioning Watson Bayou, ST #39



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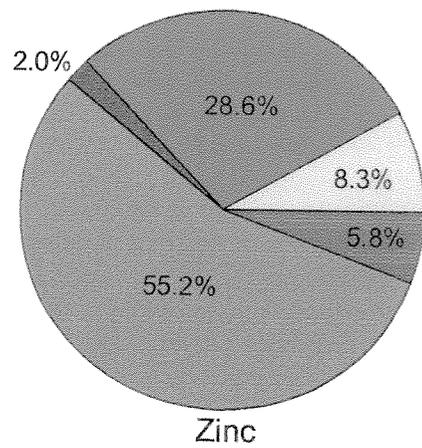
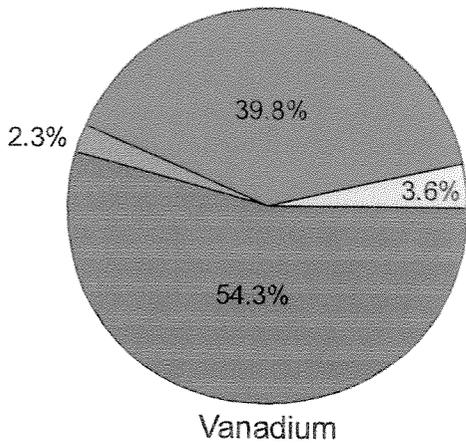


Figure 15.

Metal Site Partitioning

Watson Bayou, ST # 45

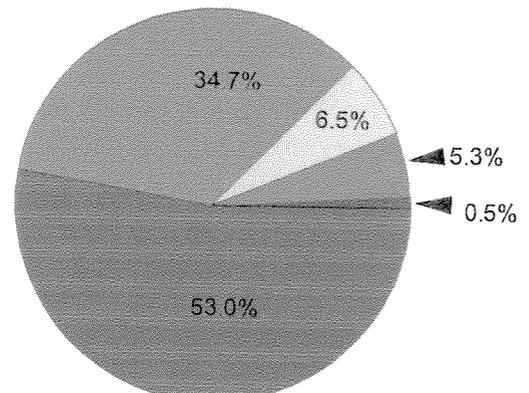
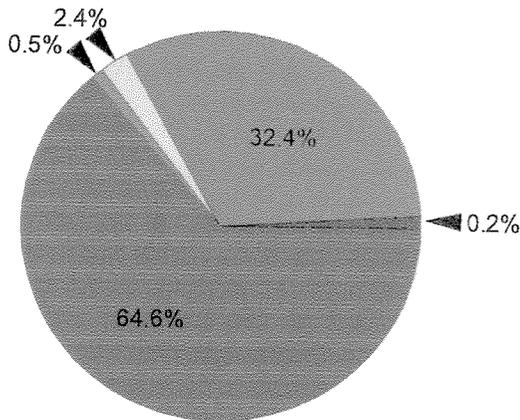
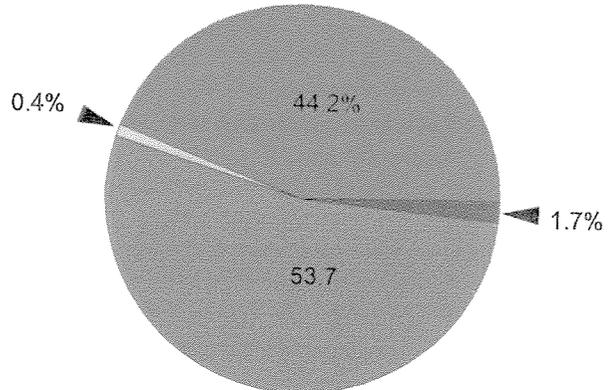
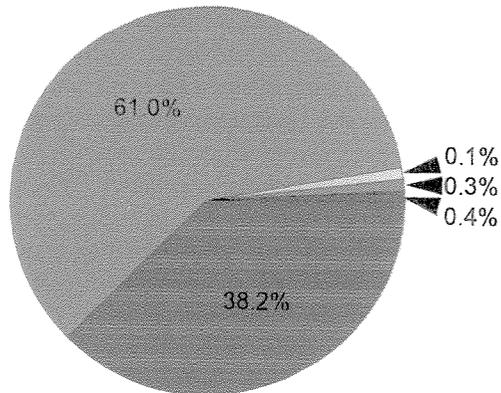
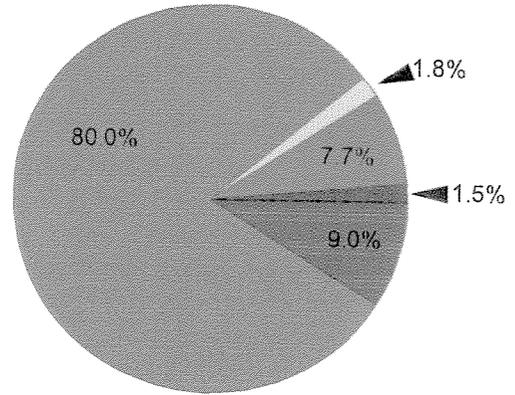
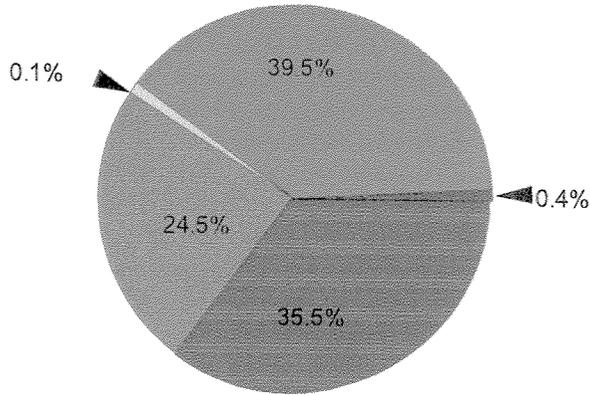
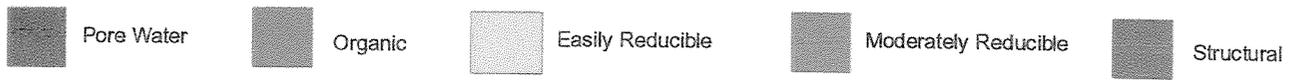


Figure 16.

Most of this contamination was related to the total PCB levels. Both stations are near industry. Four samples analyzed for PCBs at station 39 averaged 2,424 ppb (dw) and ranged from 1,266 to 4,474 ppb. These concentrations far exceed the ERM value of 180 ppb; and adverse biological effects would be expected. Three samples for PCBs at station 40 average 293 ppb and ranged from 125 to 417 ppb. The only pesticide encountered in Watson Bayou sediment was DDT (and the degradation forms DDD and DDE). Total DDT concentrations exceeded the sediment ERM value at most stations, and the common occurrence of these compounds probably reflects their wide use 2 or 3 decades ago. The contamination is probably related to residential yard maintenance or former pest control programs.

Fish and invertebrate samples collected and analyzed from Watson Bayou contained various concentrations of metals, PCBs, DDT compounds, and PAHs. No samples exceeded the State of Florida consumption advisory level for mercury. The harmful effects to aquatic organisms of many of the contaminants that were detected have been documented by Eisler (1985, 1986, 1986a, 1987, 1987a, 1988). The Environmental Protection Agency (1993a) designated Watson Bayou as contaminated due to industrial sources. In the EPA study, several indicators for fish were evaluated including: histopathology; frequency and density of splenic macrophage aggregates; frequency and type of vertebral abnormality; blood chemistry; bile fluorescence; and stable carbon and nitrogen isotopes.

The concentrations of chemical contaminants within the sediments may have changed over the last decade. However, it is unknown if these sediments have any capacity to restore themselves. Weathering and bacterial degradation of compounds such as PAHs may take place allowing sediments to partially regain their once uncontaminated status. The Service recently conducted additional sampling within the Bayou and will compare those data with the 1985 data in a subsequent report. That evaluation should provide insight on the effectiveness of the management controls of the last decade and the natural degradation rates of contaminants.

Massalina Bayou

Massalina Bayou is located on the northern shoreline of lower St. Andrew Bay (Figure 2). The Bayou is named after an admired gentleman, "Hawk" Narcisso Massalina, who for many years resided near it. The Bayou has been extensively developed as docking facilities for recreational vessels, with some limited moorage of small shrimp boats. A vessel repair facility has operated for years on the southeast shore of the Bayou. Contaminants associated with vessel use, construction, repair, and maintenance have found their way into the water and sediments. However, urban stormwater runoff and unidentified historic activities have also played a role in the contamination observed in the Bayou to date.

The highest concentrations of cadmium and mercury in St. Andrew Bay have been detected in Massalina Bayou sediments. All sediment samples at each of the three stations are Level 4 with probable adverse biological effects concentrations (Table 15). All stations were in the top 25 percentile of St. Andrew Bay Level 4 stations.

Each station would have ranked as Level 4 based solely on the concentrations (ppm, dw) of metals (Appendix 1A). At station 99 (upper bayou) four metals exceeded ERL concentrations (As, 10; Cd, 1.5; Cu, 125; Zn, 387) and two exceeded ERM (Hg, 0.88; Pb, 370). At station 100 (mid-bayou) four metals exceeded the ERL concentrations (As, 14; Cd, 1.6; Cu, 100, Zn, 353) and two metals exceeded the ERM (Hg, 1.88; Pb, 310). At station 2 (lower bayou), where two composite sediment samples have been analyzed, six metals exceeded ERL concentrations (Cr, 110; Cu, 50 & 251; Hg, 0.48; Pb, 76 & 130; Ni, 50; Zn, 197) and one metal exceeded ERM (Hg, 1.2). Trends of metal distribution within the Bayou were not substantiated, but it appears that more lead and zinc occurs in the upper half of the Bayou. The highest lead concentrations (310, 370 ppm) in the St. Andrew Bay study area were found at the upper two stations of Massalina Bayou. It is probable that lead, from historic use of leaded gasoline, was carried by stormwater into the Bayou where it built up in the sediments. The lead concentration documented at the upper bayou station was 70 percent greater than the lead ERM value. At the mid-bayou station the lead concentration was 42 percent greater than the ERM value. Adverse biological effects related to lead would be very likely at these locations. Mercury averaged 1.11

ppm in the Bayou, based on four samples. This is 56 percent greater than the ERM value for mercury of 0.71 ppm, and adverse biological effects attributable to mercury contamination could probably be expected throughout the Bayou. No pattern occurred for copper contamination, but the average concentration (131 ppm) was nearly three times the ERL value. More cadmium appeared to be in the upper half of the Bayou than the lower half; however, the values observed barely exceeded the ERL.

All three Massalina Bayou stations would have ranked as Level 4 based solely on PAH concentrations. At no station was the ERM value exceeded for any PAH compound. However, at the upper bayou station, nine compounds exceeded the ERL value; at the mid-bayou station, six compounds exceeded the ERL; and at the lower bayou station seven compounds exceeded the ERL. The upper bayou station had a sum of 6,821 (ppb, dw) total PAH; the mid-bayou sum was 5,890 ppb; and the lower bayou sum was 7,263 ppb. All sums exceed the ERL for total PAHs of 4,022. The compounds present are likely related to historic oil spills and leaks and included: anthracene, benzo(a)pyrene, chrysene, fluorene, fluoranthene, phenanthrene, pyrene, 1,2-benzanthracene, and 1,2,5,6-dibenzanthracene.

All samples would have ranked as Level 3 based on concentrations of organochlorine compounds alone. Two organochlorine pesticides (p,p'-DDE and the total DDT concentration) were responsible for this contamination. All concentrations recorded for each compound at each station exceeded the ERM values. Unlike Watson Bayou, however, no PCBs (based on total PCB analysis) were detected at any station within the Bayou. The presence of DDT compounds in Massalina Bayou reflects the historic widespread use of these persistent chemicals.

Considering the small size of the water body and the locations of the stations that were sampled, it appears that significant contamination is present throughout the sediments of Massalina Bayou. As is the case with most bayous, Massalina Bayou has a very limited capacity to flush itself of contaminated sediments. Panama City's stormwater management efforts should help to reduce additional contaminant input from adjacent uplands. However, contaminants from vessel repair facilities still need to be addressed. In addition, owners of vessels moored within the Bayou

should be educated about the environmental harm associated with the indiscriminate discharge of septic tank effluent or jettison of trash and garbage into the Bayou. A centralized sewage pumpout facility should be considered for these vessels. Finally, waterfront property owners have an ongoing responsibility to minimize runoff of fertilizers and pesticides and to conserve natural shorelines.

Other Bayous

Twenty other bayous within the St. Andrew Bay ecosystem were evaluated (Table 16 and Figures 10 - 13). It should be noted that Martin Lake is included in the group of "Other Bayous." This is because the Lake was once a bayou. Prior to and during the 1950s, paper mill effluent (process water) from the International Paper Corporation facility was discharged via a ditch directly into the Bay at a point several hundred feet west of the entrance to what was then Martin Bayou. The flood tide carried the effluent into the Bayou and eventually made conditions undesirable for residents living along the shoreline (Riley 1988, personal communication). In the 1950s, to remedy the situation, a low concrete dam was placed across the entrance of the Bayou, such that water could flow out, but not enter. The water body then became known as Martin Lake. In excess of 40 hectares (100 acres) of marine habitat were isolated from the St. Andrew Bay system by this action.

Martin Lake is heavily contaminated with PAH compounds. The Lake averaged Level 4 (based on 4 samples analyzed from 2 stations) with contamination primarily attributable to PAH compounds. Station 49 is located at mid-lake just south of Cherry Street. Station 95 is in the lower part of the Lake east of the Highway 98 bridge. Nine compounds exceeded the ERL at station 49 (mid-lake) and 3 exceeded the ERM. At station 95 (lower lake) the same 9 compounds were detected. Four exceeded the ERL and 5 the ERM. The average total PAH value at mid-lake was 9,455 ppb, which is double the ERL for total PAH. Sediment from the lower lake had a total PAH concentration of 44,688 ppb, which is very close to the ERM for total PAH (44,792). Phenanthrene and 1,2,5,6-dibenzanthracene concentrations exceeded the ERM at mid-lake. Phenanthrene, anthracene, 1,2-benzanthracene, chrysene, and 1,2,5,6-

dibenzanthracene exceeded ERM values at the lower lake station. At that station (#95) the chrysene value alone was 24,688 ppb. This is nearly 9 times the value of the ERM (2,800) for chrysene. So far, the sources of PAH contamination within Martin Lake have not been identified, but are likely related to historic discharges.

It is not particularly surprising that Martin Lake is a Level 4 area, considering the history of the Lake and its proximity to a large industrial site. However, the results for some of the other bayous are somewhat surprising. For example, Pearl Bayou is an undeveloped backwater adjacent to Tyndall AFB. Results from a composite sediment sample collected there (station 3) resulted in the Bayou being ranked as Level 4 due to concentrations of chromium (exceeded ERL), nickel (exceeded ERM), p,p'-DDE (exceeded ERM), and total DDT (exceeded ERM). The presence of the four chemicals are at concentrations great enough to cause adverse biological effects.

Robinson Bayou, Lake Huntington, Freshwater Bayou (Tyndall AFB) and the small unnamed bayou southwest of the Bay County Military Point Treatment Lagoon also all ranked as Level 4 (Table 36). Level 3 contamination was observed at Shoal Point (Tyndall AFB), Poston, Newman, Smack (Tyndall AFB) and Callaway bayous. Little Cedar Bayou (Tyndall AFB), Alligator Bayou (Naval Coastal Systems Center) and Goose Bayou were Level 2. The other bayous evaluated were Level 1 (i.e., uncontaminated).

CONCLUSIONS

Based on our survey results, contamination of some sediments of the St. Andrew Bay ecosystem has occurred. A method has been developed to rank and review sites for potential management action. The rankings range from adverse biological effects frequently occurring at Level 4 sites to no indication of biological effects due to contamination (Level 1 sites). The method is simply additive, and is conservative in that it does not take into account additional toxicity of other chemicals that were detected, but for which sediment quality guidelines have yet to be developed. Also, it does not include any effects associated with chemicals which are present,

but for which no analysis was run. Finally, the method does not address potentially synergistic, cumulative effects of any chemical interactions. Survey methods and results do not allow for an analysis of the bioavailability of the chemicals present in the sediments. Additional specific research is required.

Based on the data contained in this report, the following conclusions can be reached regarding the chemical health of St. Andrew Bay, Florida:

- 1) The sediments of the open waters of St. Andrew Bay, North Bay, East Bay, and West Bay have experienced little or no contamination by metals, organochlorine pesticides, PCBs, PAHs, or aliphatic hydrocarbons, except for some sites between the Dupont Bridge and the Panama City Marina in the lower bay where stations ranked from Level 2 (open bay) to Level 4 (near industry).
- 2) A significant number of the sampled bayous of the St. Andrew Bay ecosystem have experienced contamination ranging from Level 4 to Level 2; however, many bayous appear uncontaminated when evaluated using the sediment quality guidelines.
- 3) The most severely contaminated bayous are Watson Bayou, Massalina Bayou, Martin Lake (formerly Martin Bayou), and Shoal Point Bayou. There is also some justification for concern regarding Robinson Bayou, Lake Huntington, Pearl Bayou, Freshwater Bayou, and the small bayou near Military Point.
- 4) Based on samples taken in 1985 and 1986, some accumulation of chemicals within fishes and invertebrates has been documented. While no particular chemical was observed at significant levels, the potential for synergistic adverse effects of several compounds (present at low levels) remains undefined.
- 5) Based on a limited sediment survey, dioxin compounds are present at two widely separated locations within the open areas of lower St. Andrew Bay at concentrations of

approximately 6 ppt TEQ. One site is in the St. Andrew Bay State Aquatic Preserve. In addition, higher concentrations of these compounds were documented within West Bay (15 ppt TEQ), Watson Bayou (15 ppt TEQ), Martin Lake (21 ppt TEQ), and east of the Dupont Bridge (33 ppt TEQ). Based on biological data from the Great Lakes area, and the application of the Canadian DRAFT sediment quality guideline for marine and freshwater life, dioxin levels detected in Watson Bayou, Martin Lake and some areas of St. Andrew Bay, may have the potential to cause significant biological effects. Actual effects in these water bodies is undocumented.

- 6) Potential generic sources of contamination into the Bay probably are, or were: urban stormwater runoff, atmospheric deposition, municipal and industrial point source discharges, unregulated marine repair facilities, vessel discharges and historic oil spills.

RECOMMENDATIONS

The following recommendations are presented for consideration by regulators, users, and managers of the St. Andrew Bay ecosystem:

Research Recommendations

- 1) Re-evaluate Watson and Massalina bayous and Martin Lake to quantify if any natural recovery or additional degradation of habitat has occurred since they were originally evaluated by the Service.
- 2) Continue evaluating the presence of dioxin compounds within the sediment of St. Andrew Bay, including Massalina Bayou, Watson Bayou, and Martin Lake to determine magnitudes and areal extent of contamination. Employ the same standard methods when collecting, temporarily storing, and shipping dioxin sediment samples. Sample information should include at a minimum: sediment grain analysis, total organic carbon content, percent moisture, and analyses for all 2,3,7,8-substituted dioxin and furan congeners (n=17).

- 3) Continue the evaluation for the presence of dioxin compounds within biota of the Bay, until enough sampling has occurred to allow development of a scientifically sound statement about any biological impacts of the chemicals. Assess any natural bioconcentration of dioxin compounds in representative species of invertebrates, fishes, birds and marine mammals. Consider for evaluation: a) a deep-water bivalve mollusk, b) southern flounder and spotted seatrout, c) the brown pelican, and d) the bottlenose dolphin.
- 4) Obtain some reasonable estimate of the amounts and types of chemicals that enter the St. Andrew Bay aquatic ecosystem as the result of atmospheric deposition and identify sources.
- 5) Include an aluminum/metal ratio test to indicate the extent of anthropogenic sources. Determine the fraction that is bioavailable.
- 6) Consider collecting sediment cores (up to 8 feet) at a number of locations and analyze for chemical and physical parameters.

Ecosystem Management Recommendations

- 1) Develop a Geographic Information System (GIS) database for the St. Andrew Bay ecosystem that includes sediment chemical distributions, current and historic land use, hydrology, point source discharges, stormwater discharge, pertinent shoreline activities (marinas, marine repair yards), and sediment geologic characteristics including grain size and total organic carbon.
- 2) Reevaluate any new data in light of the GIS database, current sediment quality guidelines, and other available data regarding potentially significant biological effects.

- 3) Continue to approach ecosystem management for the Bay through the efforts and activities of the St. Andrew Bay - Bay Environmental Study Team (BEST); and expand active membership within BEST as necessary.
- 4) Review and coordinate all regulatory actions in the context of the overall St. Andrew Bay ecosystem.
- 5) Develop and implement a strong public education program that includes information about the risks of environmental chemicals, the resource benefits associated with the elimination of these chemicals from the environment, and strategies for individual and community action.

Recommendations to Industry

- 1) Assist in characterizing historic or contemporary contamination of waterways. Evaluate point source discharges, solid waste disposal, industrial or commercial runoff, and contributions associated with combustion (stacks, incinerators, medical incinerators) and atmospheric deposition. Coordinate with ecosystem managers so that practicable resolutions for the areas of concern can be achieved.
- 2) Document steps taken to eliminate dioxin by-products from all industrial processes. Identify additional steps needed and potential economic and ecologic costs.
- 3) Review the need for evaluation of dioxin compounds in smoke stack fly ash and solid wastes that are generated by combustion and/or disposed of at solid waste landfill facilities within 5 miles of St. Andrew Bay.

County and Municipal Recommendations

- 1) Design and implement a coordinated management system that provides for the control of all urban stormwater draining into St. Andrew Bay, and the conservation of wetlands, the Bay, and its tributaries.
- 2) Encourage the education of, and voluntary actions by, city and county citizens related to proper land management, and the appropriate application of residential and agricultural fertilizers, herbicides and pesticides.
- 3) Participate fully in the planning and implementation activities of the U.S. Coast Guard's Northwest Florida Oil and Hazardous Materials Spill Prevention and Response Plan, as it applies to St. Andrew Bay.

State Recommendations

- 1) Continue to evaluate fish contamination in Level 4 bayous and advise the public of fish consumption concerns.
- 2) Adopt and expand the sediment quality guidelines prepared by the Department of Environmental Protection, and utilize such guidelines to evaluate sediment habitat degradation throughout the State of Florida.
- 3) Conduct a chemical contaminants sediment evaluation, particularly for dioxin and furan compounds, of the St. Andrew Bay Aquatic Preserve, including a study of benthic fauna productivity and diversity.

Federal Recommendations

- 1) Evaluate the full extent of contamination at Pearl, Freshwater and Smack bayous adjacent Tyndall AFB part of the base Installation Restoration Program.

- 2) Continue to survey the extent of dioxin sediment contamination within St. Andrew Bay and assess and define any effects of uptake of these chemicals upon fish and wildlife resources.
- 3) Determine the levels, and any adverse effects, related to concentrations of dioxin compounds in bottlenose dolphins that populate the Bay, particularly in the breast milk of nursing dolphin mothers.

LITERATURE CITED

- Aylsworth, Debbie. 1996. Personal communication. History of the construction and operation of the City of Panama City's Millville sewage treatment plant. Engineering Department, City of Panama City, Florida.
- Ankley, G.T., D.E. Tillitt, J.P. Giesy, P.D. Jones, and D.A. Verbrugge. 1991. Bioassay-Derived 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin Equivalents in PCB-Containing Extracts from the Flesh and Eggs of Lake Michigan Chinook Salmon (*Oncorhynchus tshawytscha*) and Possible Implications for Reproduction. *Can. J.Fish. Aquat. Sci* 48:1685-1690.
- Atkeson, Thomas D. 1996. Personal communication. Mercury Program Coordinator, Florida Department of Environmental Protection, State of Florida, Tallahassee, Florida.
- Barkuloo, James M. 1995. Personal communication regarding the presence of striped bass in St. Andrew Bay.
- Beaumariage, D.S. 1964. Returns from the 1963 Schlitz tagging program. Florida Board of Conservation, Marine Research Laboratory, Technical Series 43, 34 pages.
- Beaumariage, D.S. 1969. Returns from the 1965 Schlitz tagging program including a cumulative analysis of previous results. Florida Department of Natural Resources, Marine Research Laboratory, Technical Series 59, 38 pages.
- Beaumariage, D.S. and A.C. Wittich. 1966. Returns from the 1964 Schlitz tagging program. Florida Board of Conservation, Marine Research Laboratory, Technical Series 47, 51 pages.
- Brim, Michael. 1990. Environmental Contaminants Evaluation: Sediment DDT Concentrations in Fred Bayou, St. Andrew Bay, Tyndall Air Force Base, Bay County, Florida. U.S. Fish and Wildlife Service, Panama City, Florida Field Office.
- D'Itri, Patricia and Frank M. D'Itri. 1977. Mercury Contamination: A Human Tragedy. John Wiley and Sons, New York. 311 pages.
- Eisler, Ronald. 1985. Cadmium Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. Biological Report 85(1.2), Contaminant Hazards Review Report No. 2. U.S. Fish and Wildlife Service, Department of the Interior.
- Eisler, Ronald. 1986. Dioxin Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. Biological Report 85 (1.8), Contaminant Hazard Reviews Report No. 8. U.S. Fish and Wildlife Service, Department of the Interior.

- Eisler, Ronald. 1986a. Polychlorinated Biphenyl Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. Biological Report 85 (1.7), Contaminant Hazard Reviews Report No. 7. U.S. Fish and Wildlife Service, Department of the Interior.
- Eisler, Ronald. 1987. Mercury Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. Biological Report 85(1.10), Contaminant Hazard Reviews Report No. 10. U.S. Fish and Wildlife Service, Department of the Interior.
- Eisler, Ronald. 1987a. Polycyclic Aromatic Hydrocarbon Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. Biological Report 85 (1.11), Contaminant Hazard Reviews No. 11. U.S. Fish and Wildlife Service, Department of the Interior.
- Eisler, Ronald. 1988. Lead Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. Biological Report 85(1.14), Contaminant Hazard Reviews Report No. 14. U.S. Fish and Wildlife Service. Department of the Interior.
- Environmental Protection Agency. 1975. Water Quality Study - St. Andrew Bay, Florida. National Enforcement Investigations Center, Denver, Colorado and Region IV, Atlanta, Georgia. EPA 330/2-75-003.
- Environmental Protection Agency. 1988. Health Assessment Document for Polychlorinated Dibenzo-*p*-Dioxins. EPA 600/S8-84/014F, August 1988. Project Summary. Research and Development. U.S. E.P.A.
- Environmental Protection Agency. 1989. Interim Procedures for Estimating Risks Associated with Exposures to Mixtures of Chlorinated Dibenzo-*p*-Dioxin and Dibenzofurans (CDDs and CDFs). EPA/625/3-89/016; March 1989.
- Environmental Protection Agency. 1993a. Proceedings of the U.S. Environmental Protection Agency's National Technical Workshop, "PCBs in Fish Tissue." EPA/823-R-93-003, Washington, D.C.
- Environmental Protection Agency. 1993. Louisianian Province Demonstration Report: EMAP - Estuaries: 1991. Environmental Monitoring and Assessment Program. EPA/620/R-94/001. Washington, D.C.
- Environmental Protection Agency. 1995. National Listing of Fish Consumption Advisories. Office of Water, EPA-823-C-95-001. August 1995.
- Fabacher, D.L. and P.C. Baumann. 1985. Enlarged livers and hepatic microsomal mixed-function oxidase components in tumor-bearing brown bullheads from a chemically contaminated river. Environ. Toxicol. Chem. 4:703-710.

- Florida Department of Health and Rehabilitative Services. 1993. Florida Health Advisory for Mercury in Florida Freshwater Fish.
- Gilbertson, M. 1988. *IN* Toxic Contaminants and Ecosystem Health: A Great Lakes Focus. ed. M.S. Evans, pp. 133-152. New York: Wiley.
- Gough, Michael. 1987. Dioxin: A Critical Review of Its Distribution, Mechanism of Action, Impacts on Human Health, and the Setting of Acceptable Exposure Limits. Technical Bulletin No. 524. Nat. Council of the Paper Industry for Air and Stream Improvement, Inc.
- Greene, D.H.S., and D.P. Selivonchick. 1987. Lipid metabolism in fish. Prog. Lipid Res. 26:53-85.
- Hall, R.A., E.G. Zook, and G.M. Meaburn. 1978. National Marine Fisheries Survey of Trace Elements in the Fishery Resource. NOAA Technical Report NMFS-SSRF-721. Nat. Mar. Fisheries Serv. NOAA. U.S. Dept. of Commerce. 314. pp.
- Henshel, Dianne. 1993. Morphometric Abnormalities in Brains of Great Blue Heron Hatchlings Exposed to PCDDs (1988-1992). A paper presented at the Work Session: *Environmentally Induced Alterations in Development - A Focus on Wildlife*. Wingspread Conference Center, Racine Wisconsin.
- Hunt, Randall J. 1996. Personal communication regarding accumulation of DDT compounds in fish collected from Shoal Point Bayou, St. Andrew Bay, Florida. RUST Environmental and Infrastructure, Greenville, South Carolina.
- Hurd, Craig. 1997. Personal communication. Regional Environmental Officer, Stone Container Corp., Tucker, Georgia.
- Ingle, R.M., R.F. Hutton, and R.W. Topp. 1962. Results of the tagging of salt water fishes in Florida. Florida Board of Conservation, Marine Research Laboratory, Technical Series 38, 57 pages.
- Isphording, Wayne C. 1995. Personal communication. Marine geologist, University of South Alabama. Discussions related to the geologic dynamics of St. Andrew Bay.
- Isphording, Wayne C., John A. Stringfellow and George C. Flowers. 1985. Sedimentary and Geochemical Systems in Transitional Marine Sediments in the Northeastern Gulf of Mexico. Transactions - Gulf Coast Association of Geological Societies, Vol. XXXV, pp. 397-408.

- Jones, P.D., G.T. Ankley, D.A. Best, R. Crawford, N. DeGalan, J.P. Giesy, T.J. Kubiak, J.P. Ludwig, J.L. Newsted, D.E. Tillet, and D.A. Verbrugge. 1993. Biomagnification of Bioassay Derived 2,3,7,8-tetrachlorodibenzo-*p*-dioxin Equivalents. *Chemosphere*, Vol. 26, No. 6, pp 1203-1212. Pergamon Press Ltd. Great Britain.
- Jones, Paul D., John P. Giesy, John L. Newsted, David A. Verbrugge, Donald L. Beaver, Gerald T. Ankley, Donald E. Tillitt, Keith B. Lodge, and Gerald J. Niemi. 1993a. 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin Equivalents in Tissues of Birds at Green Bay, Wisconsin, USA. *Archives of Environmental Contamination and Toxicology*, Vol 24, pp 345-354.
- Jones, P.D., J.P. Giesy, J.L. Newsted, D.A. Verbrugge, J.P. Ludwig, M.E. Ludwig, H.J. Auman, R. Craford, D.E. Tillitt, T.J. Kubiak, and D.A. Best. 1994. Accumulation of 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin Equivalents by Double-Crested Cormorant (*Phalacrocorax auritus*, Pelicaniformes) Chicks in the North American Great Lakes. *Ecotoxicology and Environmental Safety*, Vol. 27, pp 192-209.
- Keppner, Edwin J. 1996. An Inventory of the Biological Resources Reported from the St. Andrew Bay Estuarine System, Bay County, Florida. BEST 0001. Bay Environmental Study Team for St. Andrew Bay. Panama City, Bay County, Florida.
- Kubiak, T.J., H.J. Harris, L.M. Smith, T.R. Schwartz, D.L. Stalling, J.A. Trick, L. Sileo, D.E. Docherty, and T.C. Erdman. 1989. *Arch. Environ. Contam. Toxicol.* 18:706-727.
- Lambou, V. W. 1972. Problem of mercury emissions into the environment of the United States. U.S. Environmental Protection Agency, Washington, D.C.
- Long, Edward R. and Lee G. Morgan. 1990. The Potential for Biological Effects of Sediment-sorbed Contaminants Tested in the National Status and Trends Program. NOAA Technical Memorandum NOS OMA 52. U.S. Dept. of Commerce.
- Long, Edward R., Donald D. MacDonald, Sherri L. Smith and Fred D. Calder. 1995. Incidence of Adverse Biological Effects within Ranges of Chemical Concentrations in Marine and Estuarine Sediments. *Environmental Management*, Vol.19, No. 1, pp. 81-97. Springer-Verlag, New York.
- Mann, James. 1996. Personal communication. Commencement of pulp bleaching at the Panama City mill. Stone Container Corporation, Panama City Mill, Panama City, Florida.

- Mayhew, H.L., J.Q. Word, N.P. Kohn, M.R. Pinza, L.M. Karle and J.A. Ward. 1993. Ecological Evaluation of Proposed Dredged Material from St. Andrew Bay, Florida. Prepared for the U.S. Army Corps of Engineers. Battelle/Marine Sciences Laboratory. Sequim, Washington.
- MacDonald, D.D. 1993. Development of an Approach to the Assessment of Sediment Quality in Florida Coastal Waters. Prepared for the Florida Dept. of Environmental Protection, by MacDonald Environmental Sciences Ltd. Two volumes. Florida Dept. of Environmental Protection, Tallahassee, Florida.
- McNulty, J. Kneeland, William N. Lindall, Jr., and James E. Sykes. 1972. Cooperative Gulf of Mexico Estuarine Inventory and Study, Florida: Phase I, Area Description. NOAA Technical Report NMFS Circ-368, U.S. Department of Commerce.
- Moffett, A.W. 1961. Movements and growth of spotted seatrout, *Cynoscion nebulosus* in the Cedar Key, Florida, area. Quarterly Journal of the Florida Academy of Sciences 12 (3): 147-171.
- Moore, J.W. and S. Ramamoorthy 1984. Organic chemicals in Natural Waters: Applied Monitoring and Impact Assessment. Chapter 3 - Aliphatic Hydrocarbons. Springer-Verlag. pp 16-42.
- Ott, F.S., R.P. Harris, and S.C.M. O'Hara. 1978. Acute and sublethal toxicity of naphthalene and three methylated derivatives to the estuarine copepod *Eurytemora affinis*. Marine Environmental Research, Vol. 1:49-58.
- Payne, J.F., L.L. Fancey, J. Hellou, M.J. King, and G.L. Fletcher. 1995. Aliphatic hydrocarbons in sediments: a chronic toxicity study with winter flounder (*Pleuronectes americanus*) exposed to oil well drill cuttings. Canadian Journal of Fishery and Aquatic Science, Vol. 52: 2724-2735. Canada.
- Perret, William S., James E. Weaver, Roy O. Williams, Patricia L. Johansen, Thomas D. McIlwain, Richard C. Raulerson and Walter M. Tatum. 1980. Fishery Profiles of Red Drum and Spotted Seatrout. April, 1980. No. 6. Gulf States Marine Fisheries Commission. Ocean Springs, Mississippi.
- Peterson, Robert E., Robert W. Moore, Thomas A. Mably, Donald L. Bjerke and Robert W. Goy. 1992. Male Reproductive System Ontogeny: Effects of Perinatal Exposure to 2,3,7,8-Tetrachlorodibenzo-*p*-Dioxin. IN: Advances in Modern Environmental Toxicology, Volume XXI, Chemically-Induced Alterations in Sexual and Functional Development: The Wildlife/Human Connection, edited by Theo Colborn and Coralie Clement, pp 175-193. Princeton Scientific Publishing Co, Inc.

- Poland, A. and J.C. Knutson. 1982. 2,3,7,8-tetrachlorodibenzo-p-dioxin and related halogenated aromatic hydrocarbons: Examination of the mechanism of toxicity. *Ann. Rev. Pharmacol. Toxicol.* 22, 517-554.
- Pristas, Paul J. and Lee Trent. 1978. Seasonal abundance, size and sex ratio of fishes caught with gill nets in St. Andrew Bay, Florida. *Bulletin of Marine Science* 28(3): 581-589.
- Proulx, G., D.V.C. Weseloh, J.E. Elliot, S. Teeple, P.A.M. Anghern, and P. Mineau. 1987. *Bull. Environ. Contam. Toxicol.* 39:939-944.
- Rice, Clifford P. and Patrick O'Keefe. 1995. Sources, Pathways, and Effects of PCBs, Dioxins, and Dibenzofurans. Chap. 18, *In: Handbook of Ecotoxicology.* Lewis Publishers, Boca Raton.
- Riley, David. 1988. Personal communication. Environmental Officer, Stone Container Corporation, Panama City Mill. Discussions regarding the history of paper mill operations in Panama City, Florida, and activities near these operations.
- Rogillio, H.E. 1975. An estuarine sportfish study in southeastern Louisiana. *Fishery Bulletin* No. 14, Louisiana Department of Wildlife and Fisheries, New Orleans, 71 pages.
- Rust Environment and Infrastructure. 1994. Addendum to A-E Chemical Data Acquisition Plan - Quality Assurance Project Plan. Site 29 - Shoal Point Bayou, Tyndall Air Force Base, Panama City, Florida. Contract No. DACW45-89-D-0515. Prepared for: U.S. Army Corps of Engineers, Omaha District.
- Safe, S. 1990. Polychlorinated Biphenyls (PCBs), Dibenzo-p-Dioxins (PCDDs), Dibenzofurans (PCDFs), and Related Compounds: Environmental and Mechanistic Considerations Which Support the Development of Toxic Equivalency Factors (TEFs). *Crit. Rev. Toxicol.* 21:51-88.
- Schropp, Steven J., F. Graham Lewis, Herbert L. Windom, and Joe D Ryan. 1990. Interpretation of Metal Concentrations in Estuarine Sediments of Florida using Aluminum as a Reference Element. *Estuaries*, Vol. 13, No. 3, pp 227-235.
- Smith, S. L. and D.D. MacDonald. 1992. The development and use of Canadian sediment quality guidelines for the protection of aquatic life. Prepared for the Interdepartmental Working Group of MEQ Guidelines and the Canadian Council of Ministers for the Environment Task Group on Water Quality Guidelines, Ottawa, Ontario.
- Statham, C.N., M.J. Melancon, Jr., and J.J. Lech. 1976. Bioconcentration of xenobiotics in trout bile: A proposed monitoring aid for some waterborne chemicals. *Science* 193:680-681.

- Tabb, D.C. 1966. The estuary as a habitat for spotted seatrout (*Cynoscion nebulosus*). American Fisheries Society, Special Publication No. 3, pages 59 - 67.
- Tillitt, D.E., G.T. Ankley, J.P. Giesy, J.P. Ludwig, H. Kurita-Matsuba, D.V. Weseloh, P.S. Ross, C.A. Bishop, L. Sileo, K.L. Stromborg, J. Larson, and T.J. Kubiak. 1992. Polychlorinated Biphenyl Residues and Egg Mortality in Double-crested Cormorants from the Great Lakes. *Environ. Toxicol. Chem.* 11:1281-1288.
- Topp, R. 1963. The tagging of fishes in Florida, 1962 program. Florida Board of Conservation, Marine Research Laboratory, Professional Papers Series 5, 76 pages.
- Truhaut, R. 1975. Ecotoxicology - A New Branch of Toxicology: A General Survey of Its Aims, Methods, and Prospects. IN: *Ecological Toxicology Research*, pages 3-23. Edited by A.D. McIntyre and C.F. Mills. Plenum Press, New York.
- U.S. Fish and Wildlife Service. 1985. Internal memo regarding the capture and release of a Gulf sturgeon within Watson Bayou, St. Andrew Bay, Florida; July 1985.
- U.S. Geological Survey. 1990. Water Resources Data, Florida. Vol. 4, Northwest Florida. Report FL-90-4.
- Varanasi, U., and D.J. Gmur. 1980. Metabolic activation and covalent binding of benzo(a)pyrene to deoxyribonucleic acid catalyzed by liver enzymes of marine fish. *Biochem. Pharmacol.* 29:753-762.
- Vernberg, Winona B., Patricia J. De Coursey, and James O'Hara. 1974. Multiple Environmental Factor Effects on Physiology and Behavior of the Fiddler Crab, *Uca pugilator*. IN: *Pollution and Physiology of Marine Organisms*. Edited by F. John Vernberg and Winona B. Vernberg. Academic Press, New York. pp 381-425.
- Walker, Mary K. and Richard E. Peterson. 1992. Toxicity of Polychlorinated Dibenzo-*p*-Dioxins, Dibenzofurans, and Biphenyls during the Early Development in Fish. IN: *Advances in Modern Environmental Toxicology, Volume XXI, Chemically-Induced Alterations in Sexual and Functional Development: The Wildlife/Human Connection*, edited by Theo Colborn and Coralie Clement, pp 195-202. Princeton Scientific Publishing Co., Inc.
- West, G. M. 1922. St. Andrews, Florida. Third Edition. Panama City Publishing Company, Panama City, Florida.
- White, Donald. H. 1993. Dioxins and Furans Linked to Reproductive Impairment in Wood Ducks. Paper presented at Environmentally Induced Alterations in Development: A Focus on Wildlife Wingspread Conference, Racine Wisconsin.

Womack, Marlene. 1996. Personal communication. Special correspondent to the News Herald, specializing in area history, Panama City, Florida.

Wong, Christine. 1996. Personal communication. Communications Coordinator, Division of Public Relations, Arizona Chemical Company, Panama City, Florida.