TMDL Study Phase I:
Mercury Loads to Impaired Waters in the Lumber River Basin, North Carolina

November 1999

Lumber River Basin

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INTRODUCTION

Eleven waters from the Lumber River basin appear on the 1998 303(d) list for fish consumption advisories due to mercury contamination. Table 1 lists waters in the Lumber River Basin that have fish consumption advisories and appear on the 303(d) list. This document describes the sources of mercury in the Lumber River basin and development of mercury total maximum daily loads for those waters listed in Table 1. The ultimate objective of this study, and future studies or management plans regarding mercury in the coastal plain, is to reduce fish tissue levels of mercury and remove fish consumption advisories. Recommendations on how to reduce mercury pollution in surface waters are provided at the end of the document.

Table 1. Lumber River Basin 303(d) Listed Waters due to Mercury Contamination

Watershed	Name of stream or lake	Subbasin
Lumber River	Drowning Creek	030750
	Lumber River	030751
	Big Swamp	030753
	Porter Swamp	030751
	Ashpole Swamp	030754
	Pages Lake	030750
	Pit Lake (Pit Links Lake)	030750
	Watson Lake	030750
Waccamaw River	Waccamaw River	030756, 030757
	Big Creek	030756
	White Marsh	030758

303(d)/Total Maximum Daily Loads (TMDLs)

Section 303(d) of the Clean Water Act (CWA) requires states to develop a list of waters not meeting water quality standards or which have impaired uses. This list is submitted biennially to the U.S. Environmental Protection Agency (EPA) for review. The 303(d) process requires that a Total Maximum Daily Load (TMDL) be developed for each of the listed waters, where technically feasible. EPA characterizes the TMDL as the sum of the wasteload allocation (WLA), load allocation (LA), and a margin of safety (MOS), or

$$TMDL = \Sigma(WLA, LA, MOS).$$

The wasteload allocation portion of the TMDL accounts for the loads allotted to existing and future point sources. Similarly, the load allocation portion of the TMDL accounts for the loads allotted to existing and future nonpoint sources and natural background. The margin of safety addresses uncertainties in the data collection and modeling techniques (FACA 1998). The objective of a TMDL is to allocate allowable pollutant loads to known sources so that actions may be taken to restore the water to its intended uses (EPA 1991). Generally, the four primary components of a TMDL, as identified by EPA (1991) and the Federal Advisory Committee (FACA 1998) are as follows:

Target identification or selection of pollutant(s) and end-point(s) for consideration. The pollutant and end-point are generally associated with measurable water quality related characteristics that indicate compliance with water quality standards. North Carolina indicates known pollutants on the 303(d) list.

Assimilative capacity estimation or level of pollutant reduction needed to achieve water quality goal. The level of pollution should be characterized for the waterbody, highlighting how current conditions deviate from the target end-point.

Source identification. All sources that contribute to the impairment should be identified and loads quantified, where sufficient data exist.

Allocation (with margin of safety) of pollutant loads. Allocating pollutant control responsibility to the sources of impairment. When allocation is not possible, alternative methods of attaining standards may be included in the TMDL.

Section 303(d) of the CWA and the Water Quality Planning and Management regulation require EPA to review all TMDLs for approval or disapproval. Once EPA approves a TMDL, then the water may be removed from the 303(d) list. Where conditions are not appropriate for the development of a TMDL, management strategies may still result in the restoration of water quality. However, the water may not be removed from the 303(d) list until improvements in water quality have been demonstrated and the water meets designated uses.

The Federal Advisory Committee (FACA 1998) suggested three additional components of a TMDL in their April 1998 draft document. They are 1) an implementation plan, 2) monitoring and evaluation, and 3) TMDL revision procedures. These three additional components are not addressed herein. This document is the first of two parts, or phases, of the Lumber Mercury TMDL as described.

> ***Phase I*** of the TMDL establishes maximum loads for all 303(d) listed waterbodies based on simple criteria. This part of the TMDL uses existing and readily available information for evaluating maximum loads to waters and makes general recommendations for mercury reduction in these waters (not the implementation plan).
>
> ***Phase II*** of the TMDL will incorporate regional air quality modeling results from EPA Office of Air Quality Planning and Standards, provide a more detailed mercury cycling model for a portion of the Waccamaw River Basin, and establish requirements for evaluating mercury reductions. Phase II of the TMDL will also include implementation programs for atmospheric and NPDES mercury reductions and guidelines for revising the TMDL.

The remaining sections of this report discuss the following issues related to mercury in the Lumber and Waccamaw River Watersheds:

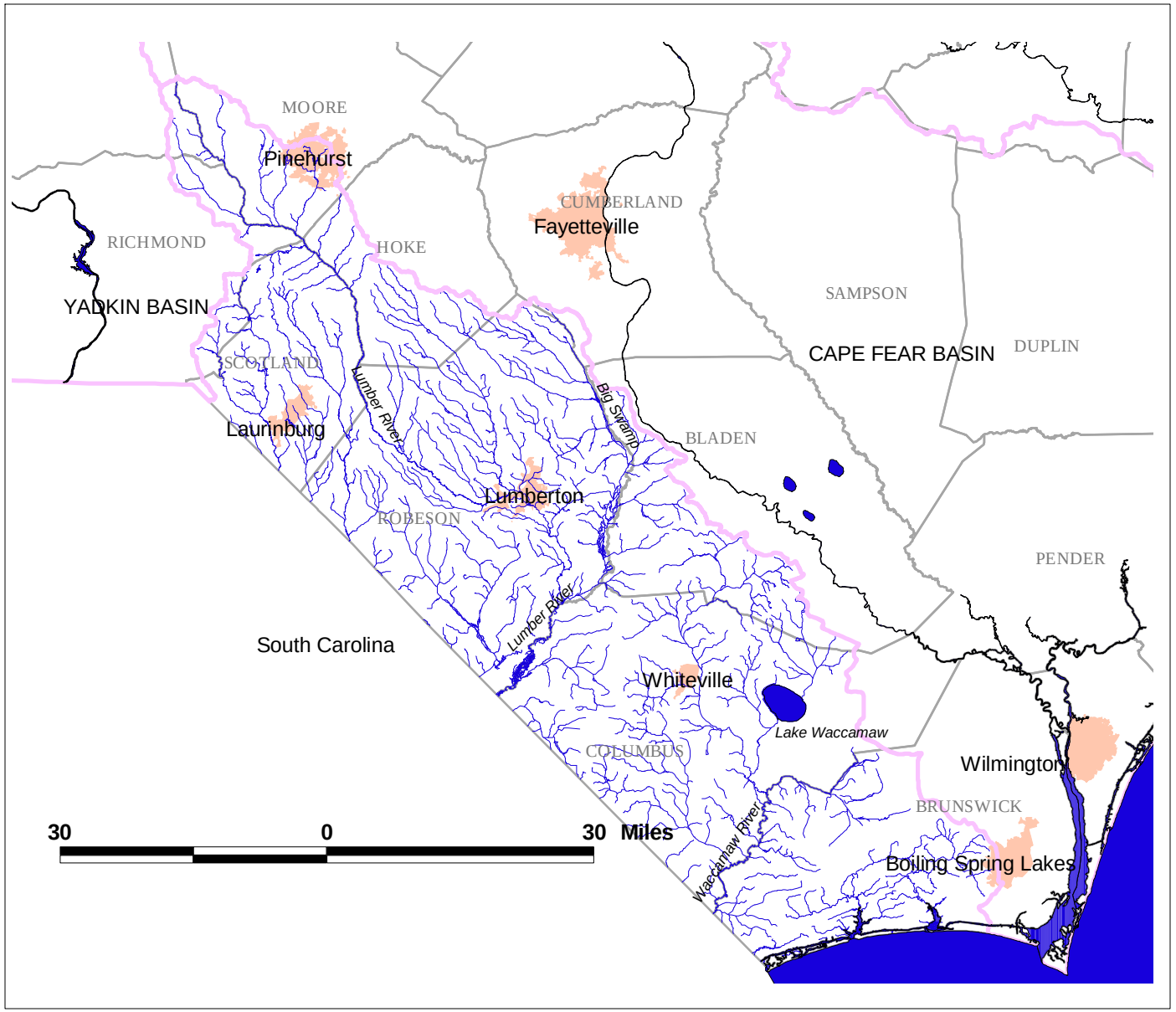
Mercury Cycling in the Environment.
Extent of Mercury Contamination
Potential Sources of Mercury
Estimates of Maximum Allowable Mercury Loads
Waste Load and Load Allocations
Summary

Site Description

The Lumber River basin, as shown in Figure 1, is located in the lower southeastern corner of North Carolina. This basin is comprised of four distinct watersheds: the Lumber River, Waccamaw River, Little Pee Dee Headwaters, and the Coastal Area. Past fish consumption advisories for waters in the Lumber River Basin have been primarily in the Lumber and Waccamaw River watersheds. The Lumber River from NC Highway 71 to the North Carolina-South Carolina state border is on the state's 1996 and 1998 303(d) lists. The impairment in the Lumber River, as well as many of its tributaries and impoundments, is due to elevated levels of mercury in fish tissues. The Lumber River watershed drains approximately 1,043,300 acres in Columbus, Robeson, Bladen, Cumberland, Moore, Montgomery, Hoke, Scotland, and Richmond counties (NCDEHNR 1994). The municipalities of Aberdeen, Lumberton, Pinehurst, and Red Springs are in this watershed. Roughly 50 percent of the watershed is forested and 40 percent is in agriculture, mostly cropland. The remainder is of mixed use including rural transportation and developed land (NCDEHNR 1994). Small streams in the Lumber River watershed tend to have little or no flow during dry summer months. A map of the Lumber River watershed is shown in Figure 2.

The Waccamaw River from the dam at Lake Waccamaw to the North Carolina-South Carolina state border is on the state's 1996 and 1998 303(d) lists. The Waccamaw River watershed drains approximately 804,400 acres in Columbus, western Bladen and northern Brunswick counties (NCDEHNR 1994). The municipalities of Whiteville, Tabor City, and Lake Waccamaw are in this watershed. Roughly 64 percent of the watershed is forested and 27 percent is in agriculture, mostly cropland. The remainder is of mixed use including pastures, rural transportation, and developed land (NCDEHNR 1994). The Waccamaw River originates at Lake Waccamaw and flows southwest into the Great Pee Dee River in South Carolina. Small streams in the Waccamaw River basin tend to have little or no flow during dry summer months. A map of the Waccamaw River in North Carolina is shown in Figure 3.

Figure 1. Lumber River Basin, North Carolina



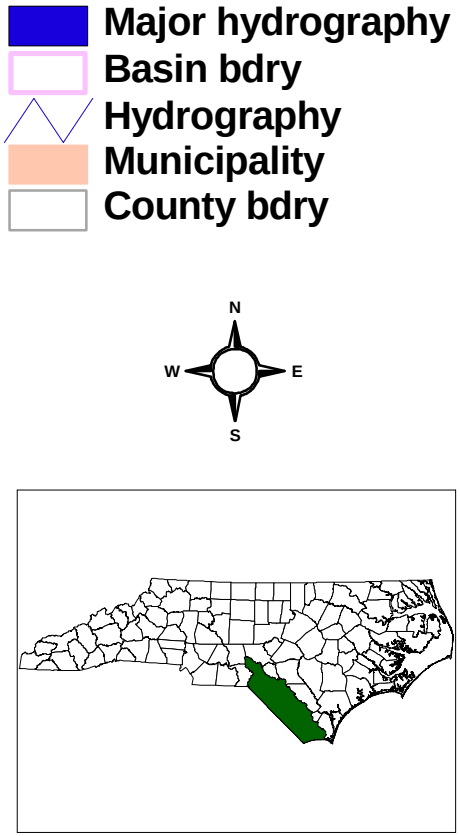
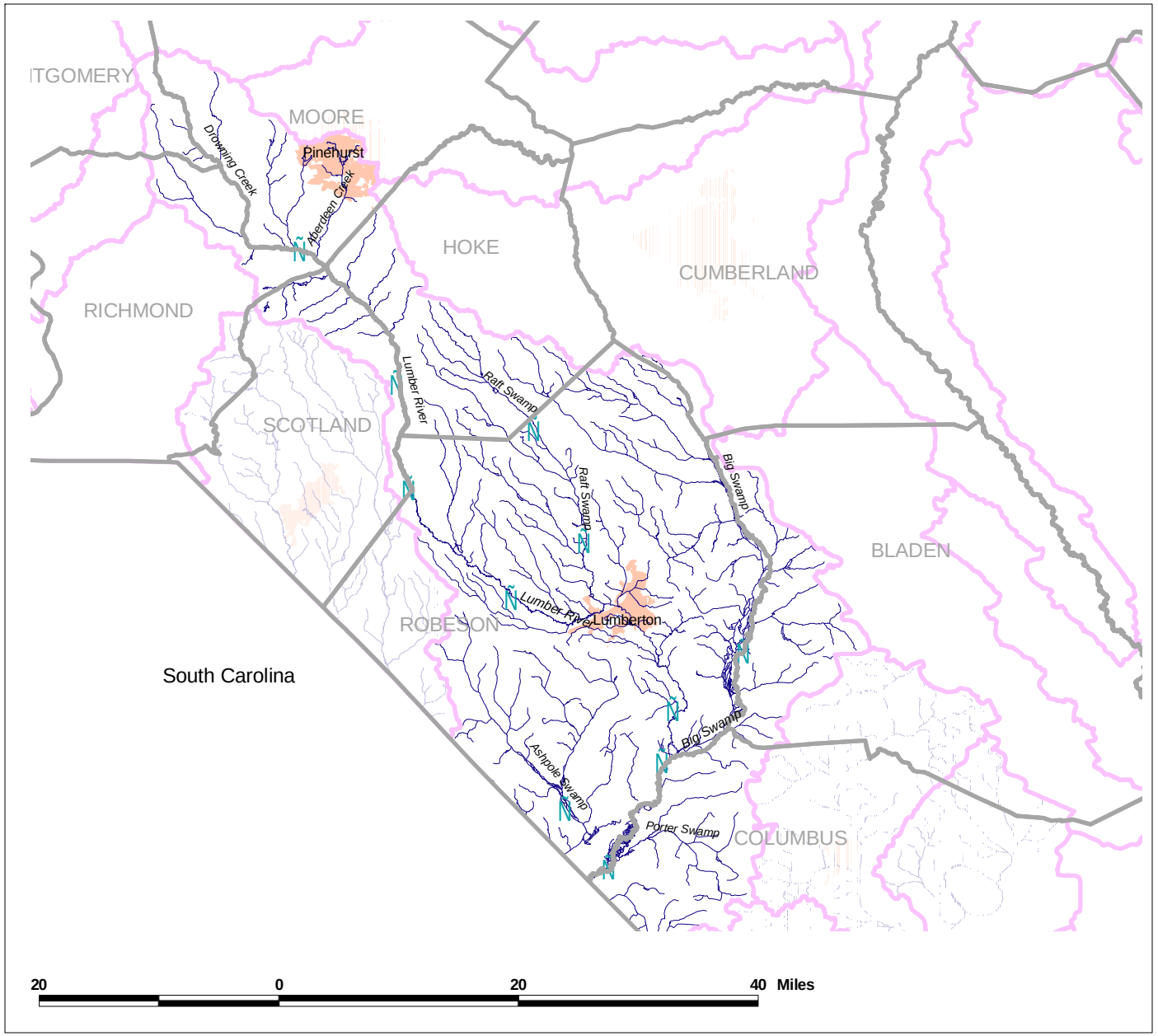


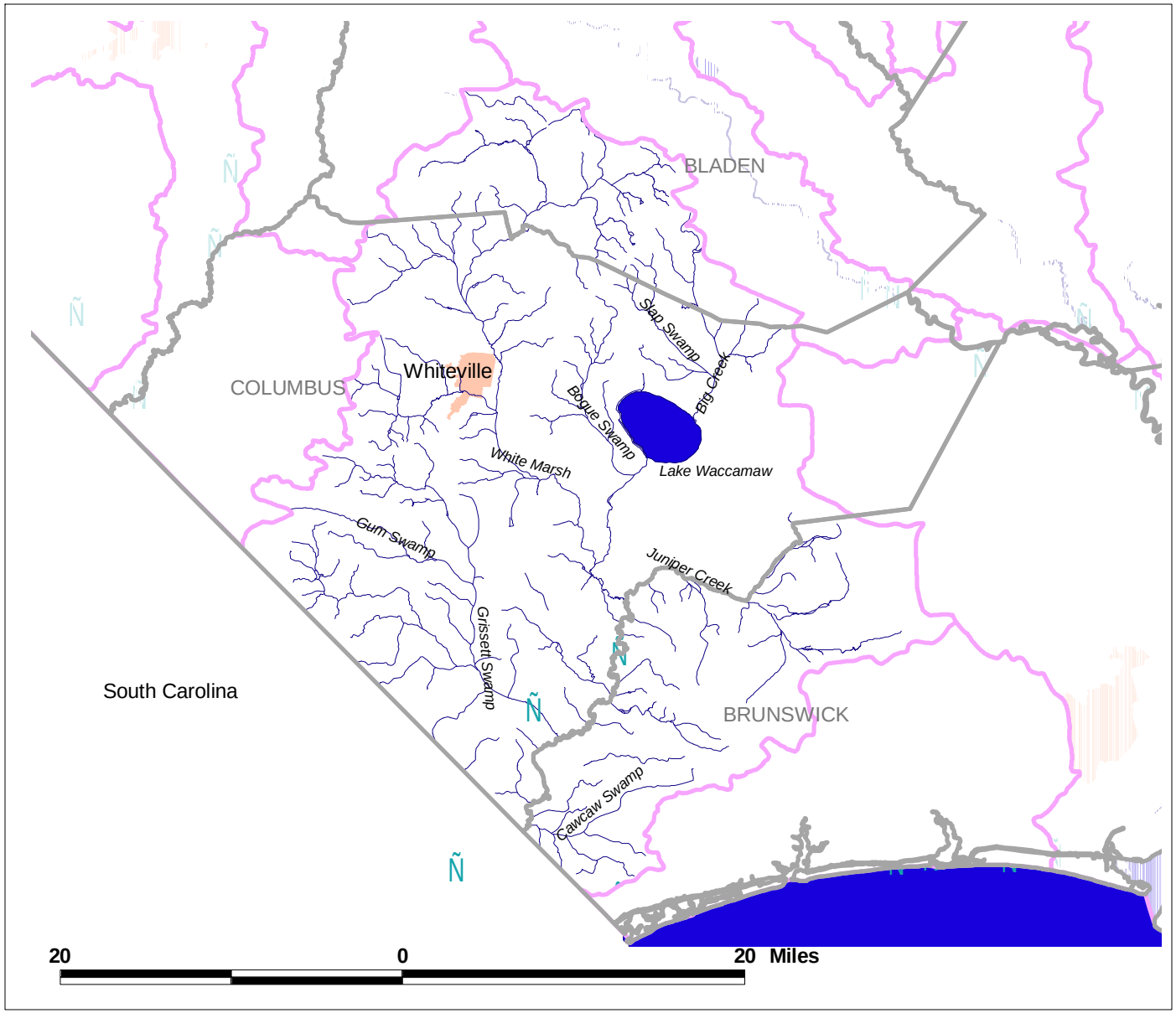
Figure 2. Lumber River Watershed, NC

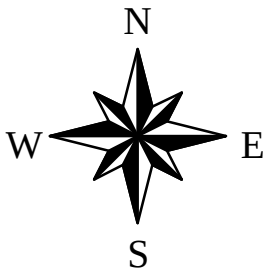


County bdry
Subbasin bdry
Ambient site
Hydrography
Municipality

N
W E
S

Figure 3. Waccamaw River Watershed, NC





MERCURY CYCLING IN THE ENVIRONMENT

Mercury has a complex life in the environment, moving from the atmosphere to soil, surface water, and into biota. A more comprehensive discussion of mercury in North Carolina can be found in "An Assessment of Mercury in North Carolina" (NCDEM 1982). EPA's Mercury Report to Congress (EPA 1997a) briefly describes the mercury cycle as well. Mercury cycles in the environment as a result of natural and human (anthropogenic) activities. The amount of mercury mobilized and released into the biosphere has increased since the beginning of the industrial age. However, the total amount of mercury on the planet has neither increased nor decreased. Human activities have simply moved the mercury from crustal soils to the biosphere. A schematic of mercury cycling in the biosphere is shown in Figure 4.

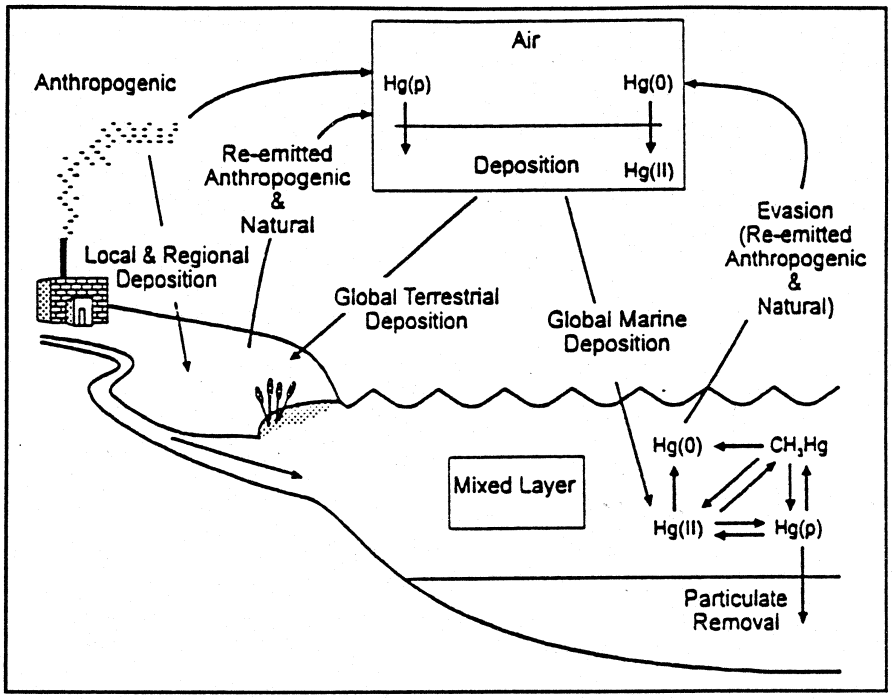


Figure 4. Schematic of Global Mercury Cycle (EPA 1997a)

As shown in Figure 4, most of the mercury in the atmosphere is elemental mercury vapor (Hg(0)) or particulate mercury (Hg(p)). Lindqvist et al. (1991) estimate that about 95-100% of atmospheric mercury is gaseous (elemental or inorganic), while the other 5% is particulate. Elemental mercury vapor may circulate in the atmosphere for up to a year. However, when converted to inorganic mercury (Hg(II)), it may only circulate for a period of hours. Thus, elemental mercury can be widely dispersed and transported thousands of miles from the source. The inorganic form of mercury, when either bound to airborne particles or in a gaseous form, is readily removed from the atmosphere by precipitation and dry deposition. Wet deposition has generally been believed to be the primary mechanism for transporting mercury from the atmosphere to surface waters and land, although new research indicates dry deposition may be equally important. Even after it deposits, mercury commonly is emitted back to the atmosphere either as a gas or associated with particles, to be re-deposited elsewhere (EPA 1997a). After

particulate or inorganic mercury deposits into surface waters, additional chemical transformations can occur. Within the water column or sediment mercury can convert back to elemental mercury or can become organic mercury (CH_3Hg). It is the organic form of mercury that is the most toxic and most likely to accumulate in fish.

Most of the mercury in water, soil, sediments, or plants and animals is in the form of inorganic mercury salts and organic forms of mercury. Generally, mercury in the water column will be bound to organic matter, either dissolved organic carbon (DOC) or suspended particulate matter (EPA 1997a). Total mercury levels in water do not necessarily correlate to mercury levels in biota or fish. This is because the organic form of mercury, methylmercury, is more likely to accumulate in fish tissue. The conversion of inorganic mercury to methylmercury is not well understood. Scientists continue to study this conversion in the Florida Everglades and the Great Lakes. However, several studies have found characteristics that are strongly correlated with the production of methylmercury, as shown in Table 2.

Table 2. Factors Associated with Increased Methylmercury Production

Factor	Description
Temperature	In freshwater sediments of northeastern acidic lakes, methylation is inhibited by low temperatures and has a temperature optimum of about 35 °C (Winfrey and Rudd 1990). Temperature seems to affect mercury methylation more strongly than demethylation (Gilmour 1995).
Color/Humic Content/Organic carbon	Mercury methylation is enhanced by increased availability of organic carbon. Increased decomposition of organic matter is a major cause of increased methylation in newly formed reservoirs and impoundments (Winfrey and Rudd 1990). Wetlands are also sites of increased decomposition of organic matter and have been recognized as sites of high mercury methylation (Gilmour 1995). Lindqvist et al. (1991) found that mercury concentrations in Swedish lakes were positively correlated to water color associated with organic content in the waters.
Hydrogen ion (pH)	Methylmercury production appears to be greater at low pH (e.g., 5-7). The formation of a more volatile form of methylmercury appears to be greater at higher pH values (e.g., >7). As pH decreases, a shift from the production of the more volatile to less volatile form of mercury occurs. A shift in pH from neutral to acidic could affect the mercury content in fish since the less volatile form is retained more efficiently (Winfrey and Rudd 1990). Release of methylmercury from the sediment surface is enhanced by reduced pH and could further increase the supply of methylmercury to fish (Winfrey and Rudd 1990). Lindqvist (1991) found a strong negative correlation of mercury in fish with lake water pH.
Oxygen	"Mercury methylation is a predominantly microbial process that occurs mainly in anoxic sediments and waters, with maximum intensity often at the interface between anoxic and oxic conditions" (Gilmour 1995). In addition to mercury methylation in anoxic subsurface sediments, methylation also occurs in the aerobic water column at the aerobic sediment-water interface, in the outer slime layer of fish, and in the intestinal contents of fish (Winfrey and Rudd 1990). Bloom et al. (1991) found that the highest methylmercury levels are reached in the anoxic, sulfide-rich bottom waters of acidic, northeastern lakes by late summer.

The Lumber and Waccamaw River Watersheds are blackwater systems that generally have all the characteristics described above: high levels of organic carbon, low pH, and during the summer months, lower dissolved oxygen levels and higher temperatures. Thus, the natural characteristics of these waters would likely contribute to the increased production of methylmercury.

Mercury accumulates efficiently in the food web. Accumulation occurs when the rate of uptake of a chemical or compound exceeds the rate of removal or elimination (EPA 1997a). Mercury present in low levels of the food chain (e.g., plankton, detritus) and water is taken up by forage fish through respiration and ingestion. Predatory organisms at the top of the food web generally have higher mercury concentrations. Within the aquatic food web, predatory fish such as bowfin and largemouth bass would have higher concentrations than forage fish (e.g., sunfish). Nearly all of the mercury that accumulates in fish tissue is methylmercury. Inorganic mercury does not tend to accumulate.

Mercury accumulation continues to move up the food chain outside of the aquatic environment. Humans, bald eagles, small mammals, and other fish eating species, as top predators, also accumulate mercury in tissue. Fish eating birds in the Great Lakes and the Everglades have already accumulated mercury at levels considered unsafe. Humans are most likely to be exposed to mercury through fish consumption, although mercury may be inhaled or ingested through other routes.

Methylmercury is a neurotoxin that may affect fetal neurological development following sufficient exposures. At higher exposure levels it can act as a neurotoxicant in adults, producing adverse effects such as tremor and parasthesia. The amount of mercury that can be safely ingested by humans is continually being reevaluated by the EPA, the Agency for Toxic Substances and Disease Registry (ATSDR) and other national and international agencies as new epidemiological data become available. The North Carolina Department of Health and Human Services (DHHS) Occupational and Environmental Epidemiology Branch has developed guidelines to instruct people on safe levels of fish consumption. When the average fish tissue mercury concentration for a particular species falls between 1 – 2 mg/kg (1-2 ppm), the general public is advised to eat no more than 2 meals per month, while women of child-bearing age and children are advised to avoid consumption of this species entirely. Above 2 mg/kg, no consumption is advised for all groups.

EXTENT OF MERCURY CONTAMINATION

Various agencies of the State of North Carolina have collected mercury data in the Lumber River Basin. DWQ maintains an ambient monitoring network in the basin where monthly water quality samples are collected. The general locations monitored are presented in Figures 2 and 3. Mercury has generally not been detected in surface waters since this monitoring network was begun. DWQ and Department of Health and Human Services fish tissue analyses have detected elevated mercury concentrations in several piscivorous fish of the Lumber and Waccamaw River watersheds. Mercury concentrations exceeding the Food and Drug Administration and North Carolina (FDA/NC) action level of 1 mg/kg have been detected in largemouth bass, bowfin and chain pickerel. A fish consumption advisory for largemouth bass and bowfin was issued in October 1994 for the entire Lumber River Basin (i.e., all four watersheds) due to elevated mercury levels in fish. In June 1997 a statewide advisory against the consumption of bowfin was issued due to mercury contamination.

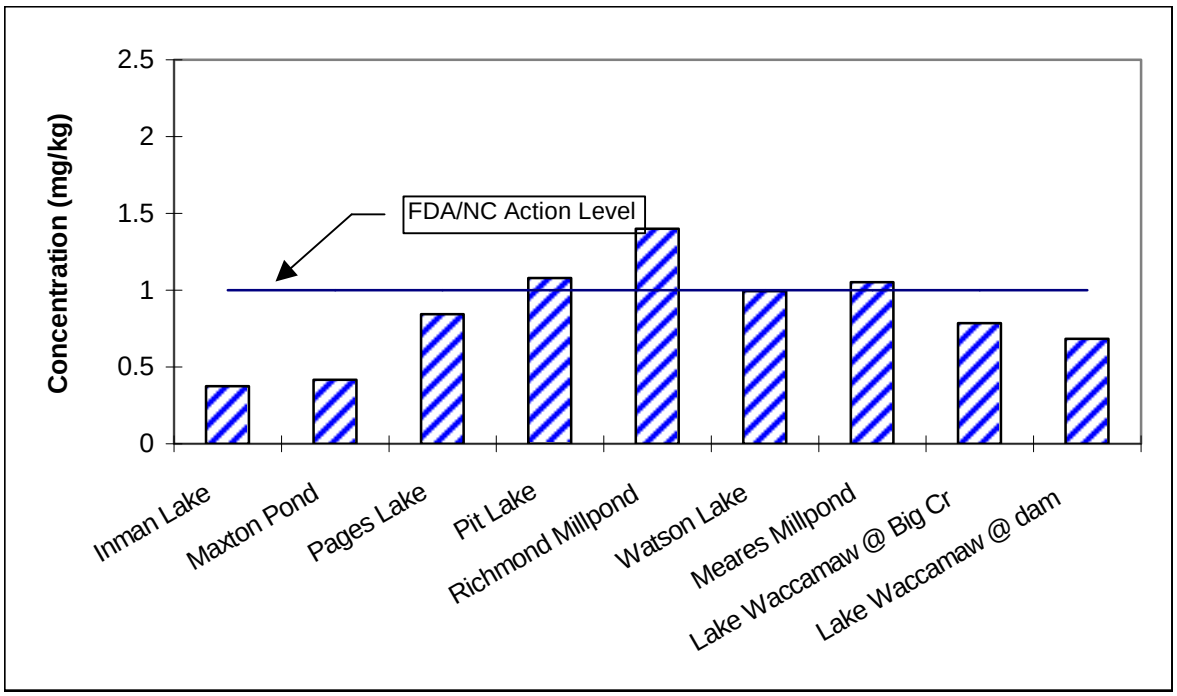
Fish tissue samples from the Lumber and Waccamaw River watersheds have been analyzed for mercury since the mid-1980s. However, the most comprehensive collection and analysis of fish tissue occurred in 1993. Thus, a large portion of the data described herein is from 1993. To illustrate the persistence of mercury in the Lumber and Waccamaw River watersheds, data collected in 1996 will also be presented. In 1993, largemouth bass, bowfin, and other predatory and forage fish species were collected and analyzed for mercury. Mean concentrations of mercury in largemouth bass and bowfin from multiple locations in each watershed were greater than the FDA/NC action level for mercury of 1 mg/kg. In general, concentrations in other predatory and forage fish were lower than the FDA/NC action level. A summary of average 1993 mercury concentrations in largemouth bass from the Lumber and Waccamaw River watersheds is presented in Figure 5. The data shown in Figure 5 include only those waters with multiple samples from which to calculate a mean (i.e., $n>1$ or more than one fish was caught). Several of the lakes shown in Figure 5 are not on the state's 303(d) list due to listing methodology. All lakes in the basin are included in the fish consumption advisory. TMDL development is focused on those lakes that are on the 303(d) list and appear in Table 1.

Several of the waters listed in Table 1 do not appear on Figure 5, primarily because of the paucity of fish tissue data. DWQ does not have data for Big Swamp from the years 1992 or 1993. Porter Swamp had one sample collected in 1992, bowfin with a mercury concentration of 1.5 mg/kg. Similarly, Ashpole Swamp had one sample collected in 1992, chain pickerel with a mercury concentration of 1.2 mg/kg. Big Creek was sampled in 1992 at two different locations. Mercury levels in largemouth bass from Big Creek near the mouth with Lake Waccamaw averaged 1.5 mg/kg (average of 22 samples), and in bass from Big Creek upstream of SR 1947 at bridge averaged 1.0 mg/kg (average of 5 samples). White Marsh was sampled once in 1993; a single chain pickerel from White Marsh had a mercury concentration of 1.9 mg/kg.

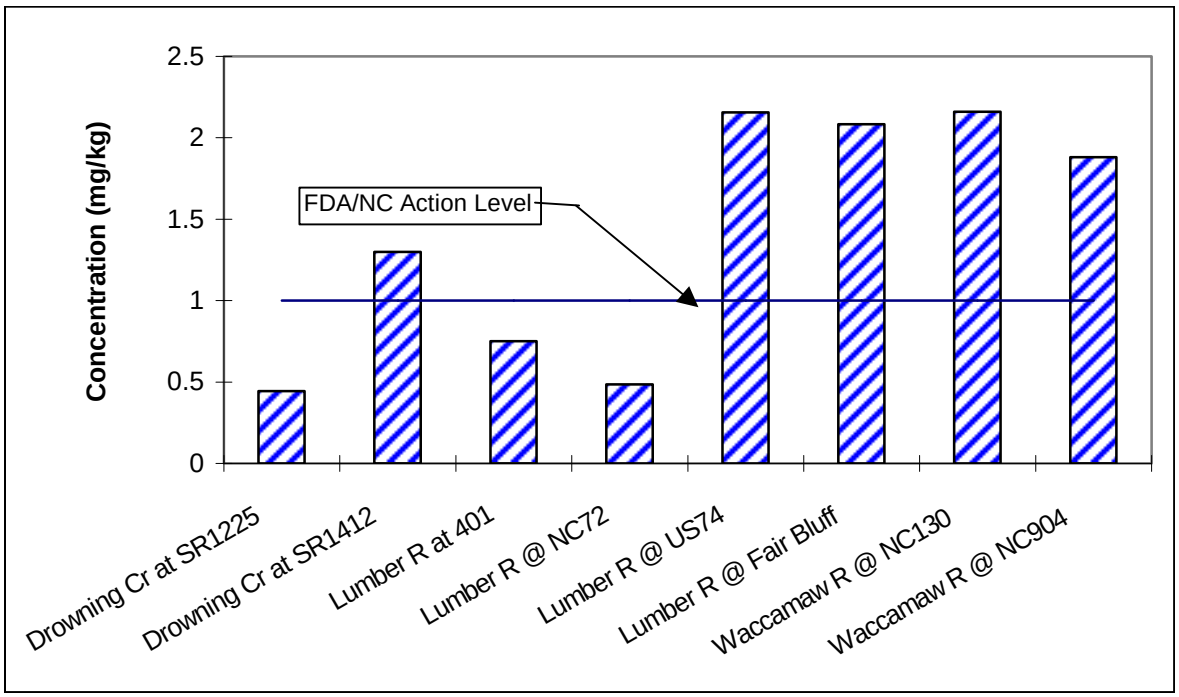
Contaminated sediment at the bottom of surface waters can serve as an important mercury reservoir. Sediment-bound mercury may recycle back into the aquatic ecosystem for decades, or longer (EPA 1997a). Two grab samples of sediment were collected from Lake Waccamaw in 1992 when fish were collected for sampling. Mercury concentrations in these samples were 0.04

Figure 5. 1993 Mean Mercury Levels in Largemouth Bass from the Lumber and Waccamaw River Watersheds

Lakes



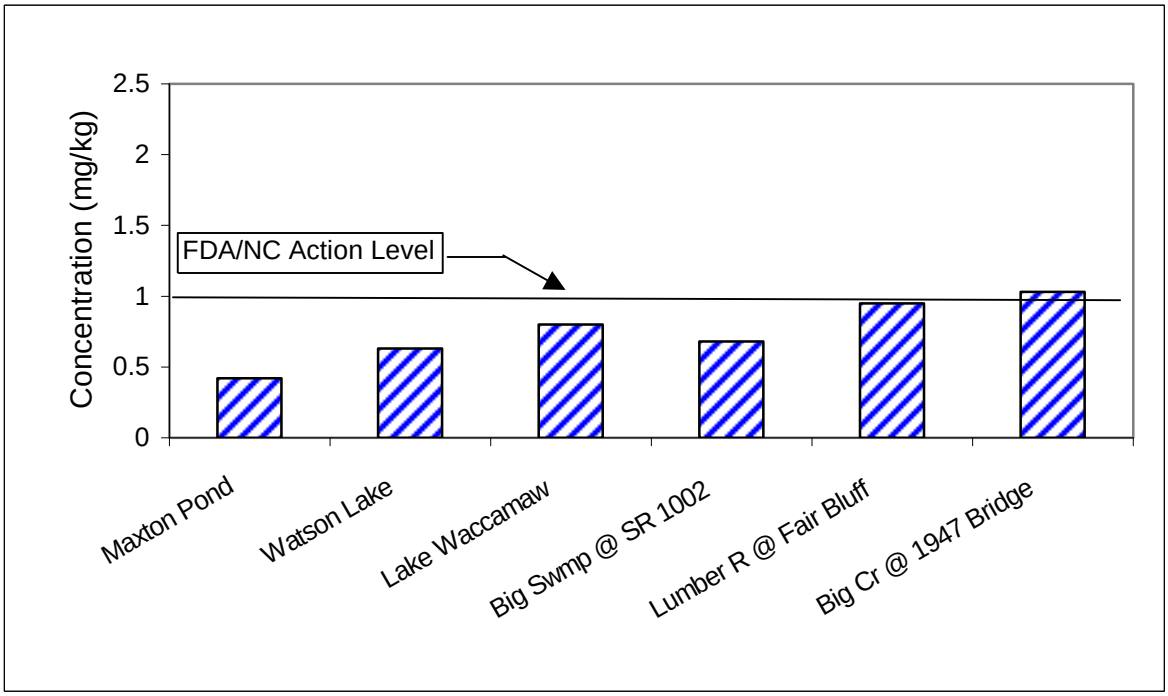
Rivers/Streams



and 0.02 mg/kg. EPA has not developed sediment quality criteria for mercury; thus there are no benchmark values to determine if these levels of mercury in sediment may be harmful to human health or aquatic life. Since 1990, mercury has sporadically been detected at the detection limit of 0.2 μg/L in the water column of both watersheds. However, none of these samples were collected or analyzed using clean techniques. This may have resulted in "false positives" or detections of mercury where there was either no mercury present or levels were below detection limits.

Data collected in 1996 are somewhat sparse. Only seven waters have multiple samples from which to calculate a mean mercury concentration in largemouth bass. As shown in Figure 6, mercury concentrations in some areas were still quite high (e.g., Big Creek at SR1947 Bridge). While it may appear that mercury concentrations in Watson Lake and the Lumber River at Fair Bluff decreased, direct comparisons between the fish tissue data must consider the size and potential age of the fish captured and analyzed. Larger, older fish would be more likely to have higher concentrations of mercury in fish tissue because of a longer exposure to mercury in the food chain. Smaller, younger fish would likely have lower concentrations. In 1993, the average weight of largemouth bass captured in Watson Lake was 1,465 grams (3.3 pounds), while in 1996 the average weight was 893 grams (~2.0 pounds). The average weight of largemouth bass from the Lumber River at Fair Bluff in 1993 was 1,270 grams (~2.9 pounds) compared to 555 grams (~1.2 pounds) in 1996. The lower concentrations shown in Figure 6 may reflect the smaller size, and reduced exposure, of fish captured in 1996 compared to 1993. Thus, although the concentrations shown in Figure 6 are at and below the action level, heavier, older fish that have been exposed to mercury for a longer time period may continue to contain mercury at levels greater than 1 mg/kg.

Figure 6. 1996 Mean Mercury Levels in Largemouth Bass from the Lumber and Waccamaw River Watersheds



POTENTIAL SOURCES OF MERCURY

Natural Sources of Mercury

The same amount of mercury has existed on the planet since the earth was formed (EPA 1997a). As a naturally occurring element, mercury is present throughout the environment, including the atmosphere, terrestrial environment, groundwater, and biota. Historically, mercury cycling in the atmosphere is believed to have been due to weathering and volcanic activities (NCDEM 1982). Mercury can naturally enter streams when scouring occurs over mercury deposits; mercury retained in the water column can be in dissolved or particulate form (NCDEM 1982). Substantial uncertainties remain concerning the level of natural movement of mercury in the environment. Studies continue to be conducted which estimate the natural fluxes of mercury to and from the atmosphere, and terrestrial and aquatic environments (EPA 1997b).

Anthropogenic Sources of Mercury

Mercury is a unique pollutant in that significant sources to surface waters can be either direct discharges to the aquatic environment or indirect discharges that move through another media (e.g., soil or air) before reaching the water column. Mercury can be emitted to air from industrial activities; once in the ambient air, mercury can be deposited back to the ground or to surface waters. This process, referred to as atmospheric deposition, has been found to be a significant source of aquatic mercury (Lindqvist et al. 1992, EPA 1994, 1997a,b). Thus, potential aquatic and atmospheric sources of mercury to the Lumber and Waccamaw River watersheds will be discussed.

Aquatic Sources. There are 39 permitted point source discharges in the Lumber and Waccamaw River Watersheds. Of these, 15 discharge 100% domestic wastewater, and 8 discharge industrial wastewater. Fourteen of these facilities are permitted to discharge at least 0.5 million gallons per day (MGD). A list of the National Pollutant Discharge Elimination System (NPDES) point source discharges is shown in Table 3, by watershed. The locations of point sources are shown in Figures 7 and 8. Permit numbers associated with each point source are shown in Appendix A.

Four NPDES point source dischargers in the Lumber River Watershed, and one in the Waccamaw River Watershed, analyze effluent for mercury, as noted in Table 3. These facilities are Moore County WWTP (MOWASA), Laurinburg-Maxton Airport Commission (LMAC), Lumberton WWTP, Red Springs WWTP, and Whiteville WWTP. Of these five facilities, Moore County and Lumberton WWTPs did not detect mercury in effluent samples collected in 1996 and 1997. LMAC, Red Springs WWTP, and Whiteville WWTP did detect mercury in the effluent during this time period. Only Whiteville WWTP has a limit for mercury in effluent stated in the NPDES permit[1]. Whiteville WWTP has a mercury limit of 0.03 µg/L prior to expansion above 2.5 MGD, and 0.02 µg/L after expansion. A summary of mercury concentrations in effluent from these facilities is presented in Table 4.

[1] The Whiteville WWTP has conducted extensive studies to reduce the mercury levels in effluent. Since beginning these studies, the frequency of mercury detection in effleunt samples has fallen from 60 percent in 1996 (n=57) to 22 percent in 1998 (n=64).

Table 3. NPDES Point Source Dischargers in the Lumber/Waccamaw River

Watershed	Subbasin	Facility	Location	Permitted discharge (MGD)
Lumber	030750	Samarkand Manor	Drowning Creek	0.04
		Southern Pines WTP	Aberdeen Creek	0
		Moore County WWTP (a^2)	Aberdeen Creek	6.70
		Camp Mackall (Army)	Drowning Creek	0.02
	030751	DOC-McCain Hospital	UT Mountain Creek	0.2
		Westpoint Stevens	Lumber River	4.5
		Robeson County WTP	Lumber River	0.2
		Pembroke WWTP	Lumber River	1.330
		Robeson Co Sch-Deep Br	Lumber River	0.004
		Robeson County WWTP	UT Lumber River	0
		Alamac Knit Fabrics	Lumber River	2.560
		Lumberton WWTP (a^1)	Lumber River	10.000
		Buckeye Lumberton, Inc.	Lumber River	1.800
		CP&L Weatherspoon SE	Lumber River	Variable
		Robeson Co Sch – Orrum High Sch	Flowers Swamp	0.006
		Fair Bluff WWTP	UT Lumber River	0.180
	030752	Red Springs WWTP (a^2)	Little Raft Swamp	2.500
		Laurinburg City-Maxton Airport (a^1)	Lumber River	1.0
	030753	Bladenboro WWTP	Bryant Swamp	0.500
		St. Pauls WWTP	Big Marsh Swamp	0.500
		Parkton WWTP	Dunns Marsh	0.200
		Robeson Co. Lumber Br	Big March Swamp	0
		Croft Metals, Inc.	Big Marsh Swamp	0.095
		Hoke Co. RWS/Antioch	Raft Swamp	No limit
		Hoke Co RWS/Arabia	Little Marsh Swamp	No limit
	030754	Fairmont WWTP	Pittman Mill Branch	0.500
Waccamaw	030756	Council Tool Company	UT to Lake Waccamaw	0.020
		Lake Waccamaw WWTP	UT to Bogue Swamp	0.400
		Tabor City WWTP	Town Canal	1.100
	030757	Columbus Co Schools-Old Dock Elem	UT to Gum Swamp Run	0.005
		Brunswick Co BOE-Waccamaw Elem	UT Bear Branch	0.0057
		Carolina Blythe Utility Co	UT to Persimmon Swamp	0.53
	030758	Whiteville WWTP (a^2)	White Marsh	3.0
		Chadbourn WWTP	Soules Swamp	0.820
		Georgia Pacific	Juniper Creek	0
		Clarkton WWTP	Brown Marsh Swamp	0.240
		Georgia Pacific Whiteville	Soules Swamp	No limit

(a) Facility is in the pretreatment program and regularly monitors for mercury in the effluent. Monitoring may be either quarterly (denoted by a^1) or at least monthly (denoted by a^2).

Figure 7. NPDES Discharges in the Lumber River Basin

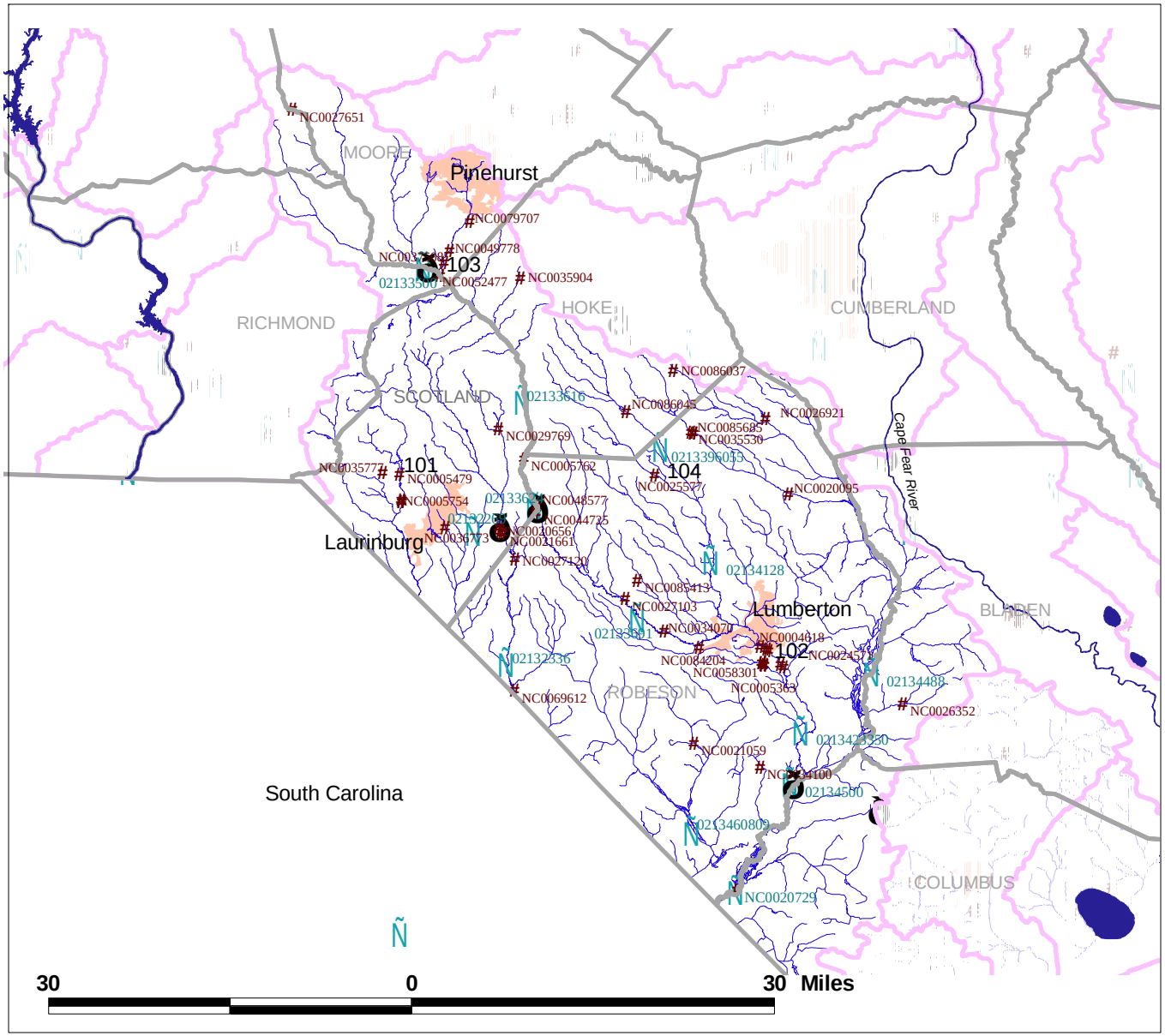


Figure 8. NPDES Discharges in the Waccamaw River Basin

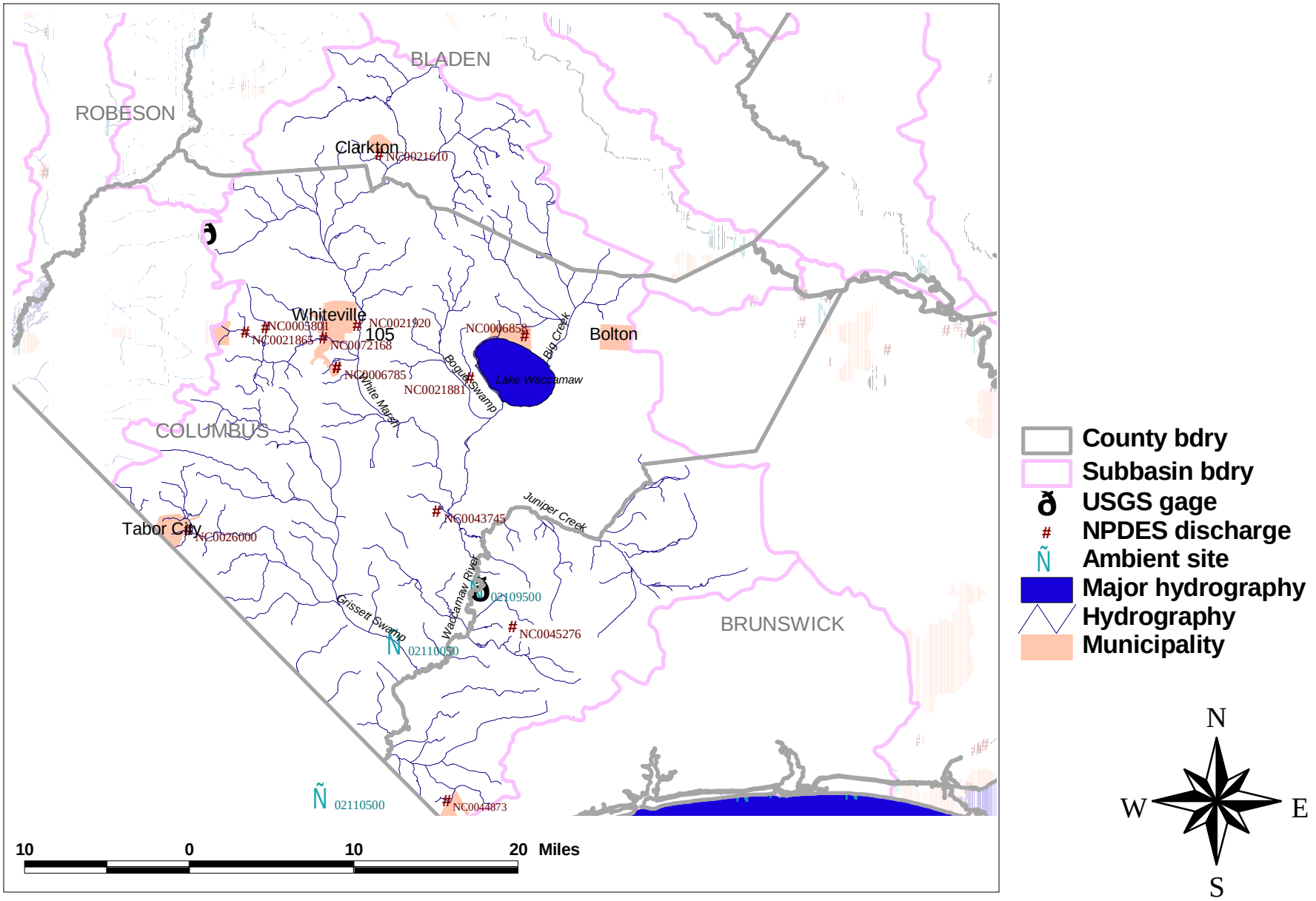


Table 4. Summary of 1996-1997 mercury concentrations in effluent, Lumber and Waccamaw River Dischargers (concentrations in µg/L)

Figure ID	Facility [Permit No.]	Frequency of detection (a)	Detection limit	Average concentration (b)	Range of detected concentrations
101	Laurinburg-Maxton Airport [NC0044725]	1 /7	0.2	0.2	0.6
102	Lumberton WWTP [NC0024571]	0 /8	0.2	-	-
103	Moore County WWTP [NC0037508]	0 /14	0.2	-	-
104	Red Springs [NC0025577]	10 /41	0.2	0.1	0.2 – 0.8
105	Whiteville WWTP [NC0021920]	56/107	0.2	0.3	0.2 – 1.4

(a) The number of samples in which mercury was detected over the number of samples analyzed.
(b) Mean mercury concentration calculated using all detected concentrations and one-half of the detection limit for samples below detection limits.

Other facilities do not regularly analyze effluent for mercury. Intermittent releases of mercury can occur from large wastewater treatment plants in response to the discharges received from medical or industrial connections. Several other smaller discharges in the Lumber River Watershed may potentially contain mercury, including hospitals and metal finishing industries.

Even if these facilities do release mercury to surface waters, NPDES point sources are not believed to be the most significant source of mercury to surface waters in the Lumber or Waccamaw River Watersheds. For example, elevated mercury levels have been found in fish where there are no upstream NPDES point sources of mercury. Therefore, NPDES point sources cannot be the only source of mercury.

Atmospheric Sources. Recent scientific studies have indicated that significant aquatic loads of hydrophobic organic chemicals (e.g., dioxins, PCBs), mercury, and nitrogen come from the atmosphere (Lindqvist et al. 1991, EPA 1994, 1997a,b). Atmospheric deposition occurs when pollutants are carried from the air to either the land or water. This deposition may be enhanced by precipitation in the form of falling rain or snow. Worldwide mercury emissions to the atmosphere have increased since the beginning of the industrial age. After the initial local deposition of mercury that occurs near a point source, the remaining mercury enters the global air current and may be transported great distances across countries and over oceans (EPA 1997a).

In EPA's Mercury Study Report to Congress (EPA 1997a,b), both regional and local atmospheric modeling was performed to estimate the average annual atmospheric deposition of mercury. Regional models consider pollutants that may be transported over long distances. Local models consider only the area around specific stack emissions. For the North Carolina coastal area, the regional model estimated that average annual total mercury deposition ranged from 10 to 30 ug/m^2. Local modeling did not focus on a specific facility, but rather was performed on hypothetical mercury emissions sources in the eastern and western US. For the eastern US, this local scale modeling predicted that 7 to 45% of locally emitted total mercury

would deposit within 50 km of a hypothetical facility (EPA 1997a). Thus, while up to half of the emitted mercury would deposit locally, the remaining mercury may be transported over great distances and could deposit in areas without local point emissions sources.

The North Carolina Division of Air Quality (DAQ) maintains an atmospheric mercury sampling site at Waccamaw State Park, adjacent to Lake Waccamaw. This site has been operating since 1995.[2] There are no other atmospheric mercury monitors in the vicinity of the Lumber and Waccamaw River Watersheds. Data collected at the Waccamaw State Park monitoring site include meteorological data (i.e., wind speed and direction, relative humidity, temperature, precipitation), and ambient air mercury vapor. Meteorological and mercury vapor data are collected at 15-minute intervals. Meteorological data is collected from atop a 65-foot pole and the mercury vapor analyzer inlet port is at a height of approximately 8-10 feet. Rainwater is also collected on a weekly basis for the National Mercury Deposition Network (MDN); samples are sent to a contract lab for analysis.

DAQ also maintains permits and other database information for industries emitting pollutants to the atmosphere in the State of North Carolina. The State of South Carolina maintains a similar database. In the vicinity of Waccamaw State Park, and within the Lumber and lower Cape Fear River Basins in general, there are fifteen facilities with reported emissions of more than ten pounds of mercury per year. The largest reported emissions are from Holtrachem Manufacturing Company, L.L.C., a chloralkali facility. Based on the information provided by the facility, approximately 1,400 pounds of mercury were emitted from the facility in 1996[3]. It is unclear whether this estimate includes fugitive emissions or potential emissions from lagoons on the site. A map showing the locations of permitted atmospheric point source emissions in the vicinity of the Lumber River basin is shown in Figure 9. Numbers corresponding to the facility name and emission rate are also included in this figure. Facility data is presented in Table 5.

DAQ conducts analysis of the meteorological and mercury vapor data from the Waccamaw site on a regular basis. Figures 10 and 11 show typical graphical representations of atmospheric elemental mercury vapor concentrations at Waccamaw State Park in May of 1998.[4] These representations of mercury concentrations in the atmosphere illustrate the influence of both globally transported mercury as well as apparent local inputs, arising from sources located to the east-northeast of the sampling site. Figure 10 displays the mercury concentration versus the date and time of day without regard to wind direction. From this figure, it can be seen that the baseline concentration of ambient air elemental mercury vapor is between 0.7 and 3 ng/m^3 at Waccamaw State Park. The peaks observed are events observed during this period and are typical event levels and durations observed for this site. Figure 11 represents the same data as Figure 10 but has only the discrete events plotted.[5] This figure shows the typical correlation of events and wind direction associated with this site; the majority of the events are associated with winds from

[2] DAQ began monitoring mercury levels in rainwater in June 1995 and ambient concentrations of mercury in May 1996.

[3] Holtrachem is upgrading machinery and processes. Mercury emissions from the stack are expected to be reduced to nondetectable levels by the end of 1999.

[4] Each point represents one 15-minute data point for atmospheric mercury concentration.

[5] Higher levels have been observed with at least one per month higher than 20-30 ng/m^3. Highest level event observed was ~90-100 ng/m^3. Data is lacking to determine the frequency of these higher level events.

Figure 9. Locations of Local Stack Emissions, 1996 Inventory
(Numbered sources emit greater than 10 lbs/yr of mercury)

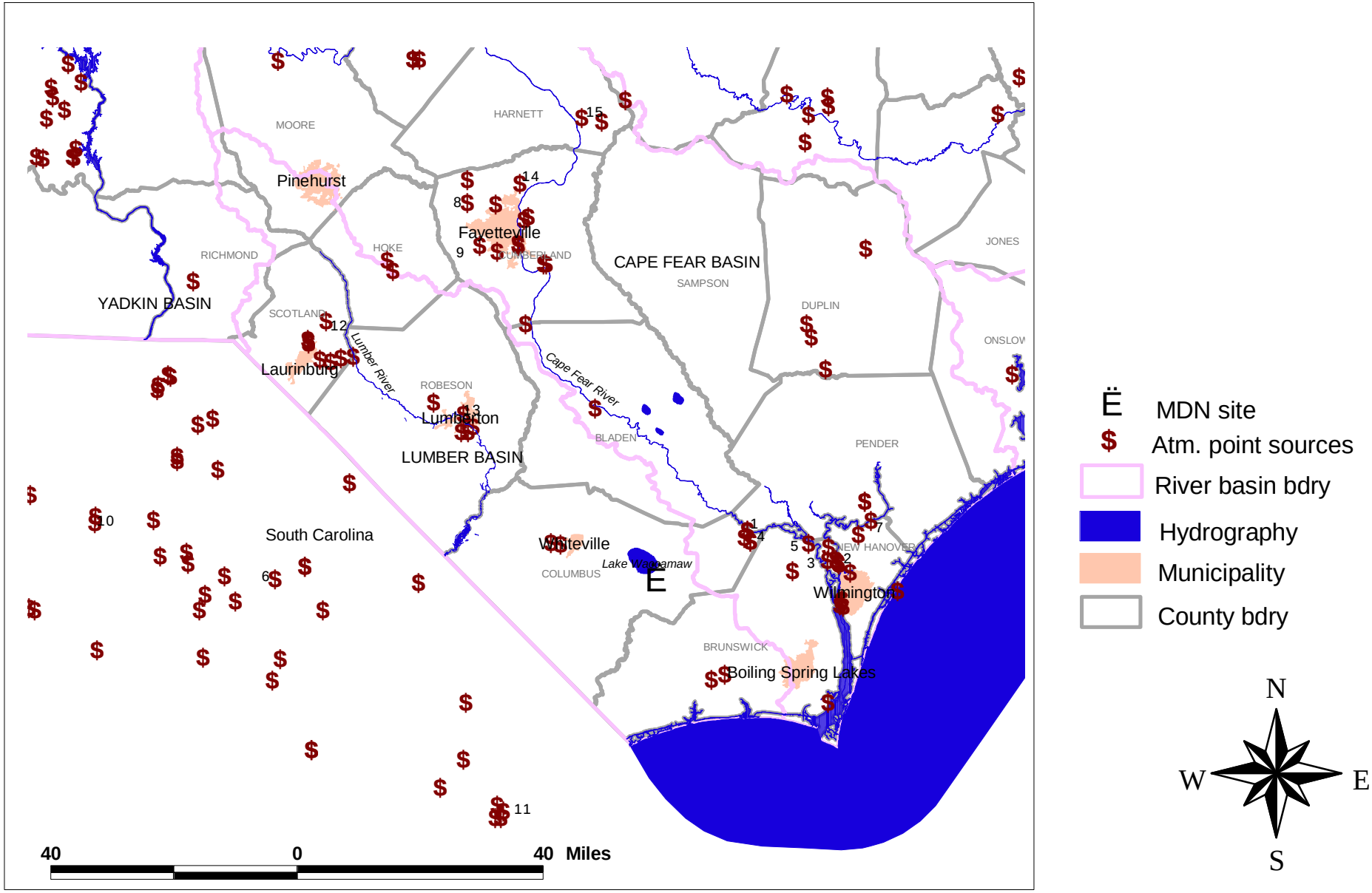


Figure 10. Atmospheric Mercury Concentrations at Waccamaw State Park, May 1998

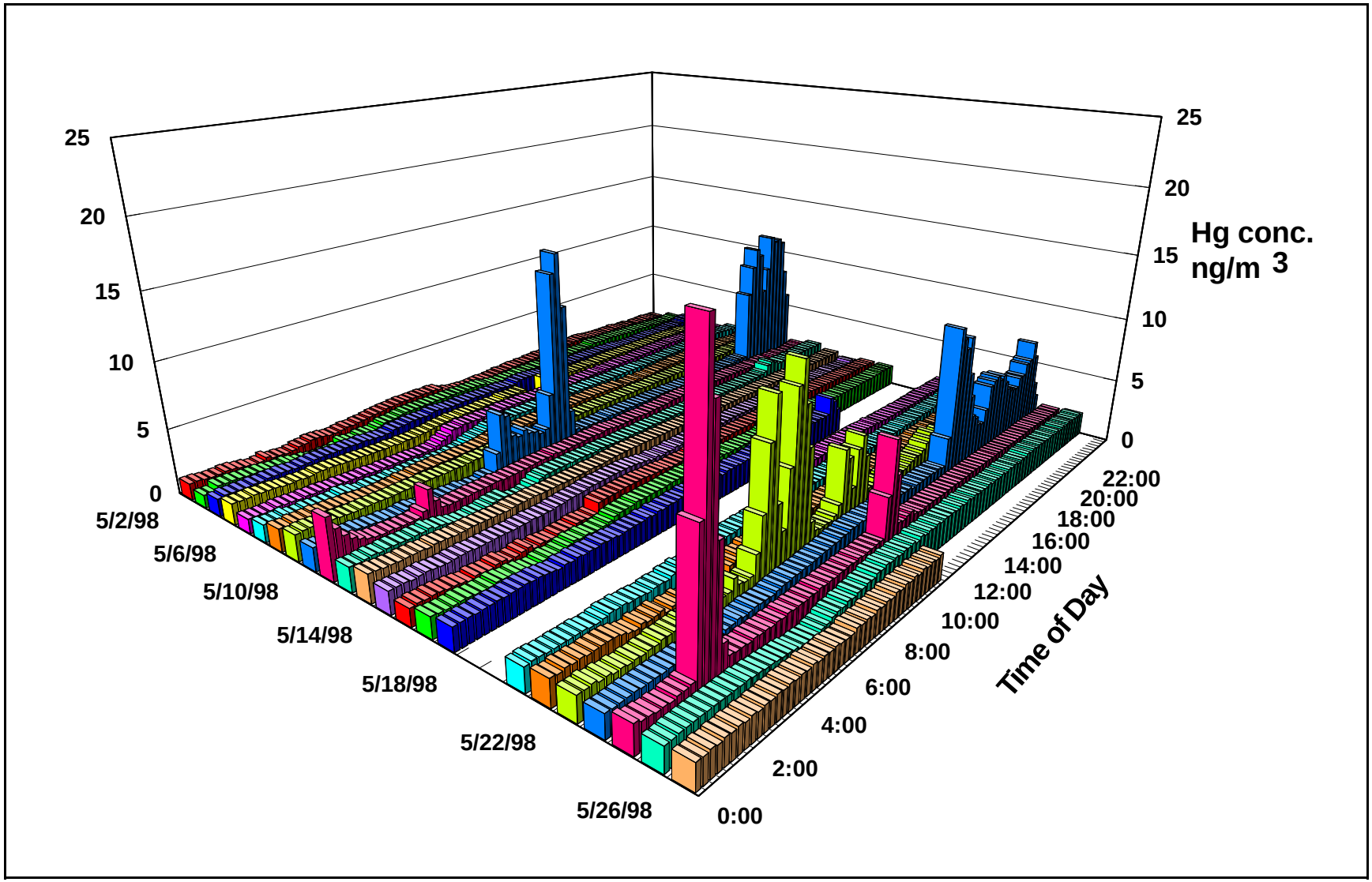
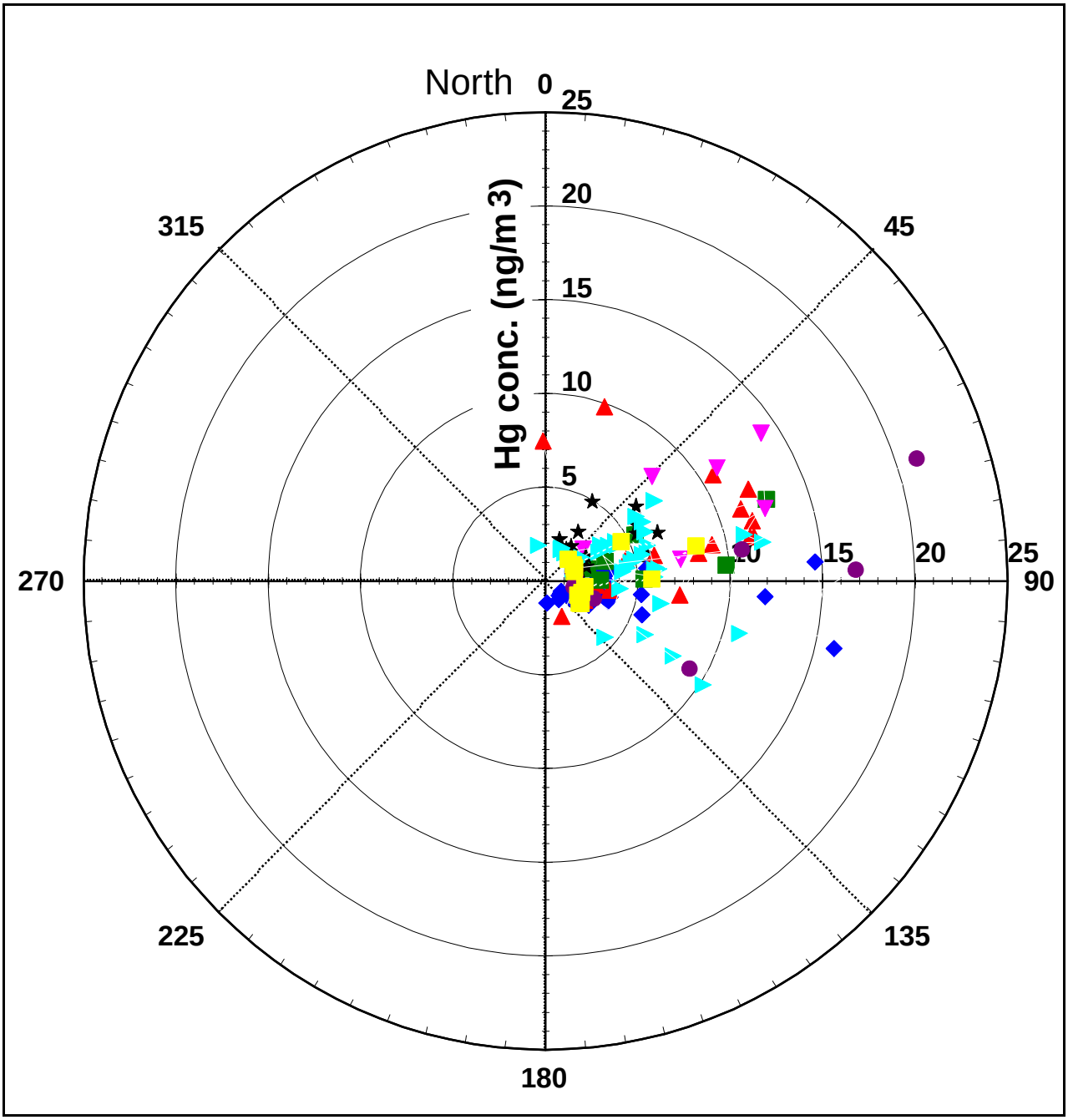


Figure 11. Wind Direction during Mercury Events at Waccamaw State Park, May 1998



the east and northeast (70 to 90-degree vectors). Atypical events have been observed from other directions but not with the frequency of ones from the east and northeast, though the prevailing winds are primarily from the southwest. Wilmington and Holtrachem Manufacturing Company are situated at approximately 90 and 75 degrees, respectively, from Waccamaw State Park. These representations of mercury concentrations in the atmosphere illustrate the influence of both globally transported mercury as well as an apparent local effect, likely from sources located east and northeast of the park. However, it is premature to directly relate atmospheric fluctuations of elemental mercury to wet and dry deposition. More information and measured data regarding the forms of mercury at Waccamaw State Park are needed prior to making this distinction.

Table 5. Local Facilities with Estimated 1996 Mercury Stack Emissions Greater than 10 lbs/year

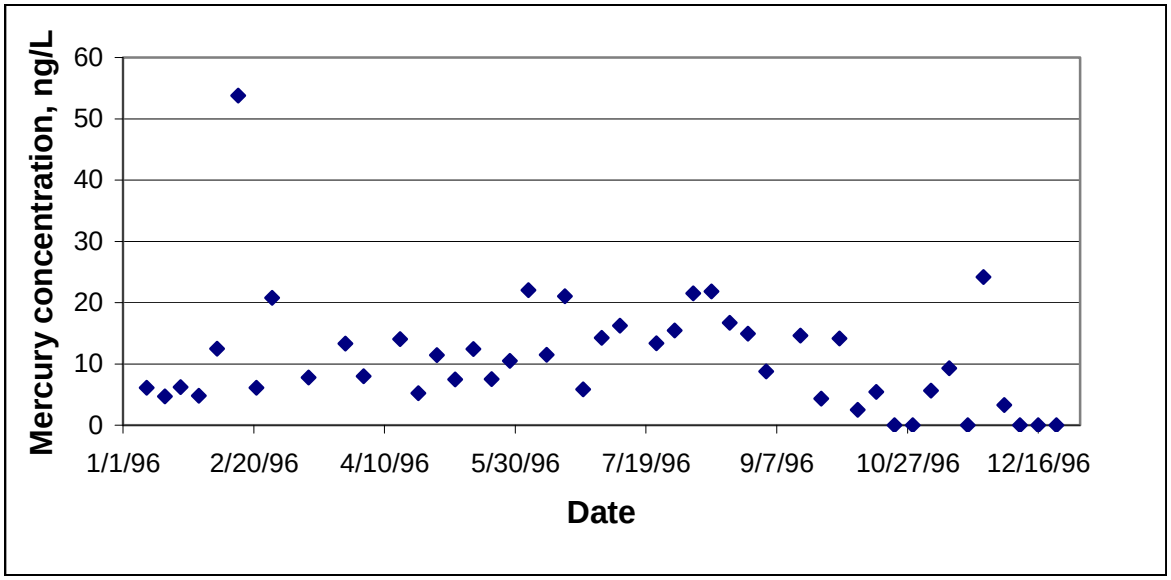
Figure ID	Facility ID	Facility Name	Emissions (lbs/year)	County, State
1	2400002	Holtrachem Manuf., CO., L.L.C.	1446.0	Columbus, NC
2	6500263	New Hanover Waste-to-Energy Facility	325.20	New Hanover, NC
3	6500036	CP&L Sutton Plant	97.00	New Hanover, NC
4	2400036	International Paper-Reigelwood	68.00	Columbus, NC
5	1000013	E.I. Dupont Company	62.00	Brunswick, NC
6	-	Stone Container, Florence	40.00	Florence, SC
7	6500055	Occidental Chemical Corp	30.52	New Hanover, NC
8	2600102	Fort Bragg Military	22.50	Cumberland, NC
9	2600014	Cape Fear Valley Med Center	20.00	Cumberland, NC
10	-	CP&L:Robinson	20.00	Darlington, SC
11	-	Santee Cooper:Grainger	20.00	Horry, SC
12	8300048	Westpoint Stevens-Wagram	18.40	Scotland, NC
13	7800087	Dyeing & Printing of Lumberton	15.00	Robeson, NC
14	2600050	Kelly-Springfield Tire Co.	14.50	Cumberland, NC
15	4300010	Swift Textiles Inc. Main Plant	12.79	Harnett, NC

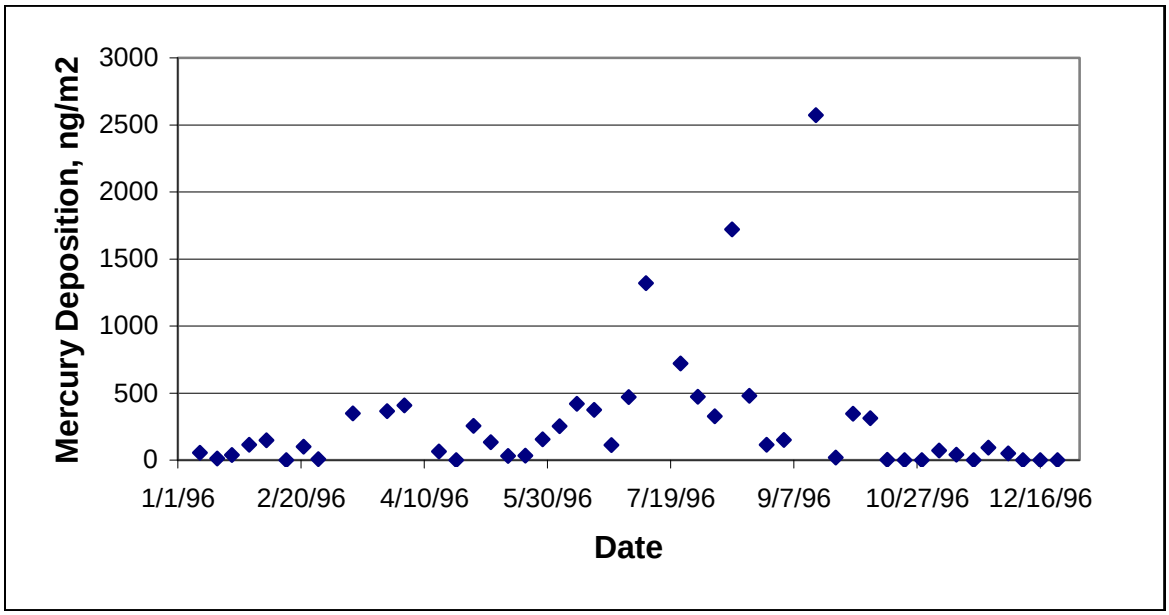
(a) Industry type based on primary reported SIC code.
(b) Data pooled from 1995 and 1997 inventories (SCDHEC 1999). The SCDHEC database contains emissions to 0.01 tons/year.

Wet deposition data from Waccamaw State Park have been collected since 1995 as part of the Mercury Deposition Network. As per the QA plans for the MDN, a total rainwater sample for a one-week period is collected on a weekly basis. This sample and additional rainfall monitoring hardcopy data are sent to a contract lab for analysis. The results are then relayed to a central MDN database for dissemination via quarterly reports back to the participating site coordinators and eventually to the MDN website (http://nadp.sws.uiuc.edu/mdn). A summary of mercury concentrations in rainwater and wet deposition data from January through December 1996 is shown in Figure 12. The mercury concentration in rainwater averaged approximately 12 ng/L[6]. The total wet deposition for 1996 was 12,700 ng/m^2 (12.7 µg/m^2). Figure 12 shows considerable evidence that a major source of mercury input to the Lumber and Waccamaw River

[6] This average mercury concentration in rainwater is equal to the water quality standard for ambient surface waters of North Carolina.

Figure 12. 1996 Waccamaw State Park Wet Deposition Data





Basins is atmospheric deposition. Additionally, Figures 10 and 11 provide suggestive evidence of a local source influence on atmospheric mercury vapor levels. Measured wet deposition rates and precipitation concentrations of mercury are consistently higher in this area than at a similar sampling site in northeastern North Carolina located at Pettigrew State Park (DAQ, personal communication). Whether the fluctuations in atmospheric elemental mercury vapor are in some way contributing to this pattern of elevated deposition still needs to be determined.

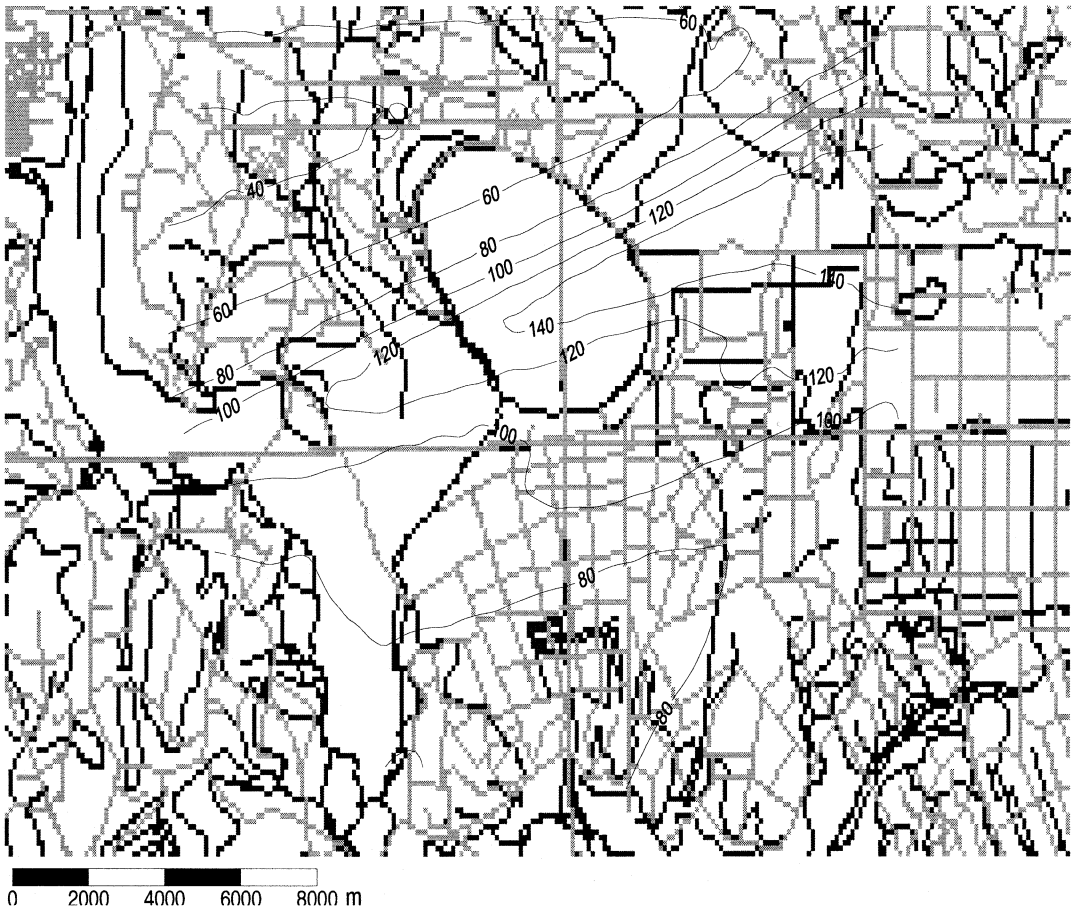
Dry deposition is not measured at either MDN site. Mercury that is deposited during dry weather is generally in the particulate phase, although recent literature indicates that reactive gaseous mercury (RGM) may also be deposited during dry weather. According to Lindberg et al. (1999), recent data from forests in Tennessee, Vermont, and Sweden suggest that dry deposition of mercury may exceed wet deposition by as much as a factor of two. In studies Lindberg et al. (1999) are conducting in the Florida Everglades, initial estimates of dry deposition during a typical March suggest that dry inputs of Hg will exceed wet. Thus, all of the above estimates of deposition may account for less than one-half of the total mercury deposition occurring at Lake Waccamaw.

USEPA- Office of Air Quality Planning and Standards (OAQPS) performed screening level dispersion and deposition modeling of mercury in the upper Waccamaw River Basin (EPA 1998). The refined gaussian plume model, ISCST3, was used to perform the analysis. DAQ provided USEPA with a database of atmospheric mercury emissions that was used to develop the dispersion and deposition model. Emissions within 50 km of Lake Waccamaw were used in the model[7]; non-permitted sources and emissions outside the 50 km radius were not included. The modeling suggests that approximately 85% of the deposition predicted at the center of Lake Waccamaw is due to emissions from the Holtrachem facility. The highest deposition rates were predicted to be in the northeast corner of the grid, closest to the Holtrachem facility, and within a portion the lake. The spatial variability of wet deposition is evident when the isopleths are plotted over a map of the area. For example, within Lake Waccamaw the model predicted deposition rates from 60 to 140 $\mu g/m^2$-year of divalent mercury deposition depending upon the location within the lake (Figure 13). A copy of the report is available in Appendix B. The divergent results of the model with the 1996 field data may be due to a number of reasons. These include the time frame considered (i.e., data is from 1996 and model is for 1991), the chemical speciation used in the model, and uncertain emissions estimates.

Waste sites. The North Carolina Division of Waste Management (DWM) maintains a database of inactive hazardous waste sites for the entire state and is currently working on electronic maps of these sites. Potential waste site sources of mercury were screened from the DWM database for Hoke, Moore, Scotland, Robeson, Bladen, Columbus, and Brunswick counties. Of the sites evaluated, only one site, the West Point Pepperell site (NCD045924032), identified mercury as a contaminant. Mercury was found above state and federal MCLs in groundwater at the West Point Pepperell site in Lumberton (Robeson County). However, these samples were collected at a time when clean techniques were not always observed, thus mercury samples may have been contaminated. This site is not believed to be a significant contributor of mercury to surface waters via groundwater.

[7] Fifty kilometers is the maximum recommended range for the ISCST3 model.

Figure 13. Estimated Wet Deposition of Divalent Mercury (Hg(II))in the Lake Waccamaw Vicinity (μg/m²) (EPA 1998)



Other sources. Mercury from the atmosphere may deposit on land or surface water. Thus, all surface waters will receive mercury directly from the atmosphere. A secondary source of mercury to surface waters comes from soil within the watershed. Mercury is naturally present in soils. Adriano (1987 as cited in Rule and Iwashchenko 1998) reported an arithmetic mean mercury concentration in soil of 0.112 mg/kg (912 samples), with geometric mean of 0.071 mg/kg. However, mercury concentrations in soil increase in response to mercury depositing from the atmosphere. For example, Rule and Iwashchenko (1998) reported significantly elevated levels of mercury, up to an order of magnitude higher than background, in surface soils within two kilometers of a former chloralkali plant in Virginia. Mercury deposited on surface soil, as well as mercury naturally present in soil, may be resuspended in runoff and transported to lakes and rivers. This indirect source of mercury may persist after atmospheric deposition of mercury is reduced.

Quantification of Mercury Sources

NPDES and atmospheric releases of mercury have been identified for the Lumber and Waccamaw River Watersheds. Ultimately, the total mercury load from each of these types of sources will be required to determine the best course of action to reduce mercury in the aquatic environment. For this analysis, the total load includes mercury from NPDES point sources, direct atmospheric deposition, and indirect mercury in overland runoff. Mercury from natural sources and urban stormwater was not estimated. This analysis is intended to demonstrate the relative magnitude of mercury that may reach the surface water. The results of this analysis will not be used to determine the load allocation portion of the TMDL.

The Waccamaw River Watershed was selected for the examination of total mercury loads because the atmospheric monitor is located within this basin at Waccamaw State Park. Two locations in the watershed were used to sum loads across media. The Lumber River was not included in this analysis because of the distance to the atmospheric monitor and the lack of NPDES effluent mercury data. These are White Marsh at US74/76 and Waccamaw River at Freeland. In Figure 8, the Waccamaw River at Freeland is the most upstream ambient site in the Waccamaw River. White Marsh enters the Waccamaw River from the northwest, upstream of the station at Freeland. Air quality is highly variable, even within a few kilometers, so application of the air concentrations and wet deposition loads from Waccamaw State Park to areas even 5 kilometers from the park introduces a great deal of uncertainty. In fact, the air quality can vary greatly even within a small river watershed, such as the Waccamaw River Basin within North Carolina. However, in the absence of additional data, mercury deposition data at Waccamaw State Park were applied to the entire Waccamaw River Basin. The following sections describe the calculation of loads for each source type.

NPDES Sources. The total annual load from point sources was determined for the only facility with an NPDES permit and mercury data in the Waccamaw River Basin, the Whiteville WWTP. Using 1996 and 1997 data from the discharge monitoring report (DMR), an average annual load of mercury was calculated for the facility. The average load of 500 g/year was calculated using one-half of the detection limit for non-detected concentrations. A summary of the DMR data are presented in Appendix B.

Direct Atmospheric Deposition. Rainwater falling directly onto surface waters is another pathway for mercury to enter the aquatic system. By multiplying the 1996 annual deposition rate of 12.7 $\mu g/m^2$ measured at the air monitoring site at Waccamaw State Park by the total surface area of the surface water body, an estimate of direct atmospheric deposition to White Marsh and Waccamaw River was made. For the White Marsh system, direct deposition was assumed to occur only on White Marsh. The segment of White Marsh upstream of US 74/76 has an average length of 28,800 meters and an average width of 9.7 meters as described in EPA's Reach File 1. Multiplying these two dimensions, the surface area evaluated is equal to $2.8x10^5$ square meters. The product of the surface area and the average annual deposition rate is 4 g/year. This is the average annual direct deposition load to White Marsh at US 74/75.

A similar calculation was made for the Waccamaw River at Freeland. The surface area was determined based on field measurements of the River. The Waccamaw River from the dam at Lake Waccamaw to the NC-SC State line is approximately 46 miles long. Below the dam the river is 12 to 14 meters wide; further downstream at NC 94 the river is approximately 30 meters wide. If the entire river receives atmospheric mercury from wet deposition at a rate of 12.7 $\mu g/m^2$-year, the total annual mercury load from direct deposition could be on the order of 20 g/year. However, the Waccamaw River at Freeland receives significant amounts of water from tributaries other than the Waccamaw River, including White Marsh, Lake Waccamaw (which is above the Waccamaw River), and Juniper Creek. The total surface area of these two major tributaries and the lake was used to calculate additional mercury loads due to direct atmospheric deposition. The surface areas of the tributaries and the estimated direct deposition loads are presented in Table 6.

Table 6. Estimate of Direct Deposition Loads to the Waccamaw River at Freeland

Stream/Lake	Surface Area (m^2)	Deposition Load (g/year)
White Marsh (a)	$5.4x10^5$	7
Lake Waccamaw	$3.6x10^7$	460
Juniper Creek	$1.7x10^5$	2
Waccamaw River	$1.6x10^6$	20
Total		*489(~500)*

(a) The surface area presented for White Marsh extends beyond US 74/76 to the mouth of the stream. When the entire stream surface area to the mouth is considered, the deposition is seven g/year.

Indirect Mercury in Runoff. The last pathway quantified is the mercury load in overland storm flow or runoff. The method used to calculate mercury loads in runoff is simplistic and assumes that all of the mercury in precipitation remains dissolved in water and does not partition to soil, plants, or sediment, or volatilize, prior to reaching the marsh. This method will overestimate the total amount of mercury reaching the marsh and is intended only as a screening method to help understand the relative magnitudes of mercury sources in the Waccamaw River Watershed.

For dissolved chemicals, Mills et al. (1985) presented two separate equations to determine the dissolved load, as follows:

$$LD = 0.1 * C_d * Q$$

and

$$Wld = LD * DA$$

where,

Wld	=	annual watershed dissolved pollutant load (kg/yr),
LD	=	dissolved loading function (kg/ha),
0.1	=	conversion factor,
C_d	=	concentration of dissolved pollutant in runoff (mg/L),
Q	=	annual average runoff from source area (cm), and
DA	=	drainage area (ha).

Combining these equations and calculating new conversion factors, the following equation determines dissolved mercury loads in runoff:

$$Wld = C_d * Q * DA * X$$

where,

Wld	=	annual dissolved mercury load to water body (g/year),
C_d	=	concentration of dissolved mercury in runoff (ng/L),
Q	=	annual average runoff from source area (cm),
DA	=	drainage area (m^2), and
X	=	conversion factor = 0.0259 (L-g/ng-cm-m^2)

For this estimate of the dissolved loading factor, the concentration of dissolved mercury in runoff was assumed to equal the concentration of mercury in rainwater; in 1996 the average mercury concentration in rainwater was 12 ng/L. Runoff estimates and drainage areas are available from many of the USGS gauging stations in the area. For the Waccamaw River near Freeland, the average annual runoff as reported in 1996 was 14.18 inches (36 cm) with a drainage area of 680 square miles (USGS 1996). There is no USGS gage at White Marsh, however the average annual runoff in the area ranged from 12.58 inches (32 cm) at Big Swamp near Tarheel to 18.78 inches (48 cm) at Drowning Creek near Hoffman. A mean runoff rate of 15.2 inches (38.6 cm) was used for White Marsh. Although there is no gage at White Marsh, USGS estimates the drainage area for White Marsh at US 74/76 to be 201 square miles. The indirect runoff mercury loads were determined to be 2,500 g/year at White Marsh and 7,700 g/year at Waccamaw River near Freeland.

Total Loads. In summary, the estimated total mercury loads to White Marsh at US 74/76 and Waccamaw River near Freeland were determined as the sum of the point source loads, the direct deposition loads, and the indirect runoff loads. The total loads are presented in Table 7.

Table 7. Summary of Estimated Mercury Loads to White Marsh and Waccamaw River (a)		
	End locations	
Source	White Marsh at US 74/76	Waccamaw River near Freeland
NPDES point sources	500	500
Direct atmospheric deposition	4	500
Indirect runoff	2,500	7,700
Total	*~3,000*	*~9,000*
(a) Loads reported in g/year.		

These estimates of mercury loads to the river are simplistic. The methods to calculate atmospheric related loads assume that rainfall in 1996 is typical, on a weekly basis, and that dry deposition does not occur[8]. Additionally, measurements of wet deposition at the Waccamaw State Park are not representative of what may occur further downstream on the Waccamaw River or in the Lumber River Watershed.

[8] In fact, 1996 is not a "typical" year since two hurricanes, Bertha and Fran, made landfall on the North Carolina coast, bringing a significant amount of rain.

ESTIMATES OF MAXIMUM ALLOWABLE MERCURY LOADS

Currently, the most sophisticated and comprehensive model of mercury cycling in the aquatic environment is the Mercury Cycling Model (MCM) developed by the Electric Power Research Institute (EPRI) and Tetra Tech. "The MCM mechanistically simulates the transport and transformations of mercury in natural waters based on the concept that aqueous chemical speciation governs the rates of these processes." (Hudson et al. 1994) This model requires large amounts of site-specific data to run and calibrate and has been successfully applied in a study of Wisconsin lakes. MCM was originally developed for lakes and impoundments, thus modeling riverine systems is not an option with this model[9]. MCM was not used to evaluate Pages, Pit and Watson lakes for several reasons, including the large amount of multimedia data required to run and calibrate the model, the limited usefulness of the model results, and the lack of measured mercury levels in the lakes. There is currently strong evidence identifying atmospheric deposition as a significant source of mercury in the surface water systems. Ambient monitoring data have demonstrated mercury concentrations in fish tissue in all levels of the aquatic food web and mercury has been detected in surface water only sporadically. While the MCM model would clarify mercury cycling in the lake systems, it would offer little towards load allocation since the primary source is atmospheric.

A simple mass balance equation was used to calculate the maximum daily load associated with an instream flow and target concentration. This equation is as follows:

$$C = \frac{W}{Q}$$

where

C	=	instream concentration of pollutant,
W	=	total allowable load of pollutant to the waterbody, and
Q	=	flow rate in waterbody.

There are many assumptions inherent in this simplistic equation. A major assumption is that the stream is at steady state; this implies that conditions in the stream are not changing with time. Additionally, this approach assumes that pollutants entering the waterbody remain suspended in the water column and do not deposit to sediment. While many metals dissolve readily in water, some forms of metals adhere to small particles floating in the water or larger particles depositing to the bottom of the waterbody. Losses of metals due to sedimentation are not considered using the above equation. Lastly, a select number of metals, including mercury, may exist in forms that could volatilize to the atmosphere. This loss of mercury also was not considered. The allowable load determined from the above equation is, therefore, a conservative estimate of the mercury load that may be assimilated by the water body.

To determine the maximum daily mercury load, a target instream concentration (C) equal to North Carolina's current mercury standard of 0.012 µg/L was used. This standard was derived

[9] EPA is currently modifying MCM for the Florida Everglades. When this model is calibrated and made publicly available it may provide additional pertinent information about mercury cycling in the Lumber and Waccamaw Watersheds.

from the lowest of three toxicological values, the Final Chronic Value (aquatic life based), Final Plant Value, and the Final Residue Value (fish tissue based). For mercury, the Final Residue Value (0.012 µg/L) is the lowest of the three values (EPA 1985). To determine the Final Residue Value, the FDA fish tissue action level of 1 mg/kg is divided by the bioconcentration factor (BCF) for the chemical. The BCF is one measure of the accumulation of a chemical in biota. In this case, a BCF is calculated by dividing the chemical concentration in fish by the chemical concentration in water. EPA (1985) cites bioconcentration factors ranging from 1,800 to 81,700 L/kg as a weighted average depending on the method of calculation and reference. A bioconcentration factor of 81,700 L/kg, based on the uptake of organic mercury by fathead minnows (*Pimephales promelas*), was used to determine the Final Residue Value.

Typically, maximum daily loads for non-carcinogenic substances are developed using a characteristic low flow such as the 7-day, 10-year low flow (7Q10) (15A NCAC 23 .0206). Average, 30Q2 and 7Q10 flows have historically been obtained from USGS for numerous stream locations throughout North Carolina. A summary of the allowable daily maximum mercury loads under average, 30Q2 and 7Q10 flows is shown in Table 8. Annual loads were determined by multiplying the mercury load based on an average flow by 365 days. In general, the allowable maximum annual mercury load for any of these waters ranged from 0 to 2 kg/year.

Data for the three lakes, Pit Lake, Pages Lake, and Watson Lake, are less readily available. Pit Links and Watson Lakes are private lakes that were sampled to support the Lumber basinwide fish consumption advisory. DWQ has no further physical, biological, or chemical information on either lake. Pages Lake has a surface area of 40 acres with a maximum depth of four meters. The lake is currently drained while repairs are made to the dam. USGS estimated an average flow from the Aberdeen Creek dam on Pages Lake as 17 cfs and a summer 7Q10 of 4.3 cfs. Using the same relationship shown above, an allowable mercury load of 200 g/year was determined.

Seasonality

Maximum allowable loads vary based on the season. During the late summer flows in the Lumber and Waccamaw River watersheds are typically much lower than average flows. This is shown in Table 8 by the 7Q10 summer and winter flows, which vary by season. Thus, the maximum allowable mercury load would also vary based on the flow rates. Table 8 also shows calculations of the daily loads based on average flows, and then based on summer and winter low flows. The summer critical conditions are when controls are most important, particularly in the more swampy areas where materials are not continually flushed from the system.

Seasonal considerations are also important with respect to the mercury cycle and the apparent seasonality of atmospheric loads. Mercury methylation generally occurs at warmer temperatures that would likely occur in the summer and early fall. This coincides with low flows. When mercury is deposited in swampy areas, mercury can be methylated and bioconcentrated in fish. When it rains, methylated mercury can move out of the swamps and into the rivers where it is available to other biota. As shown in Figure 14, the wet deposition of mercury appears to be highest in the summer (July-September). Tropical weather systems, bringing significant rainfall, typically occur during this period. In fact, in the summer of 1996 Hurricanes Bertha and

Table 8. Estimated Maximum Allowable Mercury Loads to Lumber and Waccamaw Watershed Impaired Streams

		Flows, cfs				Estimated Mercury Loads, g/day				Average
Water Body & location	Station	Average	30Q2	Summer 7Q10	Winter 7Q10	Average Flow	30Q2	Summer 7Q10	Winter 7Q10	Load, g (a)
Drowning Cr nr Hoffman	02133500	253	98	43.2	98.2	7	2.9	1.3	2.9	3000
Big Swp nr TarHeel	02134480	212		0.5		6	NA	0.0	NA	3000
Porter Swp at Mth at Fair Bluff, NC	0213451860	100	10	1.1	8.3	3	0.3	0.0	0.2	2000
Pages Lake (Aberdeen Creek at dam)	0213350700	17	9.6	4.3	9.7	0.5	0.3	0.1	0.3	200
Lumber R nr Maxton	02133624	430		92		12.6	NA	2.7	NA	5000
Lumber R at Boardman	02134500	1310	340	123	255	38.5	10.0	3.6	7.5	15000
Ashpole Swamp (b)	NA	96		14		2.8	NA	0.4	NA	2000
Big Creek upstream of mouth	NA			0		NA	NA	0.0	NA	NA
White Marsh Swp at US 74/76 nr Whitevill	0210910400	201	10	4.7	9.1	5.9	0.3	0.1	0.3	3000
Waccamaw R @ Freeland	02109500	710		0.7		20.8	NA	0.0	NA	8000
Waccamaw R bl NC 905 nr Pireway, NC	0211005650	980	48	2	6	28.8	1.4	0.1	0.2	11000

(a) Average load determined by multiplying the estimated mercury load under average flow conditions by 365 days.
(b) Flow obtained from Reach File 1 (RF1), not USGS.

Fran made landfall on the North Carolina coast resulting in significant mercury deposition events. Dry deposition rates in the region are unknown. A seasonal component to dry deposition may also be a consideration in the future.

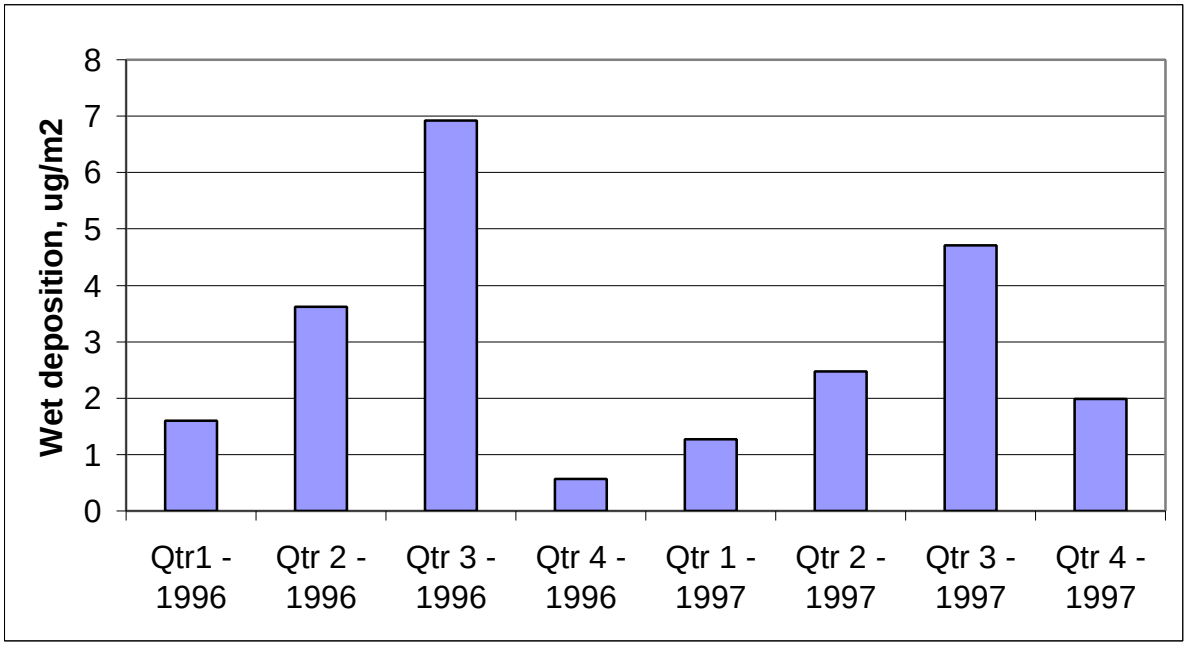


Figure 14. Seasonal Wet Deposition at Lake Waccamaw MDN Site

It is unknown how the high deposition events (i.e., late summer and tropical weather) and low flows in the area contribute to increased mercury methylation. It may be that mercury in the watershed is generally increased during tropical weather, but that a significant portion of the mercury transported to the watershed during such weather is moved out of the system and eventually to the ocean. It is more likely that dry deposited mercury retained in the swampy, low pH, anoxic areas is methylated during warmer weather and then accumulated by biota. Studies in the Everglades, Florida, may provide some insight to this process in the future.

Effluent mercury levels do not appear to be seasonal, as shown in Figure 15. However, if the critical time for mercury methylation is during the summer, then mercury loads during the summer would also be more critical. Based on known information and data, summer low flow loads should be used as the total maximum daily loads. If additional information becomes available at a later date, the TMDL should be reevaluated.

Uncertainties

There are two major sources of uncertainty associated with the mercury load for the Waccamaw River. They are 1) the method used to calculate the load, and 2) the target concentration, North Carolina's mercury standard.

The mercury cycle in the environment is still not completely understood. In addition to the simple mechanisms of transport of mercury from one medium to another, the chemistry of mercury affects the disposition. Mercury is present in the environment in three different forms:

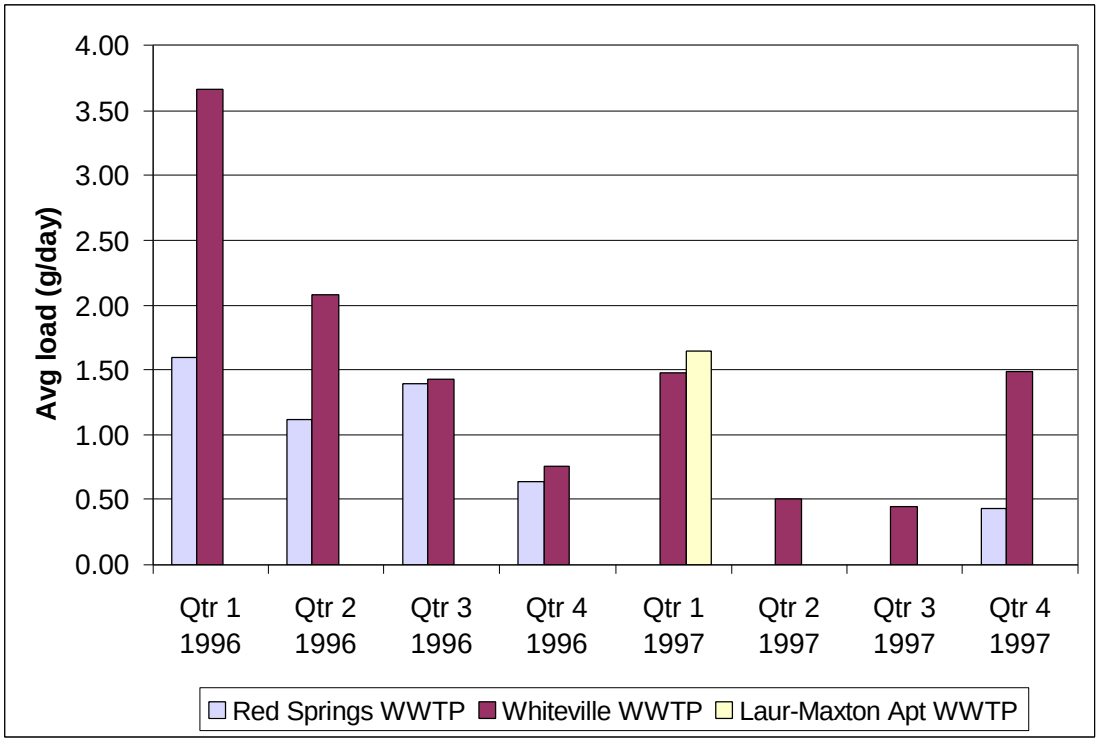


Figure 15. Seasonal NPDES Loads

metallic, organic, and inorganic. Organic mercury includes methylmercury, which is the form of greatest concern.

Generally, mercury is not in an organic form when it enters the aquatic environment, but undergoes a transformation from inorganic mercury to organic or methylmercury in either the water column or sediment. Mercury present in inorganic or metallic forms is not accumulated to a significant degree by biota (EPA 1997b), and may remain in the water column. Alternatively, under the correct environmental conditions, mercury may transform to methylmercury and accumulate in the bodies of invertebrates and fish. Nearly 100% of the mercury that accumulates in fish is methylated (EPA 1997b). The properties of methylmercury allow the accumulated chemical to be transferred up the food chain. Therefore, each level of the food web accumulates mercury from its diet and passes the burden along to animals in higher levels of the food chain (EPA 1994). Top consumers in the food web may accumulate methylmercury at levels millions of times greater than the concentrations present in surface waters (EPA 1994).

Mathematical models of mercury in the environment are still in the testing phases. Due to the complexities of the mercury cycle and the state of science regarding measurement of mercury in environmental media, models that have been developed are not easily calibrated or verified (e.g., EPRI's Mercury Cycling Model). However, if the TMDL requires reevaluation in the future, such models will be considered for use if chemical techniques have improved and more data is available. Thus, a simple mass balance model was used to estimate the maximum potential load

to the Waccamaw River. This model does not account for the various forms of mercury, nor does it account for the uptake into fish. That portion of the calculation is assumed within the target concentration, the mercury standard (discussed below). The mass balance technique used above is conservative in that a 7-day 10-year low flow (7Q10) was used to derive the target load. The theoretical margin-of-safety associated with the TMDL is primarily due to the use of the summer 7Q10 to derive loads.

The target concentration used to develop the mercury load is based upon the USEPA Ambient Water Quality Criteria (AWQC) for mercury. It has been assumed that the attainment of the instream water quality criteria, North Carolina's mercury standard, will result in acceptable fish tissue levels. However, there is some question regarding the ability of this standard to account for mercury levels in fish and, thus, adequately protect aquatic life and human health. For example, Eisler (1987) notes that EPA's recommended mercury criteria for the protection of freshwater aquatic life of 0.012 µg/L offers only limited protection to freshwater ecosystems. Zillioux et al. (1993) offers a more detailed explanation of the BCF used to derive the water quality standard. According to Zillioux et al. (1993), recent improvements have been made in sample collection, handling, and processing that have resulted in better and more accurate measurements of mercury in water. These new improvements have resulted in new BCF estimates for methylmercury generally exceeding 1 million, in comparison to the 81,700 BCF discussed above and used to develop the AWQC. However, Lindqvist et al. (1991) highlights the importance of the food web as the main mercury intake vehicle, not water. Thus, a bioaccumulation factor (BAF) may be more suitable than a BCF since a BAF accounts for uptake from food and filtering, as well as water. The use of a BAF would lower the instream standard significantly below the current standard of 0.012 µg/L.

Margin of Safety

An additional margin of safety may be applied to the TMDL. The method used to calculate the allowable load is inherently conservative and normally includes a margin of safety due to the conservative nature of the calculation. Additionally, the use of the 7Q10 flow also increases the margin of safety. However, the complexity of the fate and transport of mercury as well as the generation of methylmercury contribute significantly to the uncertainty of the TMDL. Although the water quality standard and TMDL are written in terms of total mercury, the ultimate goal is the reduction of mercury in fish. Methylmercury levels are more significant to mercury concentrations in fish. Ideally, a ratio of total mercury to methylmercury could be used as a basis for the margin of safety. However, in the absence of such a ratio, an uncertainty factor of 10 was applied to the summer 7Q10 concentrations to develop the TMDL. The use of this uncertainty factor results in a margin of safety of 90 percent.

There are many data gaps associated with mercury in the Lumber River Basin, thus a simplified method of determining the TMDLs was used. The DWQ will update the TMDL when better information is available. There is an inherent margin of safety in using a phased approach. A schedule outlining tasks for the second phase of the TMDL is included in Appendix E.

WASTE LOAD AND LOAD ALLOCATIONS

Maximum allowable mercury loads equal to the load during summer 7Q10 conditions were calculated for a variety of waters in the Lumber and Waccamaw River Watersheds; these loads ranged from 0.02 to 6 g/day, as shown in Table 9. These maximum allowable mercury loads are significantly less than the estimated mercury loads in the Waccamaw River watershed of 3,000 to 9,000 g/year of mercury.

Monitoring by the Division of Air Quality suggests that atmospheric mercury concentrations at Waccamaw State Park can be interpreted from both a global pool and local sources of mercury. However, it is impossible to estimate the mercury load due to local atmospheric sources without the use of a regional air dispersion and deposition model that considers the input from within and outside the local airshed. EPA is currently developing a regional air quality model for mercury that encompasses the entire United States. Multiple scenarios are being evaluated using the regional air quality model, including the effects of various emissions reductions. The Mercury Report to Congress (EPA 1997b) lists initiatives under the Clean Air Act that may reduce atmospheric mercury emissions from industrial sources. Currently the most significant of these initiatives is the promulgation of emission limits for municipal waste combustors and medical waste incinerators. Other initiatives involve further study of controls on various industries. The results of this model and the emissions reduction scenarios are anticipated to be available within the next year. The results of base case and reduction scenarios will be incorporated into the Phase II TMDL. Modeling results may indicate that a significant portion of the mercury load to the Lumber and Waccamaw River watersheds is not due to local sources. In this case, EPA would be needed to assist in mercury emissions reductions across state boundaries.

The State of North Carolina alone cannot eliminate the atmospheric deposition of mercury over surface waters. Actions for reducing the global pool of atmospheric mercury need to be developed at the national and international levels in order to be effective. However, some local sources of atmospheric mercury are in and surrounding the Lumber and Waccamaw River Watersheds. As previously stated, the Holtrachem facility, which was the largest emitter in the region, is changing to a process that will reduce mercury emissions to negligible levels. Other facilities should also be encouraged to reduce mercury emissions, particularly those facilities listed in Appendix A that have the highest level of emissions.

Current and future NPDES point sources in the Lumber and Waccamaw River Watersheds should not be allowed to increase the total mercury already present in the system. Therefore, less than detectable (based on North Carolina's currently accepted measurement standards) mercury levels in point source discharges to the systems should be allowed until the TMDL is revised. During this permit cycle, limits will be issued to facilities that have detected mercury in effluent in recent years. Other facilities may be asked to monitor effluent for mercury. Table 9 indicates that forty percent of the calculated loads have been allocated to point sources. The remaining allowable load (i.e., 60%) would be allocated to nonpoint sources, including atmospheric deposition and runoff. The allocation ratio may change depending upon implementation issues in Phase II. Proposals for Phase II can be found in Appendix E.

Table 9. Initial Mercury Allocations to Lumber and Waccamaw Watershed Impaired Streams

Water Body & location	Station	TMDL (a) (g/day)	Waste Load Allocation (%)	Waste Load (g/day)	Load Allocation (%)	Load (g/day)
Drowning Cr nr Hoffman	02133500	0.1	40%	0.04	60%	0.06
Big Swp nr TarHeel	02134480	0.001	40%	0.0004	60%	0.001
Porter Swp at Mth at Fair Bluff, NC	0213451860	0.003	40%	0.001	60%	0.002
Pages Lake (Aberdeen Creek at dam)	0213350700	0.01	40%	0.004	60%	0.01
Lumber R nr Maxton	02133624	0.3	40%	0.1	60%	0.2
Lumber R at Boardman (b)	02134500	0.4	40%	0.2	60%	0.2
Ashpole Swamp	NA	0.04	40%	0.02	60%	0.02
Big Creek upstream of mouth	NA	0.00	40%	0.0	60%	0.000
White Marsh Swp at US 74/76 nr Whiteville (c)	0210910400	0.01	40%	0.004	60%	0.01
Waccamaw R @ Freeland	02109500	0.002	40%	0.001	60%	0.001
Waccamaw R bl NC 905 nr Pireway, NC	0211005650	0.01	40%	0.004	60%	0.006

(a) TMDL is equal to one-tenth of the maximum daily allowable load for summer 7Q10 conditions.
(b) The Red Springs WWTP discharge to Raft Swamp enters the Lumber River above this station.
(c) The Whiteville WWTP discharge enters above this station.

SUMMARY

A basinwide fish consumption advisory was issued in 1994 after mean concentrations of mercury in largemouth bass and bowfin from multiple locations were generally greater than the Food and Drug Administration (FDA)/North Carolina action level for mercury of 1 mg/kg. The fish consumption advisories are the problem that necessitated placing waters on North Carolina's 303(d) list.

In Phase I of the TMDL document, a dilution equation (i.e., mass balance) was used to determine the maximum allowable loads for each water body. Based on these TMDLs, allocations were made to NPDES and atmospheric deposition/nonpoint sources. Generally, NPDES dischargers will not be allowed to increase the mercury pool to the system. The majority of the allocation was given to atmospheric deposition/nonpoint sources. Even with the restrictions on NPDES point sources and atmospheric emission sources, mercury levels in Lumber and Waccamaw River fish are not likely to change appreciably over the next several years. A significant amount of mercury is likely present in sediment and soils in the Lumber and Waccamaw River Basins, providing a continued source of mercury to the water column and fish. Thus, after national and international reductions in mercury emissions have been realized, mean mercury levels in fish tissue may take many subsequent years to fall below the FDA/NC criteria. Monitoring of the water column and fish tissue will continue to be performed to quantify reductions of mercury in the aquatic environment. Efforts should be made to educate the public in and around the Lumber and Waccamaw River watersheds with regards to mercury pollution.

The Phase I TMDL was publicly noticed with the Lumber River Basin Plan in Early 1999. Comments were accepted until March of 1999. Copies of the notice and comments received are provided in Appendix D. Phase II of the TMDL will incorporate regional air quality modeling results from EPA Office of Air Quality Planning and Standards and provide a more detailed mercury cycling model for a portion of the Waccamaw River Watershed. Phase II of the TMDL will also include implementation programs for atmospheric and NPDES mercury reductions, as described in Appendix E.

REFERENCES

Adriano, D. 1987. Trace elements in the terrestrial environment. Springer-Verlag, New York

Björnberg, A., L. Håkanson, and K. Lundbergh. 1988. A Theory on the Mechanisms Regulating the Bioavailability of Mercury in Natural Waters. Environmental Pollution 49:53-61

Bloom, N., Watrax, C., and J. Hurley. 1991. Impact of Acidification of the Methylmercury Cycle of Remote Seepage Lakes. Water, Air, and Soil Pollution. 56:477-491

Eisler, R. 1987. Mercury Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. U.S. Department of the Interior, Fish and Wildlife Service, Biological Report 85(1.10). 90 pp.

Gilmour, C. 1995. Mercury Methylation in Fresh Waters. National Forum on Mercury in Fish: Proceedings. USEPA Office of Water. EPA823-R-002. June

Hudson, R. J., S. Gherini, C. Watras, and D. Porcella. 1994. Modeling the Biogeochemical Cycle of Mercury in Lakes: The Mercury Cycling Model (MCM) and its Application to the MTL Study Lakes. In *Mercury Pollution: Integration and Synthesis.* Watras, C. and Huckabee, J., Eds., Lewis Publishers, Chelsea, MI

Lindberg, S.E., W. Stratton, H. Zhang, and K. Roy. 1999. Preliminary Data Summary Report. FEDDS 99 Winter Campaign (Florida Everglades Dry Deposition Study). Summary of ORNL Field Studies in Collaboration with UMAQL, Florida DEP, and USEPA. Oak Ridge National Laboratory.

Lindqvist, O., K. Johansson, M. Aastrup, A. Andersson, L. Bringmark, G. Hovsenius, L. Håkanson, Å. Iverfeldt, M. Meili, and B. Timm. 1991. Mercury in the Swedish Environment — recent research on causes, consequences and corrective methods. Water, Air, & Soil Pollution. 55:i-261

Mills, W., D. Porcella, M.J. Ungs, S. Gherini, K. Summers, L. Mok, G. Rupp, and G. Bowie. 1985. Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water. Part 1. EPA 600/6-85/002a. September. U.S. Environmental Protection Agency, Environmental Research Laboratory. Athens, GA

North Carolina Division of Environmental Management (NCDEM). 1982. As Assessment of Mercury in North Carolina. Prepared by the Water Quality Section.

North Carolina Department of Environment, Health, and Natural Resources (NCDEHNR). 1994. Lumber River Basinwide Water Quality Management Plan. Prepared by the Division of Environmental Management, Water Quality Section.

Rule, J.H. and M.S. Iwashchenko. 1998. Mercury Concentrations in Soils Adjacent to a Former Chlor-Alkali Plant. J. Environ. Qual 27:31-37

South Carolina Department of Health and Environmental Control (SCDHEC). 1999. Personal communication with Scott Reynolds, Bureau of Air. September 29, 1999

U.S. Environmental Protection Agency (EPA). 1985. Ambient Water Quality Criteria for Mercury – 1984. EPA 440/5-84-026

U.S. Environmental Protection Agency (EPA). 1991. Guidance for Water Quality-Based Decisions: The TMDL Process. Assessment and Watershed Protection Division, Washington, DC

U.S. Environmental Protection Agency (EPA). 1994. Deposition of Air Pollutants to the Great Waters. First Report to Congress. EPA-453/R-93-055. May. Office of Air Quality Planning and Standards, Research Triangle Park, NC

U.S. Environmental Protection Agency (EPA). 1995a. Great Lakes Water Quality Initiative Criteria Documents for the Protection of Wildlife. DDT, Mercury, 2,3,7,8-TCDD, PCBs. EPA 820-B-95-008. March. Office of Water, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1995b. Great Lakes Water Quality Initiative Technical Support Document for the Procedure to Determine Bioaccumulation Factors. EPA-820-B-95-005. March. Office of Water, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1997a. Mercury Study Report to Congress. Volume I: Executive Summary. EPA-452/R-97-003. December. Office of Air Quality Planning and Standards and Office of Research and Development, Research Triangle Park, NC

U.S. Environmental Protection Agency (EPA). 1997b. Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment. EPA-452/R-97-005. December. Office of Air Quality Planning and Standards and Office of Research and Development, Research Triangle Park, NC

U.S. Environmental Protection Agency (EPA). 1998. Preliminary Dispersion Modeling Analysis of Local Mercury sources in the Lake Waccamaw Vicinity. Office of Air Quality Planning and Standards. Research Triangle Park, NC.

U.S. Environmental Protection Agency, Federal Advisory Committee (FACA). 1998. Draft final TMDL Federal Advisory Committee Report. 4/24/98

U.S. Geological Survey (USGS). 1996. Water Resources Data for North Carolina. Water Year 1996. Volume 1. Surface Water Records. Report NC-96-1

U.S. Geological Survey (USGS). 1998. Personal communication with Curtis Weaver, USGS, February 18, 1998.

Winfrey, M and J. Rudd. 1990. Review. Environmental Factors Affecting the Formation of Methylmercury in Low pH Lakes. Environ Toxic. and Chem. 9:853-869

Zillioux, E.J., D.B. Porcella, and J.M. Benoit. 1993. Mercury Cycling and Effects in Freshwater Wetland Ecosystems. Environmental Toxicology and Chemistry. 12(12):2245-2264