GEOLOGICAL SURVEY OF ALABAMA

Berry H. (Nick) Tew, Jr.
State Geologist

GEOLOGIC AND WATER INVESTIGATIONS PROGRAMS

Compilation, Assessment, and Characterization of Available Mercury Data from Natural Materials in Baldwin, Clarke, Mobile, Monroe, and Washington Counties, Alabama

OPEN-FILE REPORT 0702

By
Sandy M. Ebersole, Robert E. Meintzer, and Shinisha L. Perry

Tuscaloosa, Alabama
June 2007

Submitted in partial fulfillment of U.S. Environmental Protection Agency, Gulf of Mexico Program, Agreement No. MX974830-03-0.

CONTENTS

FIGURES

TABLES

INTRODUCTION

The occurrence of mercury-contaminated fish in the five-county study area has been reported in print and broadcast media, which has resulted in numerous inquiries to various local, state, and federal agencies involved in public health and environmental protection, and a public discussion (The Mercury Forum held in May 2005 in Mobile).The purpose of this study is to compile, characterize, and spatially assess mercury data collected from natural materials (soil, sediment, surface water, fish, and atmospheric deposition) as part of various studies and projects from multiple entities. The study provides a source of information on environmental mercury occurrence for local, state, and federal agencies and entities — particularly those involved in environmental assessment and management — various non-governmental organizations, and others interested in coastal issues in Alabama.

This project was conducted by personnel in the Geochemical Laboratory (Water Investigations Program) and the Geologic Investigations Program at the Geological Survey of Alabama (GSA) to assess mercury occurrence within Baldwin, Clarke, Mobile, Monroe, and Washington Counties, Alabama (fig. 1). The study was based on data from ongoing studies as well as from past studies that were available from the literature. Through statistical and spatial analyses of the collected data (samples from 30 different studies), this research explores the overall mercury distribution in the five-county study area and the Mobile River drainage basin. In addition to the aforementioned data, a background review and a map showing superfund sites, U.S. Environmental Protection Agency (EPA) Toxic Release Inventory (TRI) facilities releasing mercury, and mercury-contaminated water bodies within the study area are included in this report. Concluding the descriptions of the methodology and results section, recommendations are given for future studies.

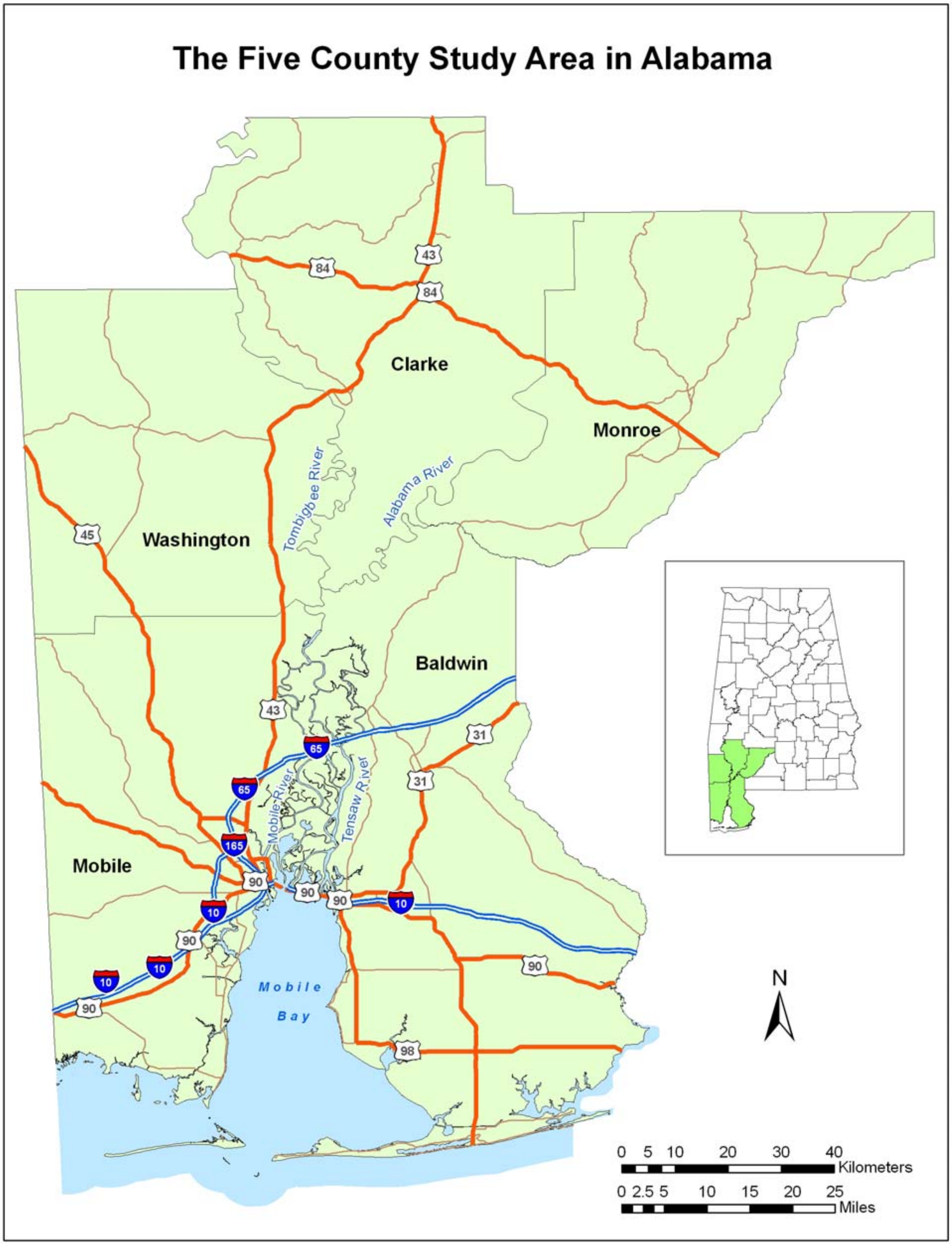

Figure 1. The study area, including Baldwin, Clarke, Mobile, Monroe, and Washington Counties, Alabama.

This project was not designed to identify point sources of mercury from the data collected. Significant limitations to interpretation of the results of the analyses in this project include small sample size relative to study area, low sample density across the five counties, and clustered spatial distribution. These shortcomings should be noted prior to using any of the maps in this report for identifying contaminated regions or ruling out areas that may or may not be contaminated. This project provides only a spatial assessment of mercury levels in data collected for multiple years and may not reflect current mercury levels and distribution.

ACKNOWLEDGMENTS

Review of project deliverables was principally performed by Michel L. Gielazyn (National Oceanic and Atmospheric Administration coastal resources coordinator), Fred Kopfler (retired EPA Gulf of Mexico Program senior environmental scientist), Pete Tuttle (U.S. Fish and Wildlife Service resource contaminant specialist), and Alabama Department of Environmental Management staff.

PROJECT DEFINITION

Each year the Agency for Toxic Substances and Disease Registry (ATSDR) produces a list of toxic substances ranked by a combination of three attributes: frequency, toxicity, and potential for human exposure. The 2005 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Priority List of Hazardous Substances ranked mercury third behind lead and arsenic (ATSDR, 2005). Moreover, over the past several years, a number of articles have appeared in the media expressing concern over mercury in coastal Alabama.

There are three sources of mercury in the environment: the natural release of mercury from geologic material, anthropogenic releases, and re-emission to the atmosphere from mercury deposited on the earth's surface in the past. As mercury moves through its biogeochemical cycles (fig. 2), it may come in contact with or be absorbed by plants and ingested by animals. In its elemental or inorganic forms, mercury is poorly absorbed by higher animals. However, inorganic forms of mercury may be transformed by bacteria and other chemical processes to methylated forms that are easily and readily absorbed by all life forms, including humans. Over time, the methylmercury can accumulate in organisms from both biotic and abiotic sources (bioaccumulation) and the concentrations become more elevated in organisms of higher trophic levels (biomagnification) (Arctic Monitoring Assessment

Programme, 1998). Mercury can be lethal or sublethal to exposed organisms depending on the concentration or dose. In animals from fish to mammals, death can result from levels as low as 100 to 500 parts per billion (ppb) body weight per day. Current reference level for sublethal effects is 100 ppb body weight per day (Moore, 2000). Mercury is a known neurotoxin in humans, and effects include decreased motor skills, tremors, the inability to walk, convulsions, and death (Center for Disease Control, 2005).

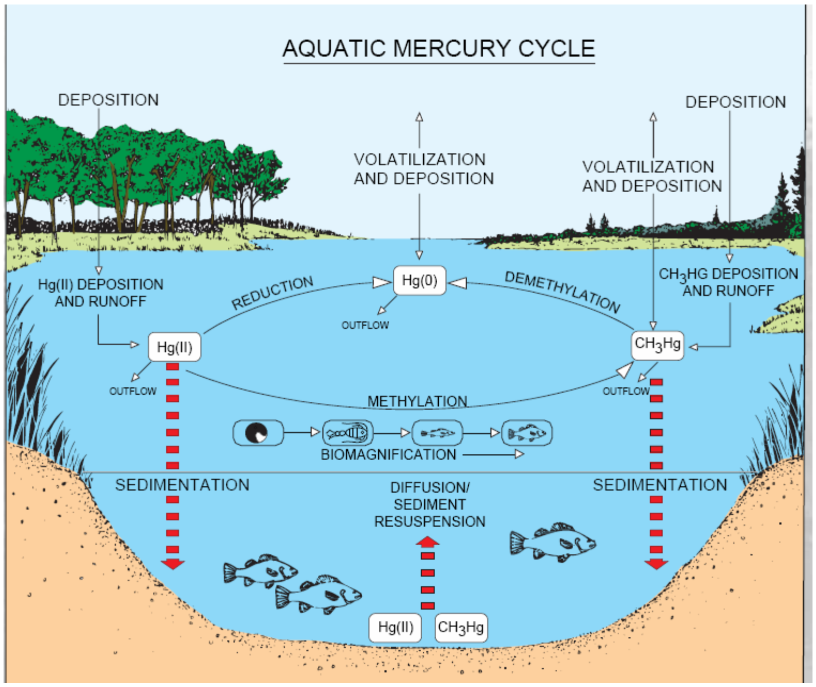

Figure 2. Mercury contamination of aquatic ecosystems (USGS, 1995a).

STUDY AREA

The study area for this project includes the Mobile-Tensaw River Delta, Mobile Bay, and adjacent areas in Baldwin, Clarke, Mobile, Monroe, and Washington Counties, Alabama (fig. 1). The Mobile-Tensaw River Delta is part of the Mobile Bay Estuary System, a coastal transition zone between the Mobile Bay watershed and the Gulf of Mexico. Terminal portions of the Mobile and Tensaw Rivers are in the Mobile Delta, and the rivers branch into a series of distributary channels, emergent delta lobes, levees, and interdistributary bays (Hummell and Parker, 1995). Mobile Bay is a submerged alluvial valley located at the terminus of the Mobile-Tensaw River Delta system. The Mobile Bay watershed is the nation's sixth largest river system in total drainage area and first in ratio of discharge to area (Isphording and others, 1985). The area is a dynamic, complex system temporally affected by tidal influx, salinity variations, and freshwater inflow and discharge. The study area is home to diverse aquatic ecosystems such as freshwater tributaries to Mobile Bay, which contains 131 species of fishes, 30 of which are marine (Mettee and others, 1996).

The study area includes state parks, national wildlife refuges, wetlands, a national estuarine research reserve, and abundant fishery and wildlife resources. Boating, fishing, hunting, hiking, camping, and other forms of outdoor recreation are popular in the area. A study performed for the Mobile Bay National Estuary Program (MBNEP) concluded that the MBNEP area is associated with about $3 billion of economic expenditures each year for seafood, saltwater sport fishing, and other industries (Chang and Canode, 1999). Natural resources found in and produced from the area include timber, oysters, shrimp, sand, gravel, shell deposits, and oil and natural gas. Natural gas processing is a major industry in southern Mobile County. The manufacture of chemicals is also a significant industry, particularly along the western side of the Mobile-Tensaw River Delta and Mobile Bay.

The environmental health of ecosystems within the study area is impacted by urban and industrial activities (fig. 3). There are a number of threatened or endangered species in the study area, including the gulf sturgeon, wood stork, bald eagle, Alabama red-bellied turtle, and inflated heelsplitter and heavy pigtoe mussels. There are six sites within the study area that are on the EPA's National Priorities List (NPL) (sites with known releases or threatened releases of hazardous substances, pollutants, or contaminants), also referred to as superfund sites (fig. 3). Those NPL sites include a ground-water contamination site at Perdido; Redwing Carriers, Incorporated, at Saraland; Stauffer Company at LeMoyne; Stauffer Company at Cold Creek; Olin Corporation at McIntosh; and Ciba-Geigy Corporation at McIntosh (EPA, 2006a). Twenty-four stream and river segments in the five-county region are listed by the Alabama Department of Public Health (ADPH) as having fish consumption advisories due to elevated mercury levels in fish (table 1) (ADPH, 2006). In addition to these streams with fish advisories, 51 other stream and river segments are listed on the Alabama Department of Environmental Management (ADEM) 2004 303(d) list (water bodies that currently do not meet water-quality standards) (ADEM, 2006) . Of those 51, 24 are listed as having mercury contamination as the primary or secondary cause for that water body segment to be placed on the 303 (d) list (table 2) (ADEM, 2006). There were eight facilities reporting releases of mercury or mercury compounds to the EPA's Toxic Release Inventory (TRI) Program (table 3) in 2004 (EPA, 2006b).

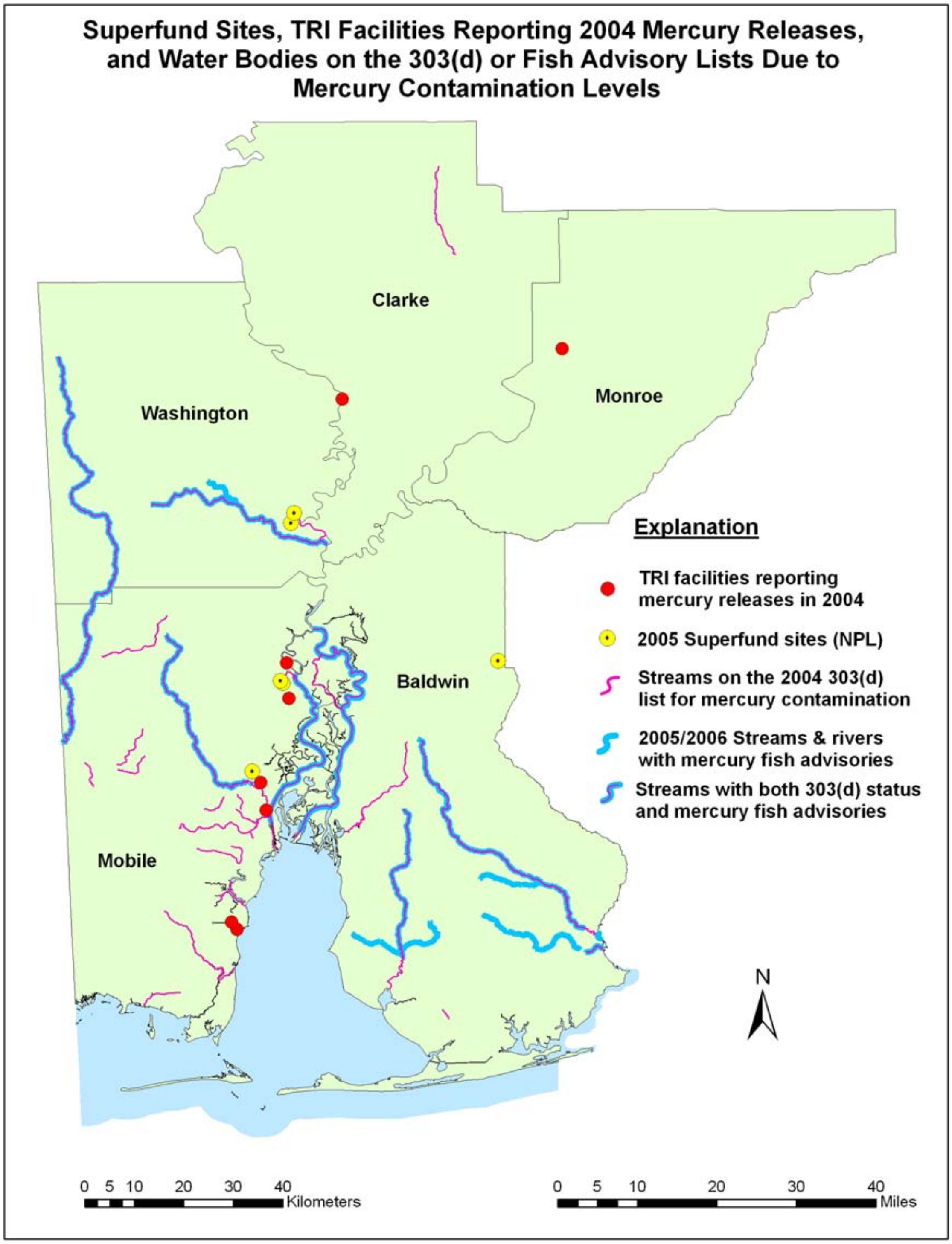

Figure 3. Sites on the 2005 superfund list (EPA, 2006a), EPA Toxic Release Inventory (TRI) facilities with reported mercury releases in 2004 (EPA, 2006b), streams on the 2004 ADEM 303(d) list due to elevated mercury levels (ADEM, 2006), and streams on the 2005-2006 fish advisory list due to elevated mercury levels in fish (ADPH, 2006).

Table 1. Streams and rivers on the 2005 - 2006 fish consumption advisory list due to elevated mercury levels (ADPH, 2006)

Water Body	County	Species	Portion	Type Advisory	Year Posted
Bilbo Creek	Washington	Largemouth bass	Upstream of the confluence with the Tombigbee River	1 meal/month	2006
Blackwater Creek	Baldwin	Largemouth bass	Area between mouth of river and the pipeline crossing SE of Robertsdale	No consumption	2005
Bon Secour	Baldwin	Largemouth bass	Vicinity of County Road 10 Bridge	No consumption	2005
Chickasaw Creek	Mobile	Largemouth bass	Entire creek	No consumption	2005
Claiborne Reservoir	Monroe/Clarke	Largemouth bass	Dam forebay area and in vicinity of Lower Peachtree Access Area approximate River Mile 96, close to the intersection of Clarke, Monroe, and Wilcox Counties	2 meals/month	2006
Cold Creek Swamp	Mobile	All species	From confluence of Cold Creek with the Mobile River west through the Swamp	No consumption	2005
Cowpen Creek	Baldwin	Largemouth bass	Upstream of the confluence with Fish River	1 meal/month	2006
Escatawpa River	Mobile	Largemouth bass and spotted bass	Entire River	No consumption	2005
Escatawpa River	Mobile	Largemouth bass	At U.S. Hwy 98 bridge crossing approximately 1/10 mile upstream of the Ala./Miss. state line	1 meal/2 months	2006
Escatawpa River	Mobile	Spotted bass	At U.S. Hwy 98 bridge crossing approximately 1/10 mile upstream of the Ala./Miss. state line	1 meal/month	2006
Fish River	Baldwin	Largemouth bass	Entire River	No consumption	2005
Fish River	Baldwin	Largemouth bass	In vicinity of confluence with Polecat Creek approximately 1 mile upstream of County Rd. 32 Bridge	1 meal/2months	2006
Fish River	Baldwin	Largemouth bass	Approximately 2 miles upstream of U.S. Hwy. 98 Bridge in vicinity of Waterhole Branch/Fish River confluence just above the two islands	2 meals/month	2006
Fowl River	Mobile	King mackerel over 39 inches	Entire coast	No consumption	2005
Gulf Coast	Baldwin/Mobile	King mackerel under 39 inches	Entire coast	Limited consumption	2005
Mobile River	Mobile	Largemouth bass	At and south of the confluence of Cold Creek	No consumption	2005
Perdido River	Baldwin	Largemouth bass	Near its confluence with the Styx River in the vicinity of U.S. Hwy 90 bridge crossing	No consumption	2005
Perdido River	Baldwin	Largemouth bass	Near confluence with Styx River in vicinity of U.S. Hwy. 90 bridge crossing	1 meal/month	2006
Perdido River	Baldwin	River redhorse	Near confluence with Styx River in vicinity of U.S. Hwy. 90 bridge crossing	2 meals/month	2006
Polecat Creek	Baldwin	Largemouth bass	Entire creek	No consumption	2005
Polecat Creek	Baldwin	Largemouth bass	Upstream of confluence with Fish River	1 meal/month	2006
Styx River	Baldwin	Largemouth bass	Entire River	No consumption	2005
Styx River	Baldwin	Channel catfish	Entire River	Limited consumption	2005
Tensaw River	Baldwin	Largemouth bass	Entire River	Limited consumption	2005

Table 2. Streams and water bodies on the ADEM 2004 303(d) streams list due to mercury contamination (ADEM, 2006)

Assessment Unit ID	Waterbody Name	River Basin	County	Uses	Sources	Downstream / Upstream Locations
AL03170008-0402-700	Collins Creek	Escatawpa	Mobile	Fish & wildlife	Unknown	Big Creek / Its source
AL03170008-0402-400	Boggy Branch	Escatawpa	Mobile	Fish & wildlife	Natural	Big Creek Lake / Its source
AL03160205-0310-101	Bon Secour River	Mobile	Baldwin	Swimming, fish & wildlife	Atmospheric deposition	Bon Secour Bay / 1 mile upstream from first bridge above its mouth
AL03160203-1103-102	Tombigbee River	Lower Tombigbee	Clarke/ Washington	Fish & wildlife	In-place contaminants	Upper end of Bilbo Island / Olin Basin
AL03160204-0505-100	Mobile River	Mobile	Mobile	Limited warmwater fishery	Unknown source	Mobile Bay / Spanish River
AL03160205-0310-102	Bon Secour River	Mobile	Baldwin	Swimming, fish & wildlife	Atmospheric deposition	1 mile upstream from first bridge above its mouth / Its source
AL03140106-0603-101	Blackwater River	Perdido-Escambia	Baldwin	Fish & wildlife	Unknown source	Perdido River / Narrow Gap Creek
AL03140106-0703-100	Perdido River	Perdido-Escambia	Baldwin	Fish & wildlife	Atmospheric deposition	Perdido Bay / Jacks Branch
AL03160204-0503-102	Bay Minette Creek	Mobile	Baldwin	Fish & wildlife	Unknown source	Bay Minette / Its source
AL03160204-0505-201	Tensaw River	Mobile	Baldwin	Fish & wildlife	Unknown source	Mobile Bay / Junction of Tensaw and Apalachee Rivers
AL03160204-0505-202	Tensaw River	Mobile	Baldwin	Outstanding Alabama water swimming, fish & wildlife	Unknown source	Junction of Tensaw and Apalachee Rivers / Junction of Briar Lake
AL03160204-0105-302	Tensaw River	Mobile	Baldwin	Outstanding Alabama water Fish & wildlife	Unknown source	Junction of Briar Lake / Junction of Tensaw Lake
AL03160205-0306-200	Polecat Creek	Mobile	Baldwin	Swimming, fish & wildlife	Atmospheric deposition	Fish River / Its source
AL03160204-0105-303	Tensaw River	Mobile	Baldwin/Mobile	Fish & wildlife	Unknown source	Junction of Tensaw Lake / Mobile River
AL03160204-0303-102	Mobile River	Mobile	Baldwin/Mobile	Fish & wildlife	Unknown source	Spanish River / Cold Creek 2013
AL03140106-0502-100	Styx River	Perdido-Escambia	Escambia/ Baldwin	Fish & wildlife	Unknown source	Hollinger Creek / Its source
AL03160204-0106-101	Cold Creek	Mobile	Mobile	Fish & wildlife	Contaminated sediments Flow regulation/ modification	Mobile River / Dam 1 1/2 miles west of U.S. Hwy. 43
AL03160204-0404-101	Chickasaw Creek	Mobile	Mobile	Limited warmwater fishery	Unknown source	Mobile River / US Hwy. 43
AL03160204-0404-102	Chickasaw Creek	Mobile	Mobile	Fish & Wildlife	Unknown source	U.S. Hwy. 43 / Mobile College
AL03160204-0402-100	Chickasaw Creek	Mobile	Mobile	Swimming, fish & wildlife	Unknown source	Mobile College / Its source
AL03160205-0206-100	Fowl River	Mobile	Mobile	Swimming, fish & wildlife	Unknown source	Mobile Bay / Its source
AL-Gulf of Mexico	Gulf of Mexico	Mobile	Mobile	Shellfish harvesting, Swimming, fish & wildlife	Unknown source	Mississippi / Florida
AL03160204-0201-200	Middle River	Mobile	Mobile/Baldwin	Fish & wildlife	Unknown source	Tensaw River(RM 20.6) / Tensaw River (River Mile 37.7)
AL03160205-0307-102	Fish River	Mobile	Baldwin	Swimming, fish & wildlife	Unknown source, Pasture grazing	Weeks Bay / Its source
AL03170008-0302-100	Escatawpa River	Escatawpa	Mobile	Swimming, fish & wildlife	Unknown source	AL-MS state line / Its source
AL03160203-1103-800	Olin Basin	Lower Tombigbee	Washington	Fish & wildlife	Contaminated sediments	All of Olin Basin

Table 3. Facilities reporting releases of mercury in pounds to the EPA's Toxic Release Inventory (TRI) Program in 2004 (EPA, 2006b)

		On-site disposal to Class I Underground injection Wells, RCRA Subtitle C Landfills, and other landfills	Other on-site disposal or other releases			Off-site disposal to Class I Underground Injection Wells, RCRA Subtitle C landfills, and other landfills	Other off-site disposal or other releases				
Facility Name	**County**	**Other on-site landfills**	**Point source air emissions**	**Surface water discharges**	**Other surface impoundments**	**Other landfills**	**Solidification/ Stabilization (metals only)**	**RCRA Subtitle C Surface Impoundments**	**Other land disposal**	**Unknown**	**Total on- and off-site disposal or other releases**
Barry Steam Plant, U.S. Hwy. 43, Bucks	Mobile	0	666	.	57	0	0	0	0	0	723
Bredero Shaw LLC, 8106 Dauphin Island Pkwy., Theodore	Mobile	0	0	.	0	0	0	0	0	1,780	1,780
Holcim (U.S.) Inc Theodore AL Plant, 3051 Hamilton Blvd, Theodore	Mobile	0	27	0	0	0	0	0	0	0	27
IPSCO Steel (Alabama) Inc., 12400 Hwy. 43 N, Axis	Mobile	0	105	.	0	1	236	0	0	0	342
Mobile Energy Services LLC, 50 Bay Bridge Rd., Mobile	Mobile	0	21	.	0	0	0	187	0	0	208
Shell Chemical LP Mobile Site, 400 Industrial Pkwy., Ext., Saraland	Mobile	0	0	0	0	0	0	0	1	0	1
Alabama River Pulp Co Inc., 2373 Lena Landegger Hwy., Perdue Hill	Monroe	4	1	1	0	0	0	0	0	0	6
Charles R. Lowman Power Plant, Carson Rd., Leroy	Wash-ington	6	192	3	11	0	0	0	0	0	212

METHODOLOGY AND RESULTS

DATA USED IN THIS STUDY

Datasets used in this study included digital and hardcopy data from 30 studies. Some studies provided mercury data for more than one type of material (water, fish, sediment, or soil) and are listed in Table 4, grouped by material. Data used in this project were collected from the following studies described below. Some studies are grouped under larger programs to which they belong, and all are listed in alphabetic order by agency. Agency abbreviations are as follows:

ADEM — Alabama Department of Environmental Management

EPA — U.S. Environmental Protection Agency

GSA — Geological Survey of Alabama

ISWS — Illinois State Water Survey

NOAA — National Oceanographic and Atmospheric Administration

USGS — U.S. Geological Survey

ADEM, Coastal Program Sediment Chemistry Baseline Study — The objective of this study was to verify the concept of using aluminum as a “normalizing factor” for interpreting metals data in coastal sediments. Aluminum was used as a geochemical normalizer, allowing for identification of sediments with higher than base level concentrations of metals (Halcomb, 1991).

ADEM, Fish Tissue Monitoring Program — This program was started in 1991 as a cooperative project with the Alabama Department of Public Health, the Alabama Department of Conservation and Natural Resources, and the Tennessee Valley Authority. The main objective of the program was to monitor fish tissue throughout the state for contaminants that pose a risk to human health (ADEM, 2004).

ADEM, A Study of the Bay Minette Creek Subwatershed — A study was performed to assess water quality of streams within the Bay Minette Creek subwatershed. The study also identified streams impaired by pollution and provided information and suggestions for pollution control strategies and management practices (Woods, 2004).

ADEM, A Survey of the Bayou Sara Watershed — This survey was performed to assess water quality of streams within the Bayou Sara watershed. The survey also identified streams impaired by pollution and provided information and suggestions for pollution control strategies and management practices (Woods, 2003).

ADEM, A Survey of the Bon Secour River Watershed — This survey was conducted to examine impacts of construction, development, and point-source pollution on habitat and biological resources (ADEM, 1996a).

ADEM, A Survey of the Chickasaw Creek Watershed — The Chickasaw Creek watershed study is an overview of land-use practices and an examination of effects of development on aquatic resources of the basin (ADEM, 1997).

ADEM, An Impervious Surface Study Over Three Regimes: Three Mile Creek, Fly Creek, and Bay Minette — A study was conducted to assess water quality within the subwatersheds of Three Mile Creek, Bay Minette Creek, and Fly Creek. It compared the water quality to data across impervious surface regimes representing high, moderate, and low levels of development (Woods, 2004).

ADEM, National Coastal Assessment (NCA) — The NCA is a strategic partnership between EPA and the coastal states and other federal agencies. Each state uses a compatible probabilistic design and a common set of environmental indicators to survey its coastal resources and assess their condition. These estimates can then be aggregated to assess conditions at the EPA regional, biogeographical, and national levels (EPA, 2007).

ADEM, A Survey of the Dog River Watershed Second Year's Findings — The focus of this survey was directed at the western and southern parts of the watershed experiencing the most active growth and development. Sediment samples from Dog River were collected and analyzed to determine concentrations of metals (ADEM, 1996b).

ADEM, A Survey of the Little Lagoon Watershed — The Little Lagoon Study was a characterization of the watershed and included a water- and sediment-quality survey. Periodic sampling of sites identified areas of impaired water quality and allowed water and sediment quality analysis of the lagoon as a whole (ADEM, 2000).

ADEM, A Survey of the Water Quality and Sediment Chemistry of Selected Sites in Mobile Delta System — This survey was conducted on the estuaries of coastal Alabama to determine the effects of anthropogenically induced environmental stress. Since point sources are typically studied, this study examined nonpoint sources and the impact that they have on water quality (ADEM, 1993).

ADEM, A Survey of Water Quality and Sediment Chemistry of Shipyards in Coastal Alabama — This report details the findings of a survey of water quality and sediment chemistry in shipyards of coastal Alabama. Surface water and sediment samples were collected from 5 streams and 10 shipyards in Mobile and Baldwin Counties (Halcomb, 1992).

EPA, Environmental Monitoring and Assessment Program — The EPA's Environmental Monitoring and Assessment Program (EMAP) is a national research program to develop the tools necessary to monitor and assess the status and trends of national ecological resources. EMAP was designed to periodically estimate the status and trends of the nation's ecological resources on a regional basis (EPA, 2005).

EPA, Gulf of Mexico Program — This program is a partnership between EPA and the gulf states to collect environmental data and find and apply solutions that work with economic development. Contaminants, including mercury, were determined for a number of natural materials (biota, water, sediment, soil, and others) (EPA, 2006e).

EPA, Mobile River Study (MRS) — This study assesses the contamination of the Mobile River by hazardous substances, pollutants, and contaminants associated with and potentially emanating from some or all of the National Priorities List (NPL) sites and entering the river (EPA, 1994).

EPA, National Sediment Inventory — This inventory includes datasets collected from the BASINS compilation including data taken from the EPA National Sediment Inventory (NSI) Version 1.2. NSI datasets contain information about accumulation and distribution of heavy metal and organic compound contaminants in aquatic systems (EPA, 1998).

EPA, National Survey of Mercury Concentrations in Fish — This survey includes data collected in a nationwide cooperative effort. Data compilation includes results from state monitoring efforts during 1990-1995 and includes mercury levels in fish tissue (EPA, 1999).

GSA, Mobile-Tensaw River Delta Water Quality Survey — This is an ongoing survey in which water and sediment samples have been collected from seven sites in the Mobile-Tensaw River Delta area to determine concentrations of selected inorganic and organic constituents. The survey is limited to the collection of samples during low and high river discharge levels.

GSA, Sand Resources Mercury Data — This project included collected data from Mobile and Baldwin Counties and the Gulf of Mexico. The Sand Resources project is a cooperative study between the U.S. Department of the Interior Minerals Management Service and the Geological Survey of Alabama. Its purpose is the study of coastal erosion, the evaluation of nonfuel mineral resources, and the identification of sand resources on the Gulf of Mexico's inner continental shelf suitable for beach nourishment programs. Determinations for mercury in sample aliquots were performed as part of additional geochemical evaluation of the sediments subsequent to completion of the sand resources study (Kopaska-Merkel and Rindsberg, 2005; Rindsberg and Kopaska-Merkel, 2006).

ISWS, Mercury Deposition Network — The Mercury Deposition Network (MDN) is an extended network of the National Atmospheric Deposition Program at the Illinois State Water Survey (ISWS). The MDN collects data nationwide to develop a national database of weekly concentrations of total mercury in precipitation to examine spatio-temporal long-term trends (ISWS, 2006).

NOAA’s National Status and Trends Program (NS&T) — This program is divided into three programs: the Mussel Watch (MW), Benthic Surveillance, and Bioeffects Assessment Projects. In addition to specimen banking and historical trends within the studies of coastal monitoring, the on-going Mussel Watch project is a distribution and temporal trend assessment of toxic pollutants and heavy metals within coastal waters and related estuaries. The MW project analyzes chemical and biological contaminant trends in sediment and bivalve tissue collected at over 280 coastal sites from 1986 to present (Center for Coastal Monitoring and Assessment, 2005).

USGS, National Geochemical Survey (NGS) — The dataset from this survey provides stream sediment and soil geochemical and physical analytical results and many other supporting attributes (USGS, 2005).

USGS, National Water Information System (NWIS) — The NWIS Web Interface serves as public portal to historical water-quality analyses in the USGS district databases through September 2005. At sites where this information is transmitted automatically, data are available from the real-time data system. Once readings for a complete day are received from a site, daily summary data are generated and made available online through the NWISWeb (USGS, 2005).

USGS, National Contaminant Biomonitoring Program (NCBP) — Contaminant concentrations in freshwater fish and birds were periodically measured. Fish were selected for monitoring aquatic ecosystems because of their tendency to accumulate pesticides and other contaminants. The USFWS maintained this National Contaminant Biomonitoring Program into the 1980's, with the objective of continuing the documentation of temporal and geographic trends in contaminant concentrations (USGS, 1995b).

Table 4. Studies grouped by material type

Material	Source	Name of the study from which data were collected	Data years
Sediment	ADEM	A Study of the Bay Minette Creek Subwatershed 03-04	2003-2004
	ADEM	A Survey of the Bayou Sara Watershed	2001-2002
	ADEM	A Survey of the Bon Secour River Watershed	1996
	ADEM	Coastal Program Sediment Chemistry Baseline Study	1991
	ADEM	A Survey of the Chickasaw Creek Watershed	1997
	ADEM	A Survey of the Dog River Watershed Second Wear's Findings	1991-1995
	ADEM	An Impervious Surface Study over Three Regimes: Three Mile Creek, Fly Creek, and Bay Minette Creek Subwatersheds	2003
	ADEM	A Survey of the Little Lagoon Watershed	1990
	ADEM	A Survey of the Water Quality and Sediment Chemistry of Selected Sites in Mobile Delta System	1992
	ADEM	National Coastal Assessment (NCA) 2000-2004	2000-2004
	ADEM	A Survey of the Water Quality and Sediment Chemistry of Shipyards in Coastal Alabama	1992
	EPA	Environmental Monitoring and Assessment Program (EMAP)	1991-1994
	EPA	Mobile River Study (MRS)	1993-1994
	EPA	National Sediment Inventory (NSI)	1980-1993
	GSA	Sand Resources Mercury Data for Baldwin County	1992
	GSA	Sand Resources Mercury Data for Gulf of Mexico	1994-1995
	GSA	Sand Resources Mercury Data for Mobile County	1990-1995
	NOAA	National Status and Trends Benthic Surveillance (NSTBS)	1984-1986
	NOAA	National Status and Trends Mussel Watch (NSTMW)	1996-1997
	USGS	National Geochemical Survey (NGS)	1997-1998
	USGS	National Water Information Systems (NWIS)	1970-2005
Soil	USGS	National Geochemical Survey (NGS)	1997-1998
Fish	ADEM	ADEM Fish Tissue Monitoring Program	1990-2003
	ADEM	National Coastal Assessment (NCA) 2000-2004	2000-2004
	EPA	Environmental Monitoring and Assessment Program (EMAP)	1991-1994
	EPA	Gulf of Mexico Programs	2003
	EPA	Mobile River Study (MRS)	1994
	EPA	National Survey of Mercury Concentrations in Fish	1990-1995
	USGS	National Contaminant Biomonitoring Program (NCBP)	1969-1986
Surface water	ADEM	Survey of the Water Quality and Sediment Chemistry of Shipyards in Coastal Alabama	1991
	EPA	STOrage and RETrieval Legacy Data Center Data (STORET)	1973-1991
	GSA	Mobile-Tensaw River Water Quality Survey	2006
Atmospheric deposition	ISWS	National Atmospheric Deposition Program (NADP), Mercury Depositional Network (MDN)	2001-2004

STATISTICAL AND SPATIAL ANALYSES

Data were analyzed both statistically (general descriptive statistics) and spatially to determine if they could be used in this project. Data that had mercury measurements recorded as negatives or 9999 were judged in error and deleted from the final datasets prior to statistical and spatial assessments. Remaining data points were imported into an ArcGIS project and plotted using their given geographic coordinates. The points were visually assessed for spatial distribution.

SURFACE-WATER DATA ANALYSES

Total water samples used in this study included 1,414 samples (fig. 4) from five studies performed by ADEM, EPA, GSA, and USGS. Many of these samples represented multiple samples over time at single sites. During the analysis of these data, mercury samples recorded as 9999.99 μg/g were discovered in the EPA STORET database for 1990 and 1991. Because no information was available specifying the meaning of these entries, they were deleted from the water database. An additional 12 methylmercury samples were also included in this study, but they were partitioned from the total water data for separate analysis. Owing to the low sample size and the clustered spatial distribution (fig. 4), statistical and spatial analyses were not performed on the methylmercury data.

The 1,414 samples of water data were divided into freshwater (1,333 samples) and saltwater (81 samples) subsets. Saltwater samples were defined using a combination of methods: salinity as based on the USGS's parameters for saline water (USGS, 2006); geographic coordinates within known saltwater areas; nearest neighbor points with saltwater salinity or saltwater geographic location. Freshwater samples numbered 1,333, with mercury levels ranging from 0.00 (below detection limit (BDL)) to 2,690 ppb. The saltwater subset contained 81 samples ranging in mercury levels from BDL to 2,200 ppb. Data points for this subset were restricted to the Gulf, Mobile Bay, and some saltwater inlets of the Mobile Bay such as Weeks Bay and the lower delta region (fig. 4).

Both the saltwater and the freshwater data were plotted in GIS. Because EPA and ADEM water-quality criteria differ for both chronic (adverse effects after continuous or multiple exposures) and acute (adverse effects following one exposure) levels, maps were produced using both EPA (figs. 5 and 6) and ADEM (figs. 7 and 8) water-quality criteria for aquatic life. The EPA's national water-quality criteria for chronic and acute mercury levels (EPA, 2006c) and ADEM's water-quality criteria for chronic and acute mercury levels (ADEM, 2007) are listed in tables 5 and 6.

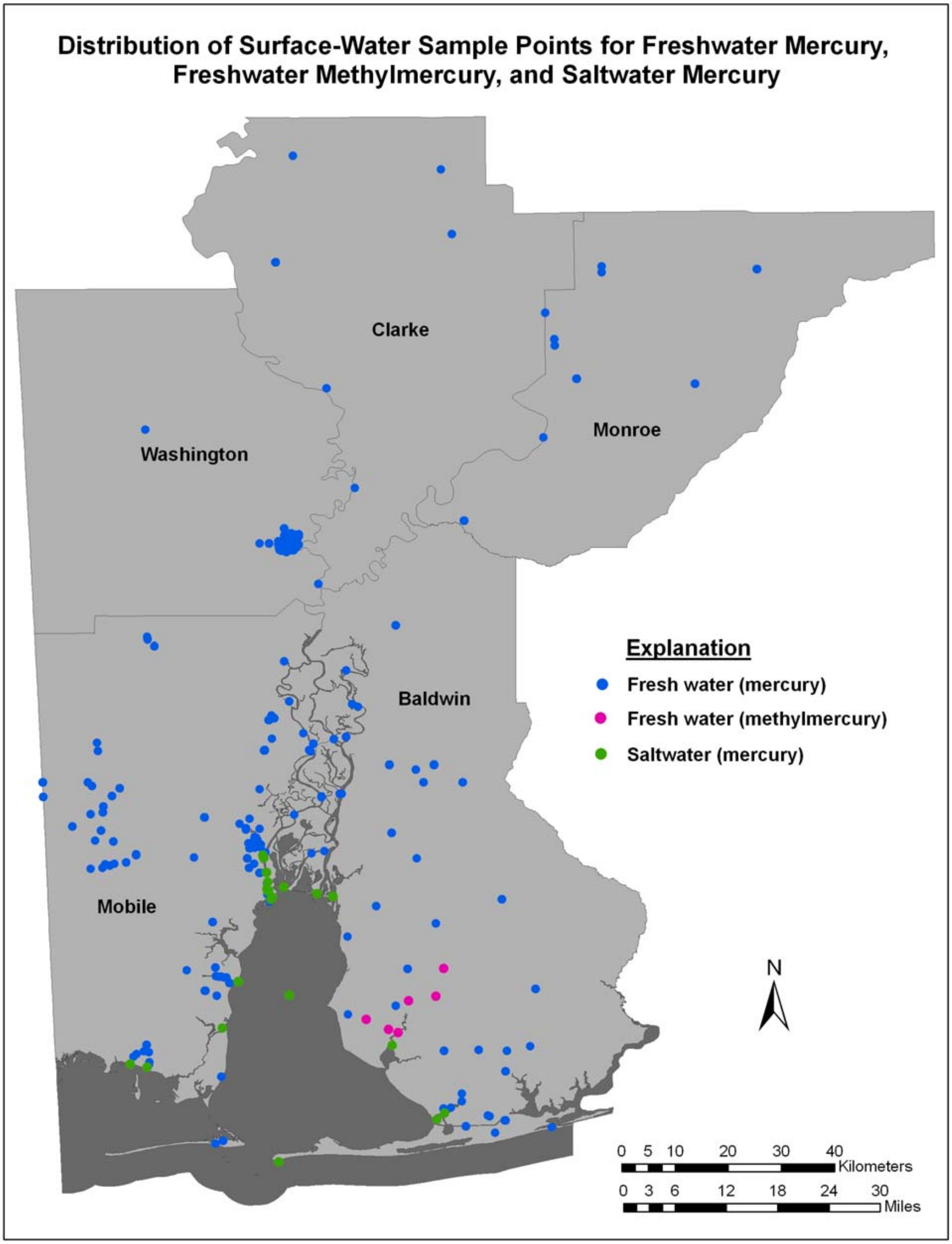

Figure 4. Point locations of all surface freshwater and saltwater data collected for this project.

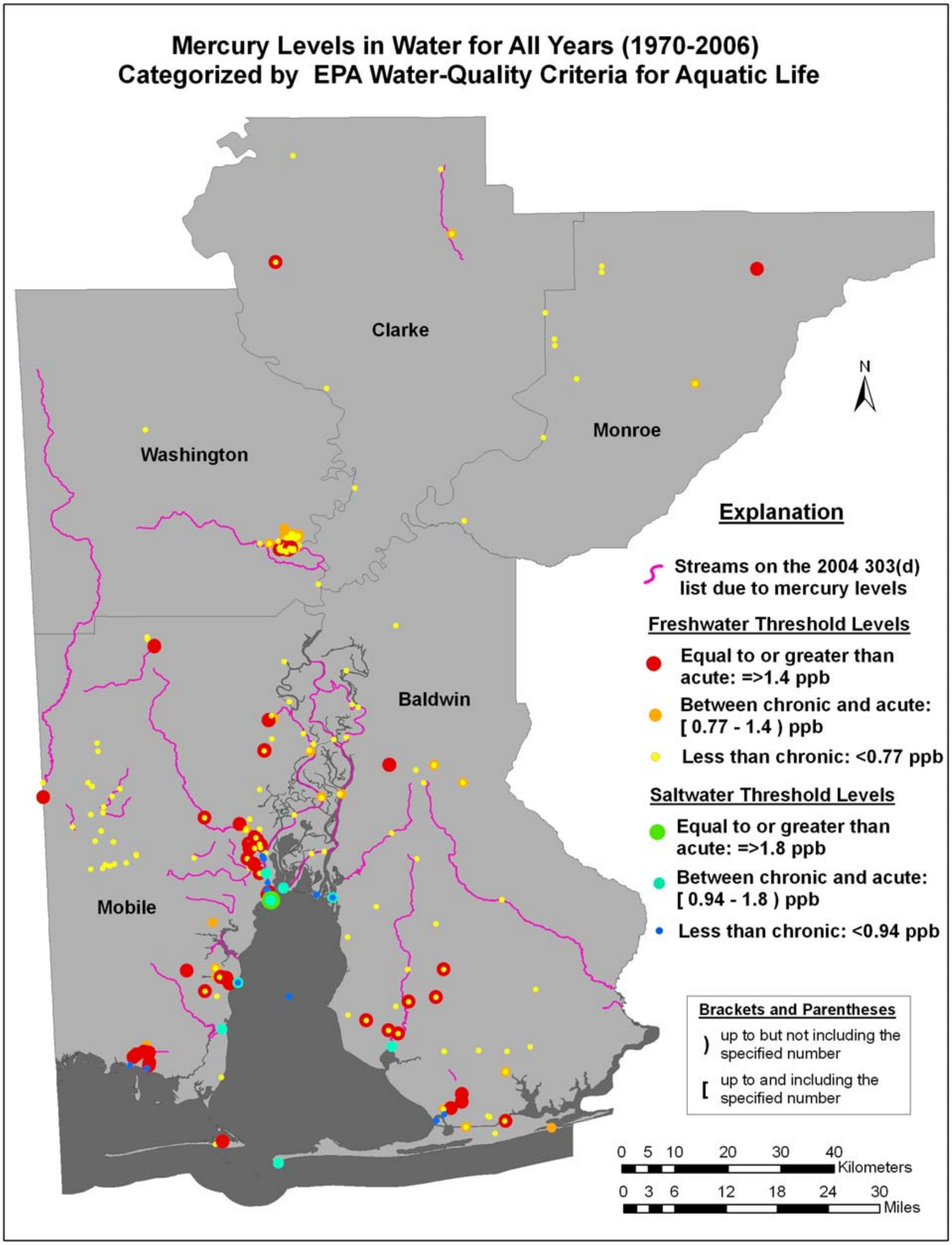

Figure 5. Categorization of freshwater and saltwater data by EPA water-quality criteria (EPA, 2006c) for years 1970 - 2006.

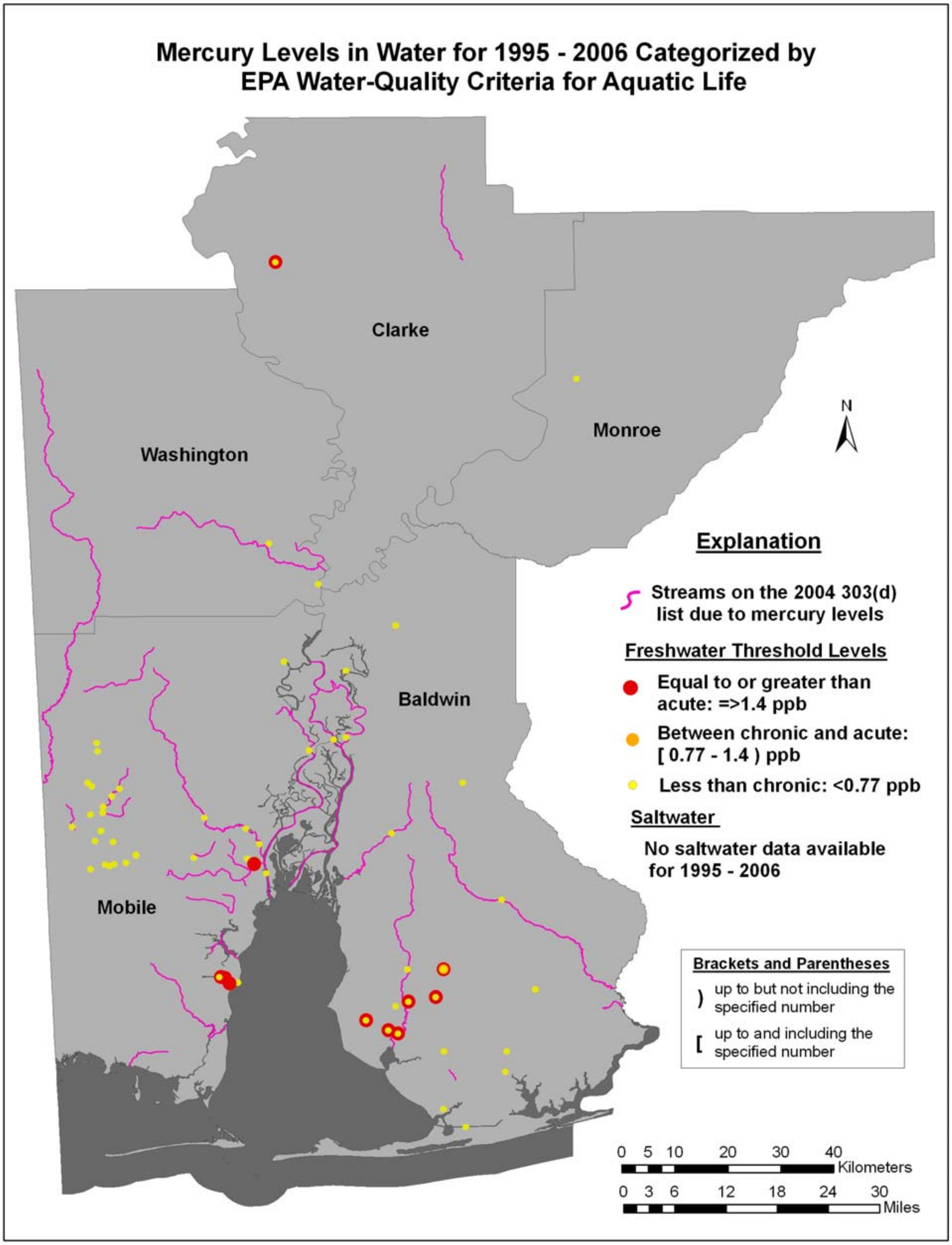

Figure 6. Categorization of freshwater data by EPA water-quality criteria (EPA, 2006c) for years 1995 - 2006.

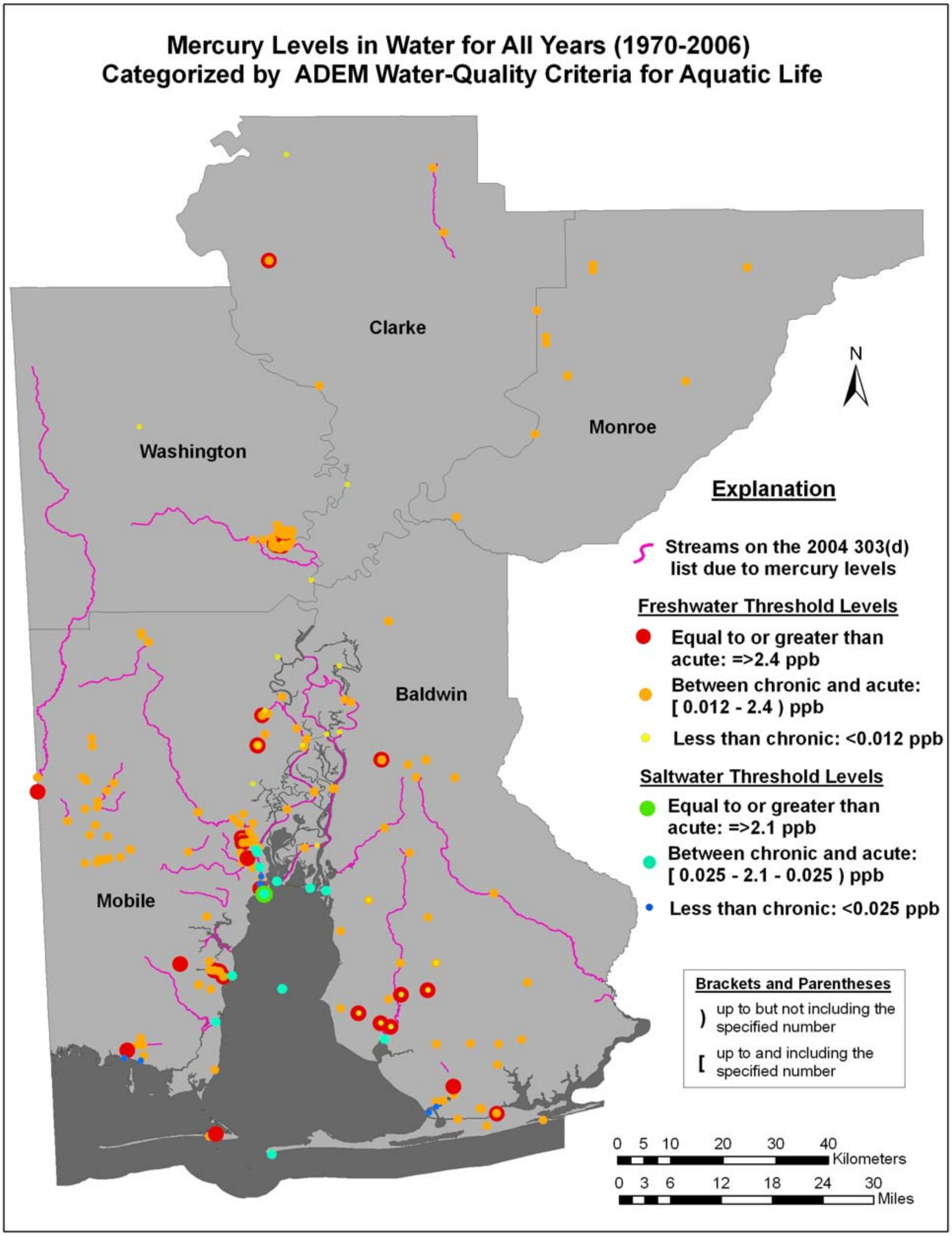

Figure 7. Categorization of freshwater and saltwater data by ADEM 2004 water-quality criteria as listed in regulation 305(b) (ADEM, 2004) for years 1970 - 2006.

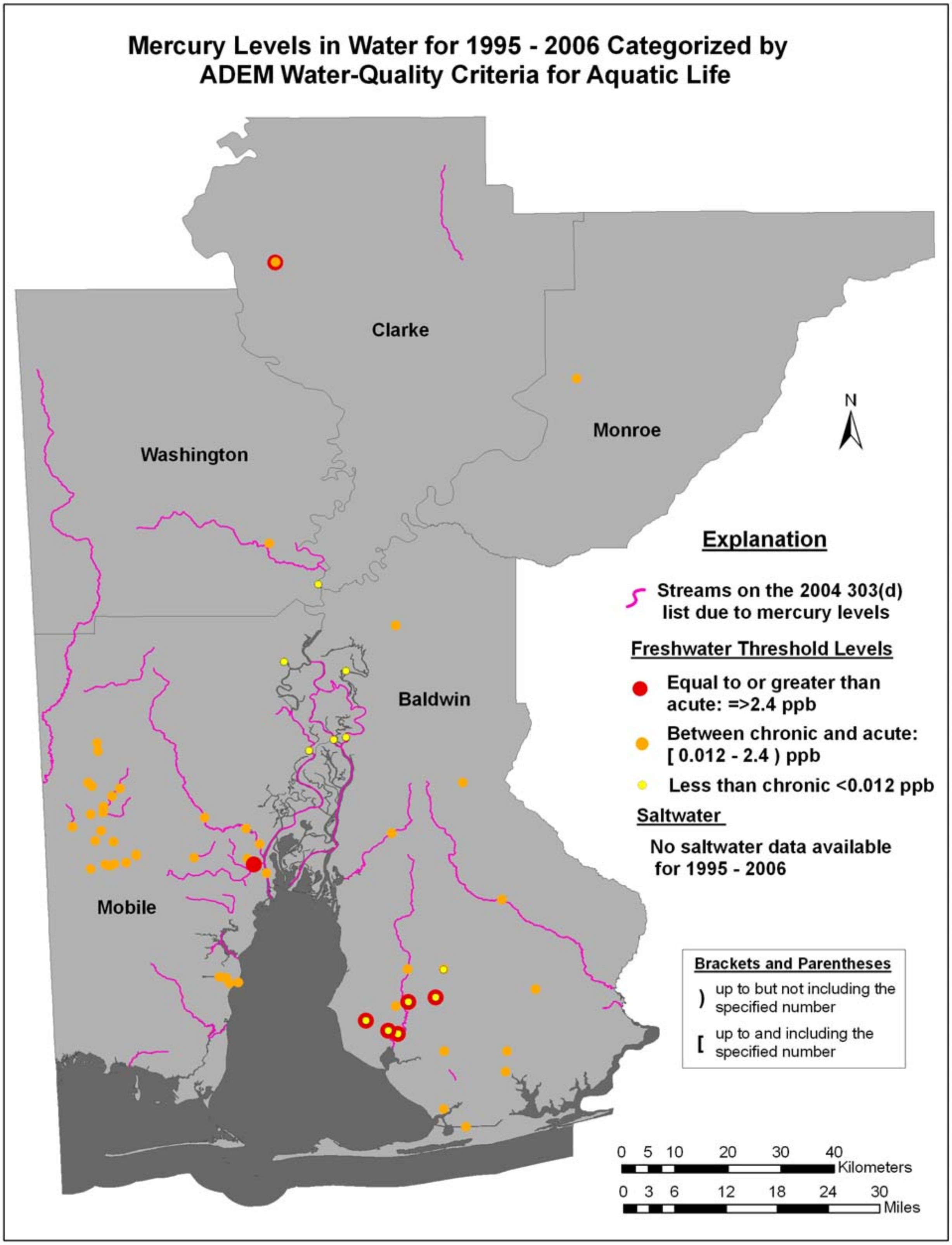

Figure 8. Categorization of freshwater data by ADEM 2004 water-quality criteria as listed in regulation 305(b) (ADEM, 2004) for years 1995 - 2006.

Table 5. Percentile data distribution among water-quality criteria threshold levels for mercury (percentages based on data for all years, 1970 - 2006)

Agency	Water type	Total number of samples	Water quality criteria in ppb		% Data above acute	% Data between acute and chronic	% Data below chronic
			Acute	Chronic			
EPA	Fresh water	1333	1.4	0.77	19.9	24.8	56.1
	Saltwater	81	1.8	0.94	2.5	83.9	13.6
ADEM	Fresh water	1333	2.4	0.012	15.9	77.3	6.8
	Saltwater	81	2.1	0.025	2.5	83.9	13.6

Table 6. Percentile data distribution among water-quality criteria threshold levels for mercury (percentages based on data for all years, 1995 - 2006)

Agency	Water type	Total number of samples	Water quality criteria in ppb		% Data above acute	% Data between acute and chronic	% Data below chronic
			Acute	Chronic			
EPA	Fresh water	132	1.4	0.77	10.3	1.9	87.8
	Saltwater	0	1.8	0.94	No saltwater data for 1995-2005		
ADEM	Fresh water	132	2.4	0.012	8.3	73.1	18.6
	Saltwater	0	2.1	0.025	No saltwater data for 1995-2005		

SEDIMENT-DATA ANALYSES

Analyses from 576 sediment samples were included in this project, representing 21 studies performed by ADEM, EPA, GSA, NOAA, and USGS. Mercury measurements in these samples ranged from BDL to 32,000 ppb, and the data were well distributed across the study region. The sediment data were plotted in GIS and categorized (fig. 9; table7) by freshwater sediment and saltwater sediment threshold levels listed in NOAA's Screening Quick Reference table for Inorganics in Solids (SQuiRTs) sediment tables (NOAA, 2007). The effects levels in the SQuiRTs table were based on toxicity levels for aquatic invertebrates as published by MacDonald and others (2003), Long and others (1995), and Long and Morgan (1991). Freshwater sediment value categories were based on Threshold Effects Level (TEL) and Probable Effects Level (PEL). The TEL represents a toxicity level below which adverse effects occur infrequently and PEL represents a chemical concentration above which adverse biological effects are expected to occur frequently (MacDonald and others, 2003). Saltwater sediment data were categorized by Effects Range Low (ERL) and Effects Range Median (ERM). Values below ERL represent a category in which adverse effects are estimated to rarely occur (Long and others, 1995). Values between ERL and ERM represent contaminant levels for which possible effects would occasionally occur and values above ERM represent a range in which effects would occur frequently (Long and others, 1995). Sediment data were plotted for all years, and no additional maps were created with respect to year collected due to poor record of sampling dates (60% of the freshwater sediment data and 42% of the saltwater sediment data had no sampling year recorded in the datasets obtained for this study).

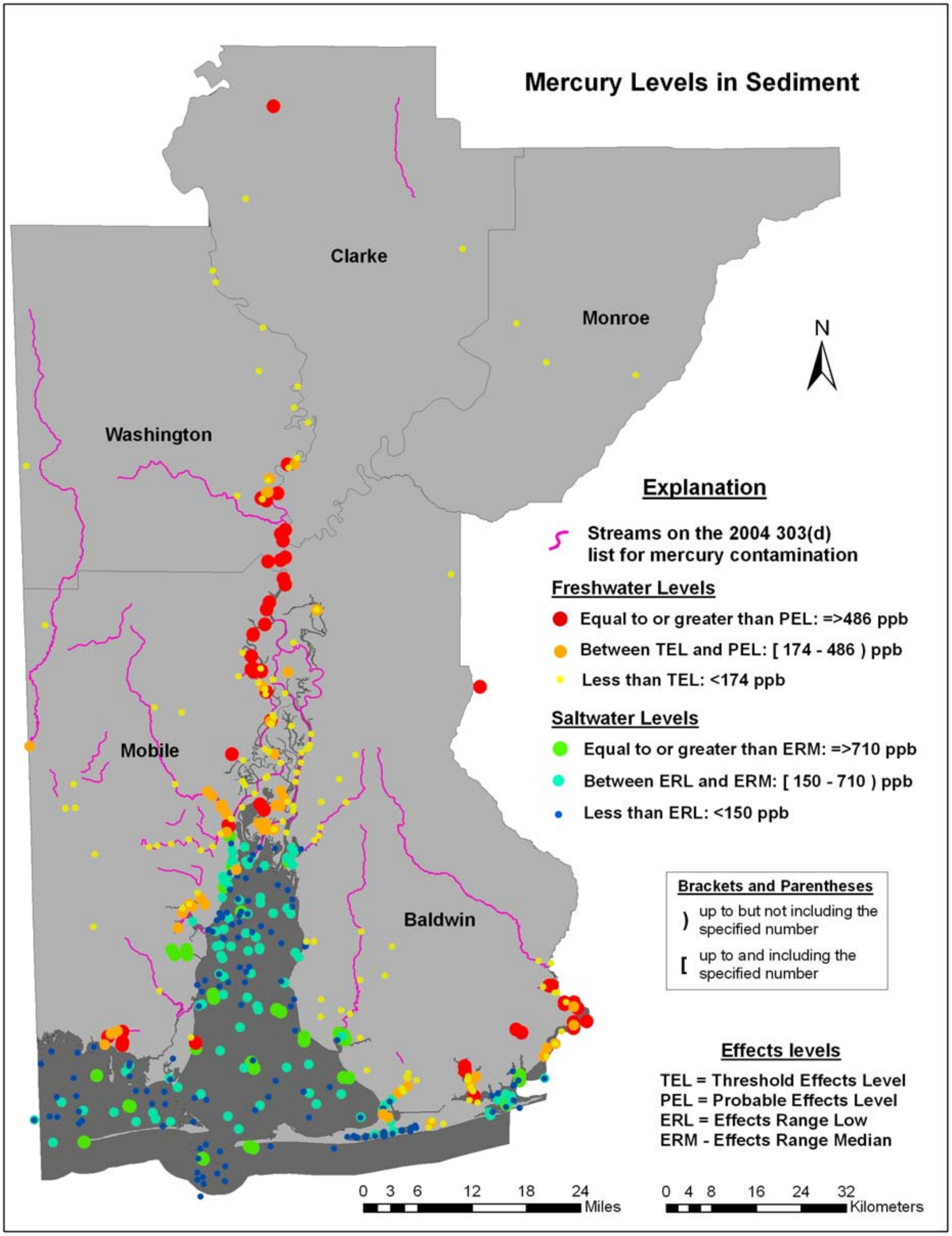

Figure 9. Sediment data categorized by biological effects levels for all years.

Table 7. Freshwater and saltwater sediment statistics for mercury by threshold level

Freshwater Levels Threshold effects level (TEL) = 174 ppb Probable effects level (PEL) = 486 ppb		
% Data above PEL	% Data between PEL and TEL	% Data below TEL
19.0	21.3	59.7
Saltwater Levels Effects Range Low (ERL) = 150 ppb Effects Range Median (ERM) = 710 ppb		
% Data above ERM	% Data between ERL and TEL	% Data below ERL
11.5	32.3	56.2

SOIL-DATA ANALYSES

Soil data included analyses from 74 soil samples (fig. 10). All soil data were from the National Geochemical Survey (USGS, 2006) and represent dried soil samples collected from soil horizon A. Soil data were plotted in GIS and categorized using Ecological Screening Values (ESV) of 100 ppb as reported in Supplemental Guidance to RAGS: Region 4 Bulletins, Ecological Risk Assessment (EPA, 2001). The 100 ppb ESV represents a mercury contamination level associated with only a low probability of effects to organisms having direct soil exposure such as earthworms (EPA, 2001). The level is based on conservative endpoints and sensitive effects data and represents only preliminary screening to aid in deciding if further testing should be performed (EPA, 2001). Of the 74 soil samples, only 4 had mercury levels above the ESV.

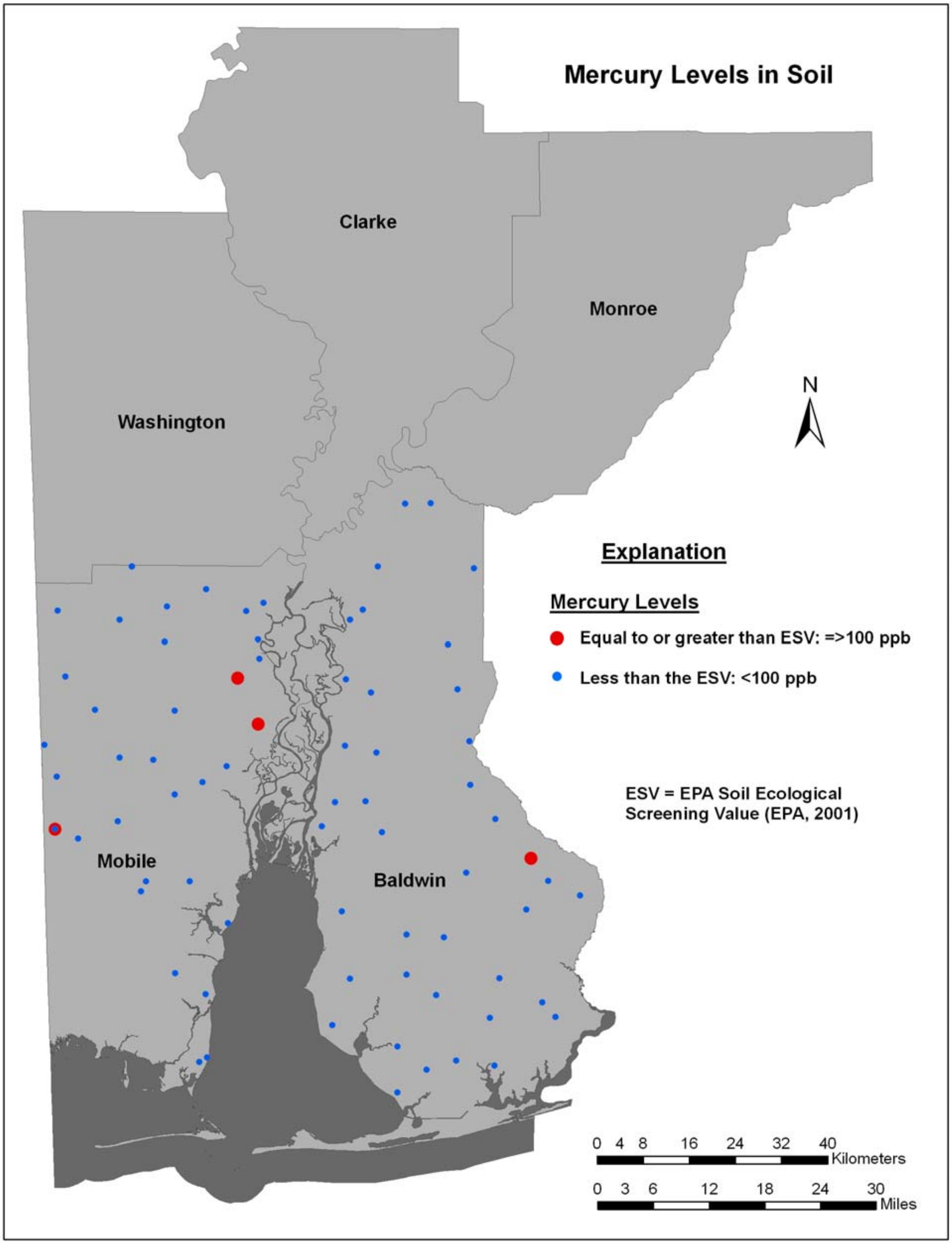

Figure 10. Soil data categorized by EPA ecological-screening values (EPA, 2001).

FISH-DATA ANALYSES

Data from 910 fish samples were included in the fish database for this project representing 9 studies performed by ADEM, EPA, NOAA, and USGS measuring mercury levels in fish. Mercury values in the dataset were not specified as total mercury or methylmercury; however, studies have shown that 99 percent of total mercury in fish is methylmercury in form (Grieb and others 1990). Data were recorded as negative numbers or blanks in their original studies were judged as errors and not included in the final fish database. Fish data were combined into a larger database, and taxonomic and trophic data for each species were determined for comparison of mercury levels across trophic and taxonomic groups. Three fish families comprise 79.8 percent of the total fish samples with sunfishes (Centrarchidae) equaling 42.6 percent of the total fish data. Of the sunfish, largemouth bass (*Micropterus salmoides*) totaled 302 samples (33.2 percent of the total fish data). Piscivorous fish constituted 53.1 percent of the total data, and omnivores comprised 33.0 percent of the total fish data. For all fish, the mean mercury level measured 435 ppb with a median of 186 ppb. For piscivores, the mean mercury level measured 696 ppb with a median of 450 ppb (this significantly higher mean and median may be attributed to the higher biomagnification factor of predators previously discussed). Omnivores averaged 164 ppb with a median of 90 ppb.

The fish data were divided into whole-body fish (for biological effects analysis) and fillet fish (for human health effects analysis). The whole-body fish dataset was plotted in ArcGIS and categorized based on the tissue-based threshold effects levels (t-TEL) in fish (fig. 11), with the biological effects level (200 ppb) representing sublethal endpoints (growth, reproduction, development, and behavior) as reported by Beckvar and others (2005). Of the whole-body fish data (disregarding year sampled), 18.2 percent of the data exceeded the t-TEL. The fillet fish data were also plotted in GIS and categorized by the human-health based consumption limits (fig. 12) from the EPA's *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories* (EPA, 2006d) (table 8), on which effects levels of methylmercury are noncarcinogenic health endpoints, with chronic systems effects.

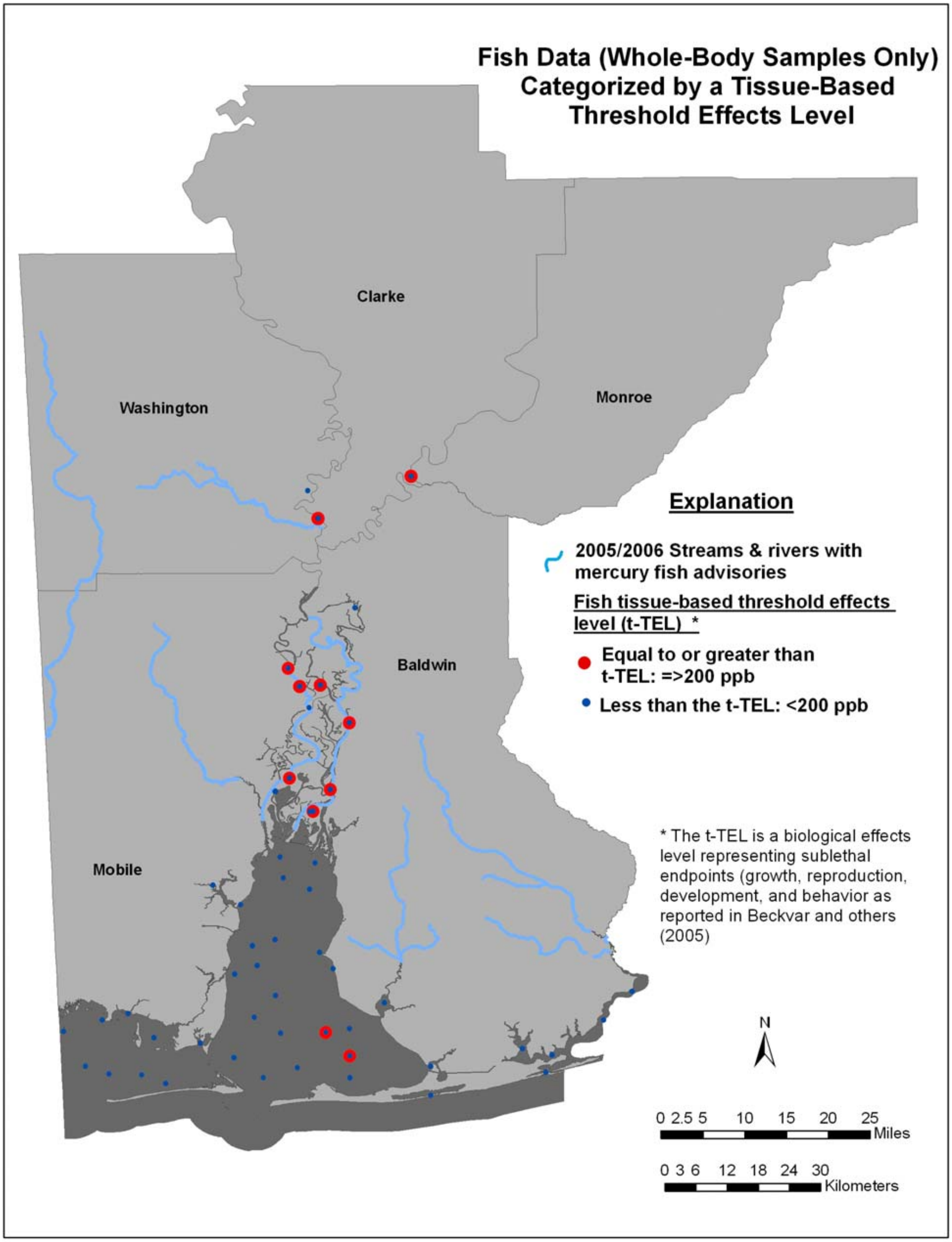

Figure 11. Fish data (whole body only) categorized by biological effects levels (from Beckvar and others, 2005).

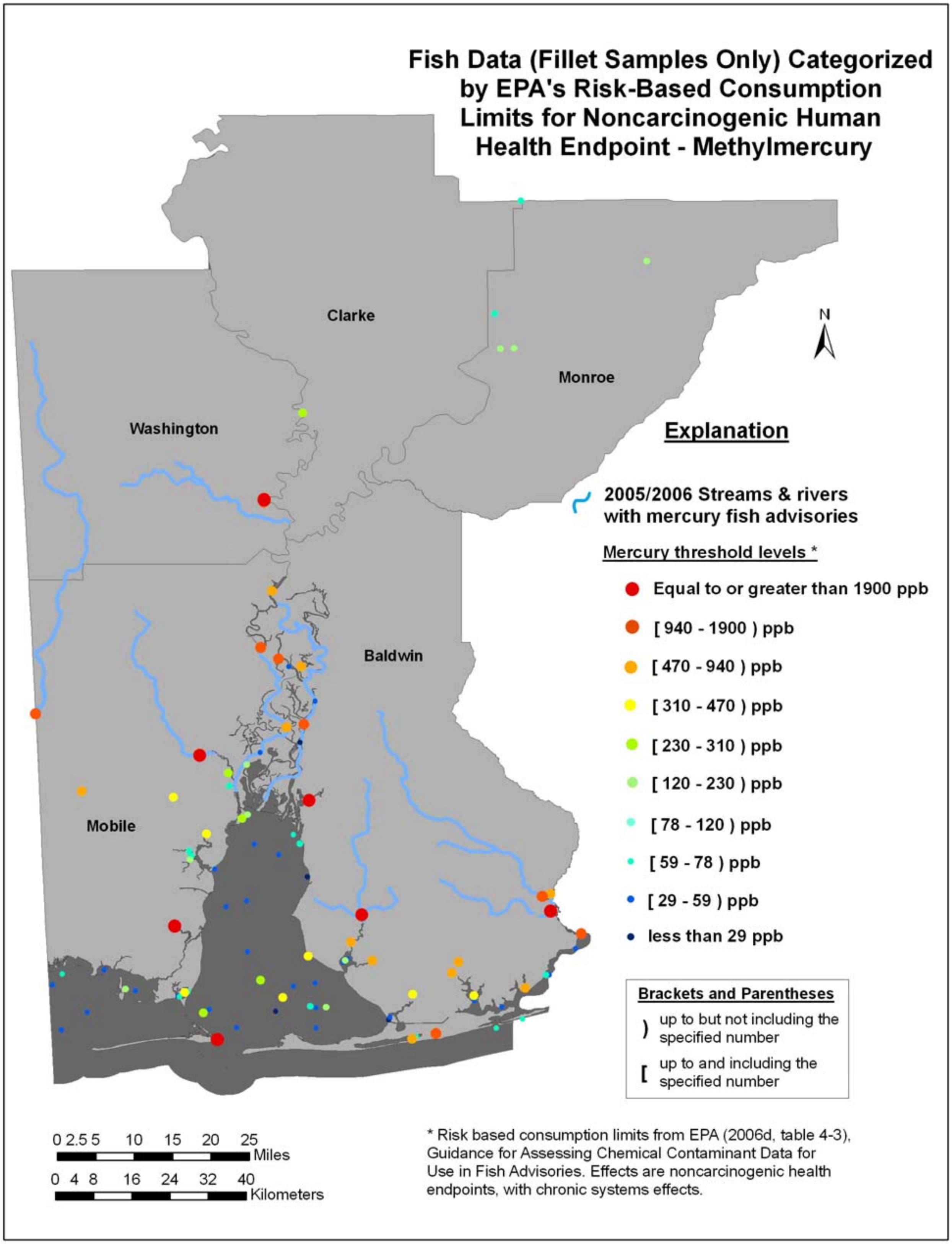

Figure 12. Fish data (fillet only) for all years, categorized by EPA's risk-based consumption limits for noncarcinogenic human-health endpoints (EPA, 2006d).

Table 8. Percentages of the total fish data used in this study, categorized by noncancer health endpoints (from EPA, 2006d, table 4-3)

Noncancer Health Endpoints	
Fish tissue concentrations of methylmercury (ppb)	**Percent of total data**
=< 29	5.6
29 –59	4.5
59 – 78	2
78 – 120	15.5
120 – 230	15.8
230 – 310	6.2
310 – 470	11.4
470 – 940	19.8
940 – 1900	14.4
>1900	4.8

ATMOSPHERIC DEPOSITION

Monitoring of mercury deposition in the study area has been through the National Atmospheric Deposition Program's (NADP) Mercury Deposition Network (MDN). The MDN seeks to develop a national database of weekly concentrations of total mercury in precipitation and the annual flux of total mercury in wet deposition (ISWS, 2006). The NADP is a cooperative monitoring program comprised of federal and state agencies, academic institutions, Native American tribal governments, and private organizations and is supported through the U.S. Department of Agriculture (ISWS, 2006).

Two monitoring sites are located in the study area, one in Mobile County and one in Baldwin County (fig. 13). The MDN has collected data at both sites since late spring of 2001. The nearest additional sites, located in Bibb County, AL; Perry County, MS; Citrus County, FL; and Charlton Co., FL (fig. 14), show mercury depositional data in ng/m^2 reflecting the variability associated with atmospheric monitoring. Figure 14 depicts total mercury wet deposition in 2005. The highest concentrations are along the Gulf Coast, reflecting the incidence of heavy rainfall and tall convective thunderstorms. Guentzel (2002) suggests that the deposition of mercury is mediated by long-range transport of mercury coupled with strong convective thunderstorm activity during the wet season.

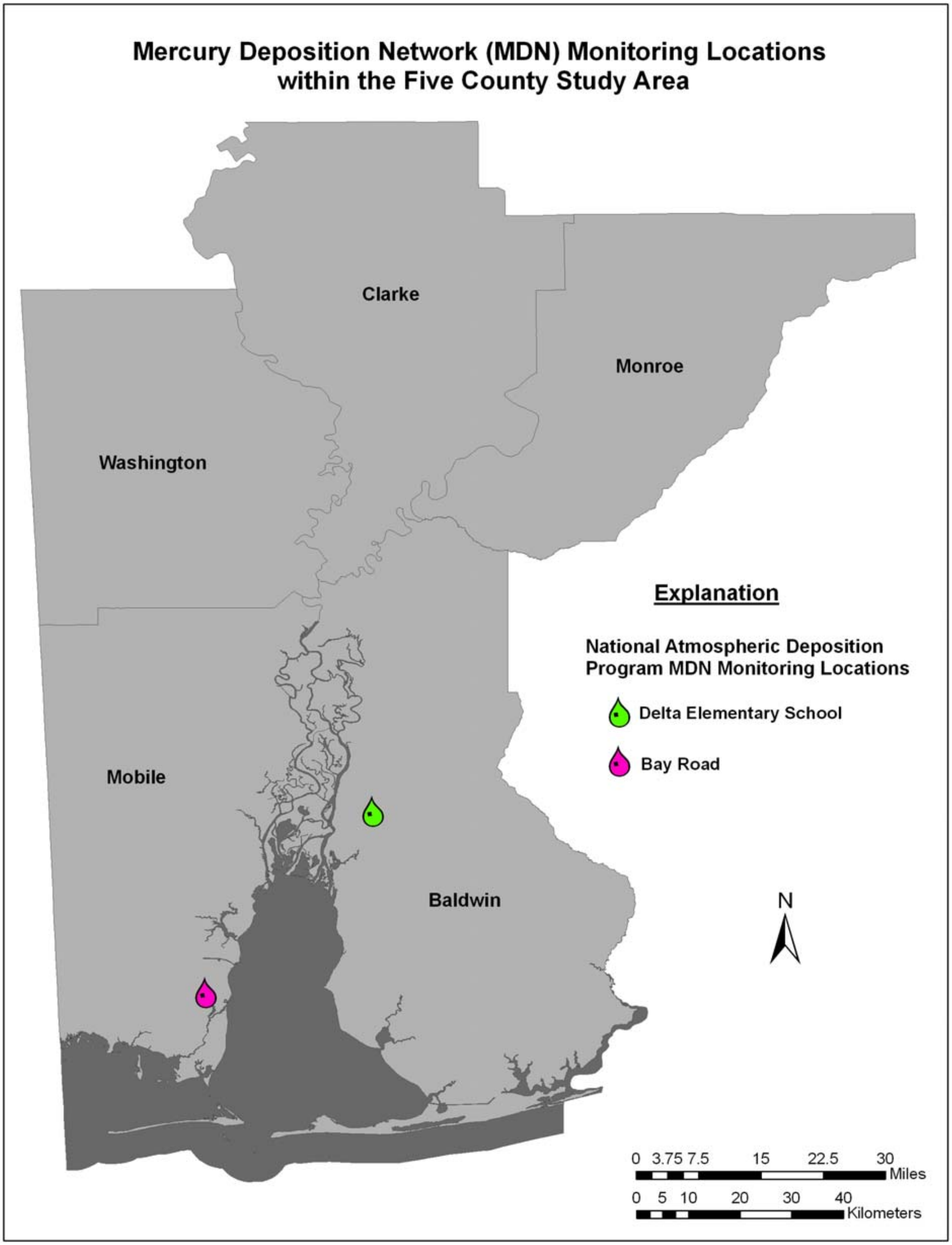

Figure 13. Location of the two MDN monitoring sites within the study area (ISWS, 2006).

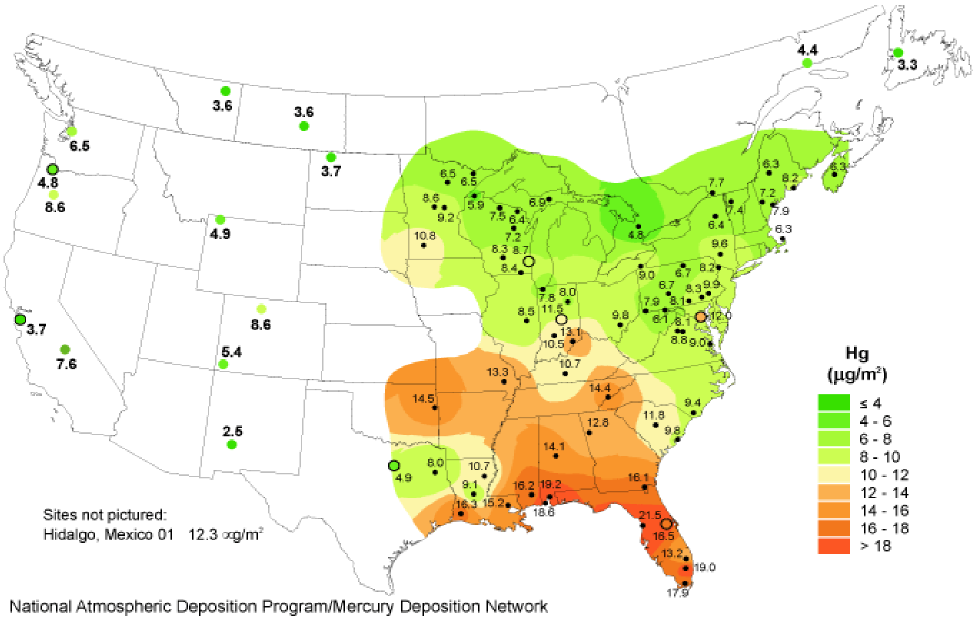

Figure 14. 2005 Mercury deposition from rainfall (ISWS, 2006).

Mercury depositional data from the two south Alabama monitoring sites for 2001 to 2004 (figs. 15 and 16) reflect the variability associated with atmospheric monitoring. The highest peak from the Delta Elementary School monitor occurred on July 1, 2003, and measured 3,667 nannograms per square meter (ng/m^2). This spike may be associated with the heavy rainfall from Tropical Storm Bill as the storm moved through the area, flooding parts of southern Alabama on June 30 with more than 7 inches of rainfall in some areas (NOAA, 2003). The highest peak from the Bay Road monitor occurred from June 24, 2003 data, and measured 2,316 ng/m^2, but has not yet been associated with a storm event occurring during that time.

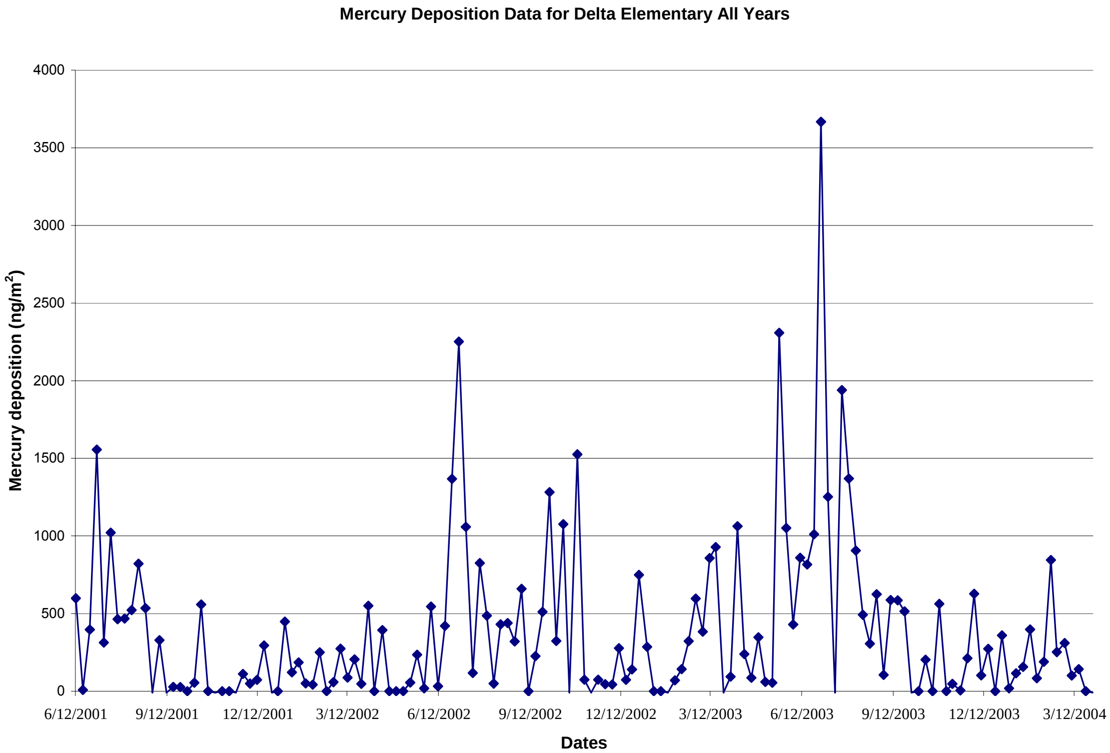

Figure 15. Mercury depositional data from precipitation for the Delta Elementary NADP MDN Monitoring Location from 2001 – 2004 (ISWS, 2006).

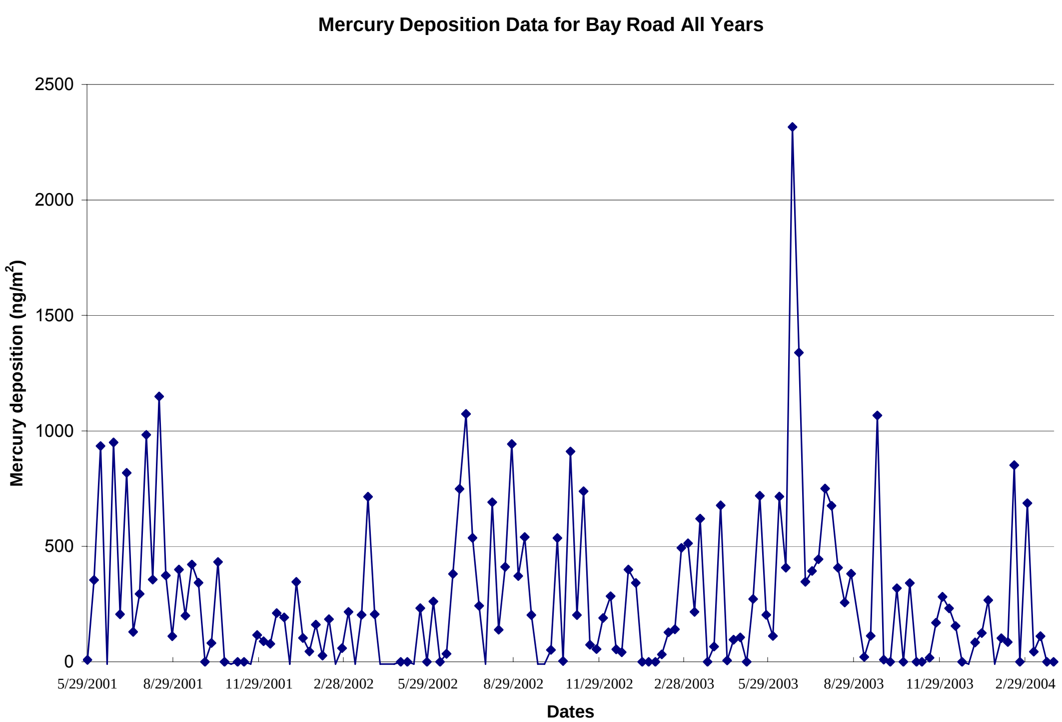

Figure 16. Mercury depositional data from precipitation for the Bay Road NADP MDN Monitoring Location from 2001 – 2004 (ISWS, 2006).

HIGH CONTAMINATION LEVEL POINTS FROM ALL MATERIALS

To examine mercury concentrations of all materials together across the study area, points within the highest contamination threshold levels of each material (water, sediment, fish, and soil) for all years were plotted together on one map (fig. 17). Because no threshold levels were used for the atmospheric deposition data, these data (representing only two geographic points) were not included in Figure 17. Highest contamination threshold levels used for water, sediment, fish, and soil include the following:

- Water — ADEM's water-quality criteria acute mercury levels (ADEM, 2007) of equal to or greater than (≥) 2.4 ppb for freshwater and ≥2.1 ppb for saltwater.
- Sediment — MacDonald and others' (2003) Probable Effects Level of ≥486 ppb for freshwater sediments and Long and others' (1995) Effects Range Median of ≥710 ppb for saltwater sediments.
- Fish — Beckvar and others' (2005) tissue-based biological effects level of ≥200 ppb for whole-body fish and EPA's human-health based consumption limit of ≥1900 ppb (EPA, 2006d) for fillet fish.
- Soil — EPA's Ecological Screening Value of ≥100 ppb (EPA, 2001).

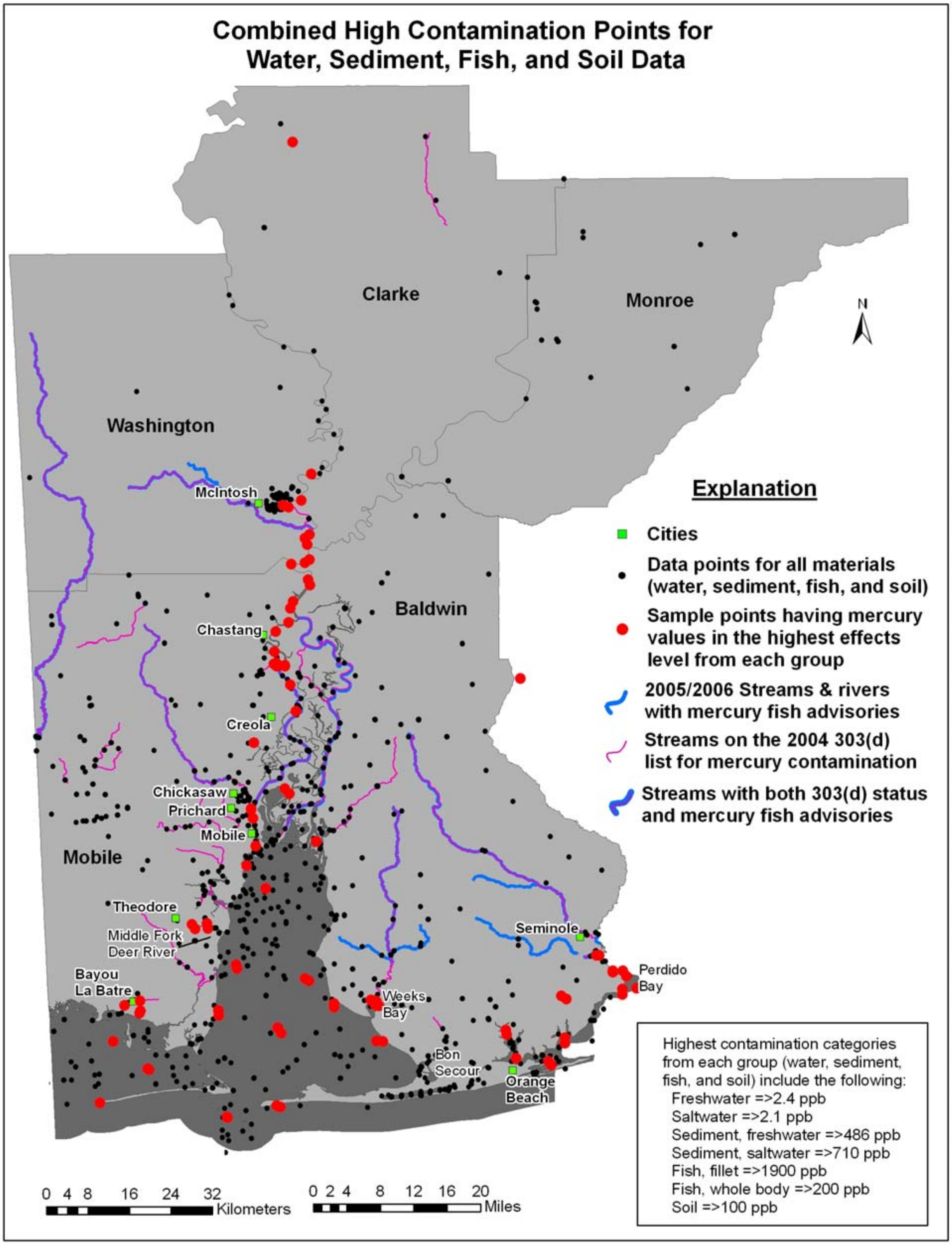

Figure 17. Location of high-contamination areas from combined results.

DISCUSSION AND FUTURE RESEARCH

While the main objective of this project was not to identify point sources, the project did provide a view of the spatial distribution of mercury levels in data collected across the study area. These results can be used as a tool for identifying areas within the five counties that may need further investigation where the data indicate high mercury levels with respect to effects levels. Using multiple datasets from numerous studies independent from one another, as performed in this project, allows a broader understanding, both spatially and temporally. However, the data collected for this project represent a small portion of the data needed for in-depth study of mercury contamination and point sources within the study area. The following paragraphs suggest additional studies that would further refine our understanding of mercury concentration and sampling distribution in the study area.

WATER

In addition to the surface-water data described in this report, more current freshwater and saltwater data are needed for a detailed investigation of water-column mercury. Out of the data collected in this study, there were only 129 freshwater samples between 1995 and 2005, and no saltwater samples available for that time period. The 129 freshwater samples were collected in only two of the five counties. Moreover, spatial distribution and varying hydrologic conditions of the sampled data should be considered.

Project personnel collected and analyzed surface-water data, but did not investigate ground water. Since most wells are not required to test for contaminants on a regular basis, testing well water samples would provide additional information not examined in this study. Data from municipal wastewater and drinking water plants could also provide additional temporal information. Municipal drinking-water plants have to meet water-quality and drinking-water standards and frequently test for mercury, making these sources good indicators of the water quality for this area.

SEDIMENT

Of the freshwater sediment data, the largest cluster of highest contamination category samples is located on the Mobile River in southern Washington County and northern Mobile County. Since these samples represent recent data (all samples were collected since 1992), further data collection and sampling could reveal important information on the point source(s) of the contamination in this stretch of the river. Another aspect of further research in the Mobile River and Delta area relates to the many oxbows around the river that trap and hold sediment and water. These areas have fine-grained sediments, low dissolved oxygen, decreased pH, and increased nutrient concentration — all attributes that can enhance the methylation of mercury (Horowitz, 1991; Brigham and others, 2003). Sampling from these oxbows could lead to identification of areas of high mercury concentration.

SOIL

The soil data reflected in this project are distributed across only two of the five counties in the study area. Further determination of mercury in soil from the remaining counties should be performed for a meaningful assessment. Additional sampling would provide a better representative sample of the larger area. Moreover, additional sampling needs to be done in the vicinity of those sites from which the soil mercury concentration is greater than the ESV to verify and define the indicated levels.

ATMOSPHERIC DEPOSITION

Precipitation data would also be useful in examining mercury contamination of soil or water as a result of global and local atmospheric transport of mercury. As only two MDN monitoring stations are in the five-county study area (fig. 14) and other sites along the coast and inland are distant, additional sites in the study region could provide more data that could be paired with meteorological information to study correlation between storm events and mercury deposition in a geographic context. Better coupling of depositional geochemistry with real-time attributes of precipitation events, such as cloud height and condensation layer, would help in evaluating local and global transport.

FISH

The fish dataset represented the second largest dataset in this study and contained many attributes that would allow further analyses and correlations. Owing to time and financial constraints, more in-depth analyses of the fish data for this study was not performed beyond what has been described previously. Future research on mercury in fish should include a thorough search for more recent fish data as well as older data. Historical records should be collected for streams that have been included in ADEM's 303(d) list owing to mercury contamination and streams for which there have been fish advisories due to mercury levels. By examining multitemporal fish data, mercury contamination trends through time can be better evaluated, and streams with persistent problems can be identified.

MUSSELS

Only 21 measurements of mercury levels in tissue from benthic organisms were obtained. These data were taken from the NOAA NSTMW project. Owing to the small sample size, no analyses were performed on the mussel data in this project. However, because these data represent tissue from organisms that filter particulates from the water in their environments, additional mussel data collection and testing would provide important information on mercury levels in the water and the sediment over the life span of the organisms sampled.

METHYLMERCURY

Additional data collection and analysis is recommended to further investigate methylmercury and bioaccumulation of mercury. One previous study that should be included, is a study by Warner and others (2005) that examined mercury accumulation in relation to different environmental compartments in the Mobile River Basin. For that study, mercury concentrations were obtained for sediment, water, and largemouth bass and included some methylmercury measurements. For our study, only 12 methylmercury water samples were obtained and all were from the USGS NWIS. Additional methylmercury data exist and should be analyzed. For a thorough investigation, new sampling should also be performed.

CONCLUSIONS

This project provides a general statistical and spatial overview of available mercury data for the five-county study area surrounding Mobile Bay, Alabama. Identification of point sources of mercury contamination in the study area and understanding the effects and significance of contamination within the ecosystems of the Mobile Bay and delta area are critical concerns, and further collection and analysis of additional data are strongly recommended. The results show that mercury concentrations exceed both human and wildlife effects threshold levels in multiple areas of south Alabama and warrants further investigation and analysis for the welfare and protection of this unique and important area.

REFERENCES CITED

Alabama Department of Environmental Management, 1993, A survey of the water quality and sediment chemistry of selected sites in Mobile Delta system: Montgomery, Alabama, Technical Report, 41 p.

Alabama Department of Environmental Management, 1996a, A survey of the Bon Secour River watershed: Montgomery, Alabama, Technical Report, 59 p.

Alabama Department of Environmental Management, 1996b, A survey of the Dog River watershed, second year's findings: Montgomery, Alabama, Technical Report, 51 p.

Alabama Department of Environmental Management, 1997, A survey of Chickasaw Creek watershed: Montgomery, Alabama, Technical Report, 95 p.

Alabama Department of Environmental Management, 2000, A survey of the Little Lagoon watershed: Mobile, Alabama, Technical Report, 57 p.

Alabama Department of Environmental Management, 2004, 2004 integrated water quality monitoring and assessment report: 305(b) Report, on the World Wide Web at URL http://www.adem.state.al.us/WaterDivision/WQuality/305b/2004Report/2004.htm.

Alabama Department of Environmental Management, 2006, 303 (d) List, on the World Wide Web at URL http://www.adem.state.al.us/WaterDivision/WQuality/303d/WQ303d.htm.

Alabama Department of Environmental Management, 2007, Chapter 335-6-10, Water quality criteria, on the World Wide Web at URL http://www.epa.gov/waterscience/wqs/al/al_4_wqs.pdf.

Alabama Department of Public Health, 2006, Alabama waterways: Fish advisories, on the World Wide Web at URL http://www.adph.org/RISK/Default.asp?TemplateID=1349.

Arctic Monitoring and Assessment Programme, 1998, Assessment report: Arctic pollution issues. Oslo, Norway: Arctic Monitoring and Assessment Programme.

Agency for Toxic Substances and Disease Registry, 2005, 2005 CERCLA priority list of hazardous substances, on the World Wide Web at URL http://www.atsdr.cdc.gov/cercla/05list.html.

Beckvar, N., Dillon, T. M., and Read, L. B., 2005, Approaches for linking whole-body fish tissue residues of mercury or DDT to biological effects thresholds: Environmental Toxicology and Chemistry, v. 24, no. 8, p. 2094-2105.

Brigham, M. E., Krabbenhoft, D. P., and Hamilton, P. A., 2003, Mercury in stream ecosystems – new studies initiated by the U.S. Geological Survey: USGS Fact Sheet 016-03, on the World Wide Web at URL http://pubs.usgs.gov/fs/fs-016-03/.

Center for Coastal Monitoring and Assessment Program, 2005, National Status and Trends Program: National Oceanic and Atmospheric Administration, on the World Wide Web at URL http://ccma.nos.noaa.gov/stressors/pollution/nsandt/.

Center for Disease Control, 2005, CDC's third national report on human exposure to environmental chemicals: NCEH Pub 05-0664, 4 p.

Chang, Semoon, and Canode, Shelia, 1999, Toward valuation of the Mobile Bay: A study: University of South Alabama, Mitchell College of Business, Center for Business and Economic Research, CBER Research Report 44, 130 p.

Dennis, Ian, Clair, T. A., Driscoll, C. T., Kamman, Neil, Chalmers, Ann, Shanley, Jamie, Norton, S. A., and Kahl, Steve., 2003, Distribution patterns of mercury in lakes and rivers of northeastern North America: Ecotoxicology, v. 14, p. 113-123.

Grieb, T. M., Driscoll, C. T., Gloss, S. P., Schofield, C. L., Bowie, G. L., 1990, Factors affecting mercury accumulation in fish in the Upper Michigan Peninsula: Environmental Toxicology and Chemistry, v. 9, no. 7, p. 919-930.

Guentzel, J., 2002, Atmospheric deposition of mercury (abs.), Mobile, AL, The Mercury Forum, Mississippi-Alabama Sea Grant Consortium, variously paginated.

Halcomb, Gary, 1991, A sediment chemistry baseline study of coastal Alabama: Mobile, Alabama, Alabama Department of Environmental Management Technical Report, 74 p.

Halcomb, Gary, 1992, A survey of the water quality and sediment chemistry of shipyards in coastal Alabama: Montgomery, Alabama, Alabama Department of Environmental Management Technical Report, 62 p.

Horowitz, A. J., 1991, A primer on sediment-trace element chemistry (2nd ed.): Chelsea, Michigan, Lewis Publishers, 136 p.

Hummell, R. L., and Parker, S. J., 1995, Holocene geologic history of Mobile Bay, Alabama: Alabama Geological Survey Circular 186, 97 p.

Isphording, W. C., Stringfellow, J. A., and Flowers, G. C., 1985, Sedimentary and geochemical systems in transitional marine sediments in the northeastern Gulf of Mexico: Gulf Coast Association of Geological Societies Transactions, v. 35, p. 397-408.

Illinois State Water Survey, 2006, National atmospheric deposition program, on the World Wide Web at URL http://nadp.sws.uiuc.edu/.

Kopaska-Merkel, D. C. and Rindsberg, A. K., 2005, Sand-quality characteristics of Alabama beach sediment, environmental conditions, and comparison to offshore sand resources: Alabama Geological Survey Open-File Report 0508 (on CD-ROM), Annual Report 1 under U.S. Minerals Management Service Cooperative Agreement 1435-01-04-CA-34423.

Long, E. R., and Morgan, L. G., 1991, The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program: Seattle, Washington, National Oceanic and Atmospheric Administration, NOAA Technical Memoradum NOS OMA 52, 231 p.

Long, E. R., MacDonald, D. D., Smith, S. L., Calder, F. D., 1995, Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments: Environmental Management, v. 19, no. 1, p. 81-97.

MacDonald, D. D., Ingersoll, C. G., Smorong, D. E., Lindskoog, R. A., Sloane, G., and Biernacki, T., 2003, Development and evaluation of numerical sediment quality assessment guidelines for Florida inland waters: Florida Department of Environmental Protection Open-File report, 111 p.

Mettee, M. F., O'Neil, P. E., and Pierson, J. M., 1996, Fishes of Alabama and the Mobile Basin: Birmingham, Alabama, Oxmoor House, 820 p.

Mobile Press Register, 2005, Press-Register, http://www.mobileregister.com/archive.htm.

Moore, C. J., 2000, A review of mercury in the environment (its occurrence in marine fish): South Carolina Marine Resources Division Technical Report 86, 22 p.

National Oceanic and Atmospheric Administration, 2003,Tropical Storm Bill - June 27-July 3, 2003, on the World Wide Web at URL http://www.hpc.ncep.noaa.gov/tropical/rain/bill2003.html.

National Oceanic and Atmospheric Administration, 2007, Screening quick Reference Tables (SquiRT), on the World Wide Web at URL http://response.restoration.noaa.gov/type_subtopic_entry.php?RECORD_KEY%28entry_subtopic_type%29=entry_id,subtopic_id,type_id&entry_id(entry_subtopic_type)=90&subtopic_id(entry_subtopic_type)=5&type_id(entry_subtopic_type)=2.

Rindsberg, A. K., and Kopaska-Merkel, D. C., 2006, Sand-quality characteristics of Alabama beach sediment, environmental conditions, and comparison to offshore sand resources: Alabama Geological Survey Open-File Report 0607 (on CD-ROM).

U.S. Environmental Protection Agency, 1994, Mobile River study 1993-1994: EPA Region 4 Electronic Reading Room, on the World Wide Web at URL http://www.epa.gov/Region4//foiapgs/readingroom/.

U.S. Environmental Protection Agency, 1998, National Sediment Inventory (NSI) Version 1.2 for the conterminous U.S, on the World Wide Web at URL http://www.epa.gov/waterscience/BASINS/metadata/nsi.htm.

U.S. Environmental Protection Agency, 1999, The National survey of mercury concentrations in fish database summary 1990-1995, Washington, D.C., 210 p.

U.S. Environmental Protection Agency, 2001, Supplemental guidance to RAGS: Atlanta, EPA Region 4 Bulletins, Ecological Risk Assessment, on the World Wide Web at URL http://www.epa.gov/region4/waste/ots/ecolbul.htm.

U.S. Environmental Protection Agency, 2005, Environmental monitoring and assessment program: EPA, on the World Wide Web at URL http://www.epa.gov/emap/.

U.S. Environmental Protection Agency, 2006a, National Priorities List (NPL), on the World Wide Web at URL http://www.epa.gov/superfund/sites/npl/index.htm.

U.S. Environmental Protection Agency, 2006b, Toxic Release Inventory (TRI) program, on the World Wide Web at URL http://www.epa.gov/tri/.

U.S. Environmental Protection Agency, 2006c, Current national recommended water quality criteria, on the World Wide Web at URL http://www.epa.gov/waterscience/criteria/wqcriteria.html.

U.S. Environmental Protection Agency, 2006d, Guidance for assessing chemical contaminant data for use in fish advisories, on the World Wide Web at URL http://www.epa.gov/waterscience/fishadvice/volume2/.

U.S. Environmental Protection Agency, 2006e, Gulf of Mexico program, on the World Wide Web at URL http://www.epa.gov/gmpo/.

U.S. Environmental Protection Agency, 2006f, Better Assessment Science Integrating point and Nonpoint Sources (BASINS) , on the World Wide Web at URL http://www.epa.gov/waterscience/basins/.

U.S. Environmental Protection Agency, 2007, National coastal assessment, on the World Wide Web at URL http://www.epa.gov/emap/nca/ .

U. S. Geological Survey, 1995a, Mercury contamination of aquatic ecosystems: U. S. Geological Survey Fact Sheet FS-216-95, on the World Wide Web at URL http://wi.water.usgs.gov/pubs/FS-216-95/mercury.pg3.pdf.

U. S. Geological Survey, 1995b, National contaminant biomonitoring program, on the World Wide Web at URL http://www.cerc.usgs.gov/data/ncbp/fish.htm

U. S. Geological Survey, 2005, National water information system, on the World Wide Web at URL http://waterdata.usgs.gov/nwis.

U. S. Geological Survey, 2006, Saline water, on the World Wide Web at URL http://ga.water.usgs.gov/edu/saline.html .

U. S. Geological Survey, 2006, National geochemical survey database, on the World Wide Web at URL http://tin.er.usgs.gov/geochem/.

Warner, K. A., Bonzongo, J. C., Roden, E. E., Ward, G. M., and others, 2005, Effect of watershed parameters on mercury distribution in different environmental compartments in the Mobile Alabama River Basin, USA: Science of the Total Environment, v. 347, p. 187-207.

Woods, Philip, 2003, A survey of the Bayou Sara watershed, Mobile, Alabama: Alabama Department of Environmental Management Technical Report, 202 p.

Woods, Philip, 2004, An impervious surface study over three regimes: Three Mile Creek, Fly Creek, and Bay Minette Creek subwatersheds: Alabama Department of Environmental Management Technical Report, 107 p.

GEOLOGICAL SURVEY OF ALABAMA
P.O. Box 869999
420 Hackberry Lane
Tuscaloosa, Alabama 35486-6999
205/349-2852

Berry H. (Nick) Tew, Jr., State Geologist

A list of the printed publications by the Geological Survey of Alabama can be obtained from the Publications Sales Office (205/247-3636) or through our web site at http://www.gsa.state.al.us/.

E-mail: info@gsa.state.al.us