PCB's reach the environment in several ways including industrial effluents, landfills, and equipment storage sites. PCB's bond tightly with particulate matter, which enables PCB's to be resuspended in lakes and streams. This resuspension has been documented to occur for up to 15 years and is indicative of the slow degradation of PCB's (Eisler, 1986).

PCB's were detected at 78 percent of the sites sampled (fig. 13) between 1985 and 1998. Concentrations of PCB's ranged from 0.1 to 85 mg/kg in fish fillet samples and were detected at 63 of the 75 sampling sites in the LTEN River Basin (table 1). Fourteen samples that exceeded the 2.0 mg/kg action level were collected between August 1985 and March 1987. Fish fillet samples collected at some sites after this time period had levels of PCB's that were below the action level. Concentrations of PCB's in whole fish ranged from less than 0.05 to 0.30 mg/kg. Whole fish samples did not have the high detection percentage of fish fillets, but were detected at 3 of the 10 whole fish sampling stations. Two samples exceeded the NYDEC criteria of 0.13 mg/kg (Newell and others, 1987). When compared to the data collected by Schmidt and others (1990), the detection percentage for total PCB's is similar with 90 percent of the 117 NCBP sampling sites having detections of PCB residues. According to Schmidt and others (1990), this percentage has remained steady since the mid-1970's. Mean concentrations of total PCB's for the same NCBP data, however, have declined significantly when comparing data from the mid-1970's to data of the early-1980's. Currently (2000), fish consumption advisories are in effect for Woods Lake and Nickajack Lake as a result of PCB contamination (Tennessee Department of Environment and Conservation, 2000).

OCCURRENCE AND DISTRIBUTION OF TRACE ELEMENTS IN FISH TISSUE

Trace elements in the aquatic environment are derived from human activities and from natural geologic processes. Human activities that lead to the introduction of trace elements in the water column, and subsequently to aquatic organisms, include fossil-fuel combustion (coal-fired generating plants), discharges from point and non-point sources, emissions from automobiles, mineral and strip mining, textile and smelting operations, and agricultural application of fertilizers and pesticides. Coal-fired power generation contributes trace elements to the environment when fly ash containing concentrations of trace elements becomes airborne and then settles on the land, rivers, streams, and reservoirs to become part of the water column and the sediment layer. In addition to airborne precipitate, fly ash has historically been used to surface roads, make soap, and produce charcoal (Sorenson, 1991). Stream channels cutting through formations that contain high amounts of trace elements, as well as eroding rocks and soils, can transport trace elements into the aquatic environment.

Fish fillet samples were analyzed for 10 trace elements at 102 sites in the LTEN River Basin between 1980 and 1996. Trace elements without an available action level for comparison include chromium, copper, lead, nickel, silver, and zinc. The information used for comparison included FDA action levels (U.S. Food and Drug Administration, 1989) and U.S. EPA screening criteria (U.S. Environmental Protection Agency, 1995). The trace element data discussed in this report are based on fish fillet samples collected by the TVA from 1980 through 1996. Arsenic, mercury, cadmium, and selenium are the only trace elements listed on the U.S. EPA Priority Pollutant List (U.S. Environmental Protection Agency, 1994) that have existing action levels (table 2). Generally, trace elements were detected in the highest concentrations in reservoirs, such as Wheeler and Wilson, along the main stem of the Tennessee River.

Application of herbicides used as defoliants also can contribute to the presence of trace elements. Defoliants are used to desiccate leaves from plants prior to harvesting to reduce the amount of leaf debris in harvesting equipment. Arsenic used in defoliants is usually in the form of arsenic acid (H_3AsO_4). In the 1940's, arsenic was used not only to desiccate crops for harvesting but also to reduce the amount of vegetation (water lilies, bulrushes, and other rooted plants) in reservoirs. Studies have shown that arsenic was still present in reservoirs as many as 13 years after application was discontinued (Sorenson, 1991). Concentrations of arsenic in fish fillet samples (fig. 14) ranged from 0.02 to 0.38 µg/g with no sample having a concentration higher than the 3.0 µg/g screening criteria (table 2). Arsenic was detected in fish fillets at 45 of the 102 sampling sites.

Mercury is a naturally occurring element present in the Earth's crust throughout the world. Various manufacturing processes and agricultural chemicals have increased the mercury levels in surface water, and subsequently, in the tissue of fish that feed

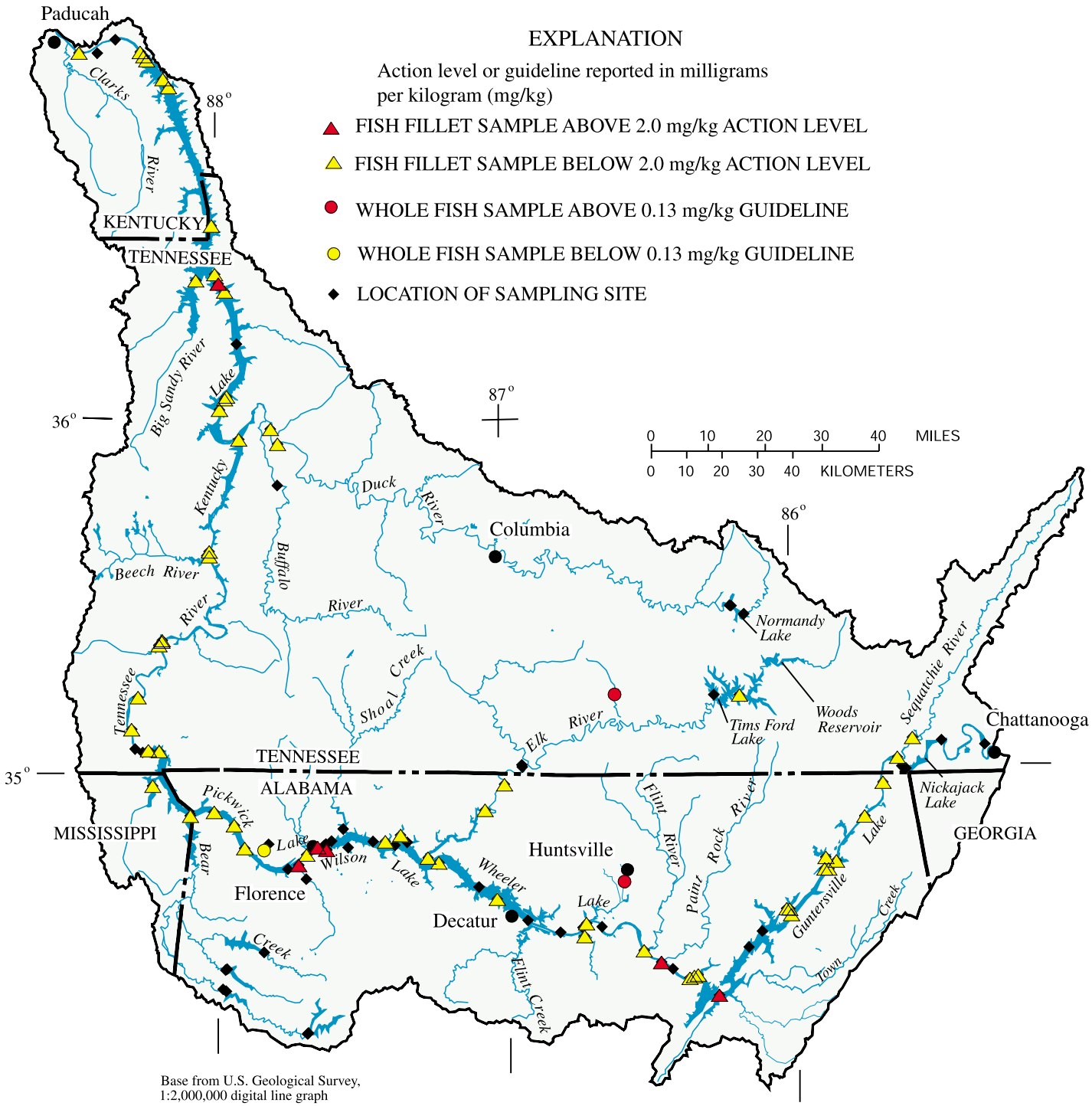

Figure 13. Location of sampling sites with detections of PCB's in fish tissue in the lower Tennessee River Basin, 1980-98.

Table 2. Summary of trace elements in fish fillet samples collected in the lower Tennessee River Basin, 1980-96

[Trace elements in **bold** were detected at or above established action levels; µg/g, microgram per gram; ---, no information]

Compound	Number of samples	Number of detec-tions	Number of sites sampled for contaminant	Number of sites with detec-tions	Range of data (µg/g)	Action level (µg/g)	Number of sites with detections above lowest action level
Arsenic	397	71	102	45	0.02 - 0.38	[a]3.0	0
Cadmium	397	138	102	55	.002 - .5	[a]10.0	0
Chromium	397	153	102	56	.02 - 2.6	---	---
Copper	397	103	102	55	.2 - 5.6	---	---
Lead	397	147	102	69	.02 - 3.0	---	---
Mercury	**397**	**108**	**102**	**51**	**.11 - 5.0**	**[a]0.6/[b]1.0**	**8**
Nickel	397	10	102	7	1.0 - 9.0	---	---
Selenium	397	185	102	70	.05 - .71	[a]50.0	0
Silver	397	0	102	0	---	---	---
Zinc	397	220	102	79	3.0 - 46.0	---	---

[a]U.S. Environmental Protection Agency screening criteria for protection of human health. Based on 1 X 10^{-5} risk factor for an average-sized adult (70 kg) and a consumption of 6.5 grams of fish per day (U.S. Environmental Protection Agency, 1995).

[b]Food and Drug Administration legal limit for removing fish from marketplace (U.S. Environmental Protection Agency, 1992).

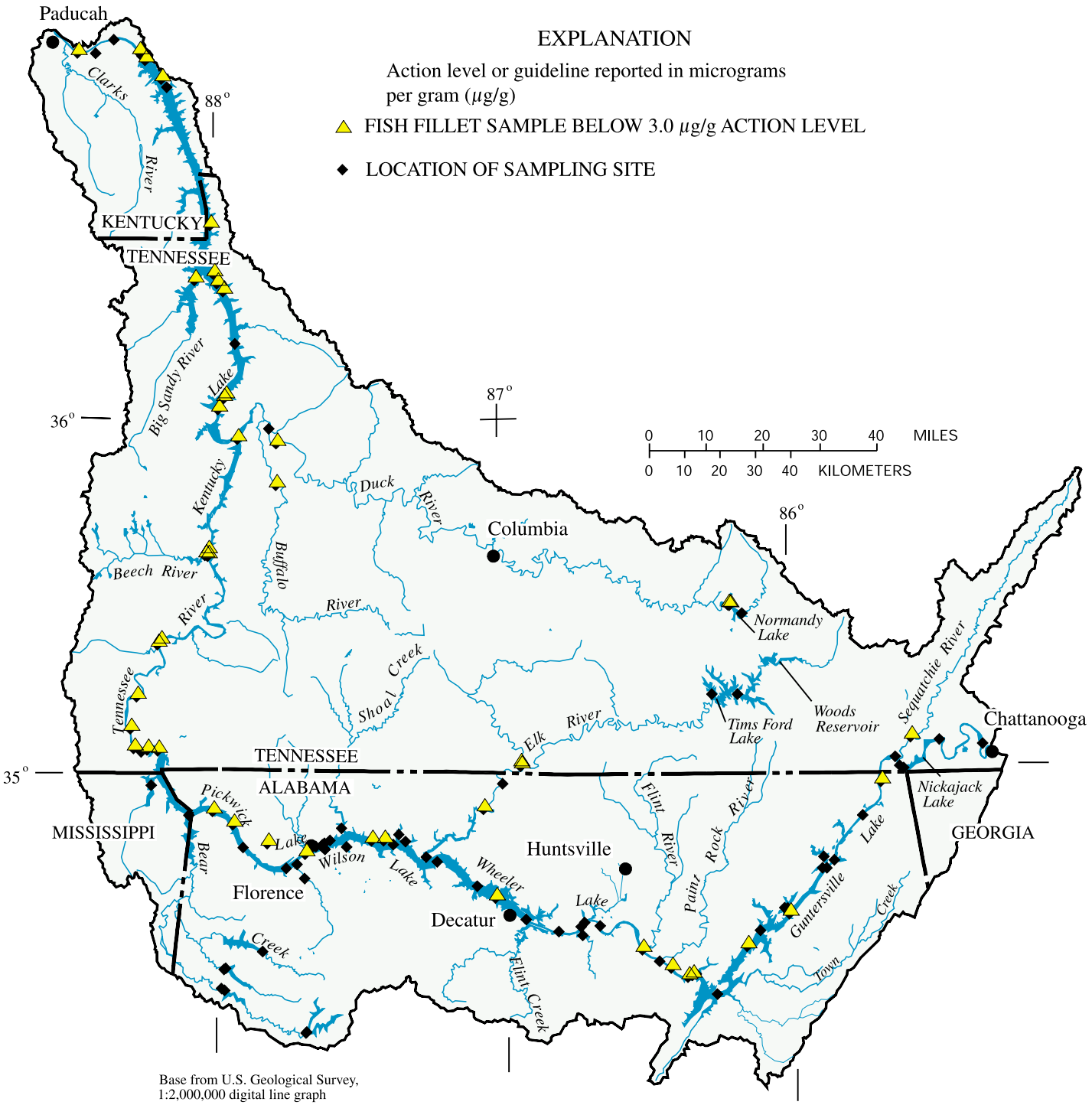

Figure 14. Location of sampling sites with detections of arsenic in fish tissue in the lower Tennessee River Basin, 1980-96.

in our streams and rivers. Until the early 1970's, the process of electrolysis was one of the main sources of mercury in surface water. After the use of electrolysis diminished, the primary source of mercury was the burning of fossil fuels and smelting. This latter source may have lead to the increased background levels of mercury worldwide (Hem, 1989). Other possible sources of mercury include slimicides used to control fouling of mechanical pumps, preservation of wood fiber at paper plants, the manufacture of plastics and electronics, and biocide use to control mold on seed grain. Elevated mercury concentrations in fish tissue in northwestern Alabama (fig. 15) are the result of industries located along the main stem of the Tennessee River (Don Dycus, Tennessee Valley Authority, oral commun., 2000). Methylated mercury, considered to have the highest toxicity of mercury compounds, is the most bioavailable form of mercury (Eisler, 1987); however, data presented in this report describe total mercury concentrations. Mercury was detected in fish fillets at 51 of 102 sampling locations with concentrations ranging from 0.11 to 5.0 µg/g (table 2). Mercury concentrations were higher than the 0.6 µg/g U.S. EPA screening criteria in 62 samples and at 8 sites (fig. 15 and table 2).

Concentrations of cadmium in fish tissue varies and depends on fish species. In a study conducted by Murphy and others (1978), 11 fish species from an industrially polluted lake showed that piscivorous fish (black crappie and largemouth bass) tended to have lower cadmium levels than did omnivorous fish (warmouth and bluegill). Higher levels of cadmium were found in redear sunfish (*Lepomis microlophus*), which consumed considerably higher amounts of benthic macroinvertebrates from the cadmium-rich sediment than do other omnivores (Murphy and others, 1978). In the LTEN River Basin, cadmium (fig. 16) was detected at 55 of the 102 sampling sites and in 35 percent of the fish fillet samples; however, all detections were below the 10 µg/g screening criteria (table 2).

Selenium availability is almost entirely attributed to human activity. Coal and petroleum combustion provide approximately 70 percent of available selenium to the air, whereas glass manufacturing provides about 20 percent, and metallurgical processes provide 8 percent. Electronics, xerography, and mining provide the remaining 2 percent. Fly ash from fossil-fuel combustion, which contains 300 to 1,100 times more coal-derived selenium than any other element, is responsible for most of the selenium in the environment (Sorenson, 1991). Selenium had the highest detection frequency in fish tissue of the 10 trace elements analyzed and approximately 70 percent of the sampling sites (fig. 17) had a measurable concentration. Selenium concentrations varied from 0.05 to 0.71 µg/g (table 2); however, selenium did not exceed the U.S. EPA screening criteria of 50 µg/g.

SUMMARY

Over 200 sites were sampled for the presence of organochlorine pesticides, polychlorinated biphenyls, and trace elements in fish tissue. The sampling sites presented in this report are located primarily along the main stem of the Tennessee River, a small spatial coverage when compared to the entire LTEN River Basin study unit, which encompasses approximately 19,500 square miles.

Between 1980 and 1998, 101 sites in the LTEN River Basin study unit were sampled to determine the presence of 28 organochlorine compounds in fish tissue. The compounds *p,p′*-DDT, *p,p′*-DDD, and *p,p′*-DDE were detected at 60, 70, and 84 of the 101 sampling sites, respectively. The compound *p,p′*-DDD was detected above action levels and guidelines at two fish tissue sampling sites. The compound *p,p′*-DDE was the most frequently detected compound in fish tissue with detections at 83 percent of the sites sampled. Fish tissue samples from five sites exceeded *p,p′*-DDE action levels and guidelines. PCB's were detected in fish tissue at 66 of 85 sampling sites, but only samples from 8 sites had concentrations exceeding action levels or guidelines. PCB and *p,p′*-DDE concentrations were detected above action levels and guidelines in both whole fish and in fish fillet samples. Dieldrin was detected at 13 of 85 fish tissue sampling sites with 1 whole fish sample having a detection equal to the 0.1 mg/kg guideline. Endrin was detected at 30 of 92 fish tissue sampling sites with 1 whole fish sample exceeding the 0.025 mg/kg guideline. Total chlordane was detected at 28 of 96 fish tissue sampling sites. Concentrations above action levels and guidelines occurred in one fish fillet sample and one whole fish sample.

Fish fillet samples were analyzed for 10 trace elements at 102 sites in the LTEN River Basin between 1980 and 1996. Mercury, a naturally occurring element, was detected in fish fillet samples at 51 of 102 sampling sites and was the only trace element to exceed an action level. Eight sampling sites had fish

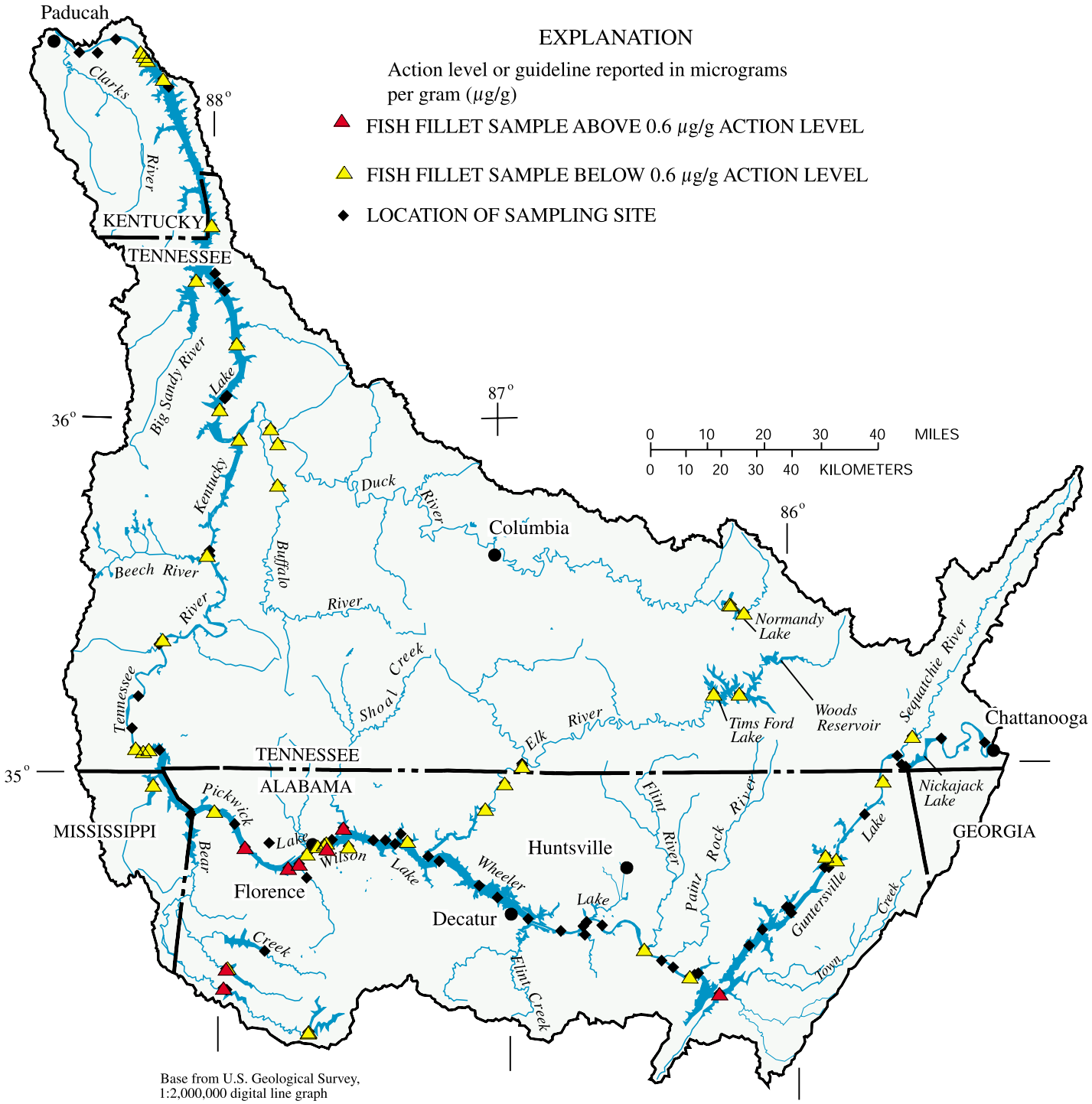

Figure 15. Location of sampling sites with detections of mercury in fish tissue in the lower Tennessee River Basin, 1980-96.

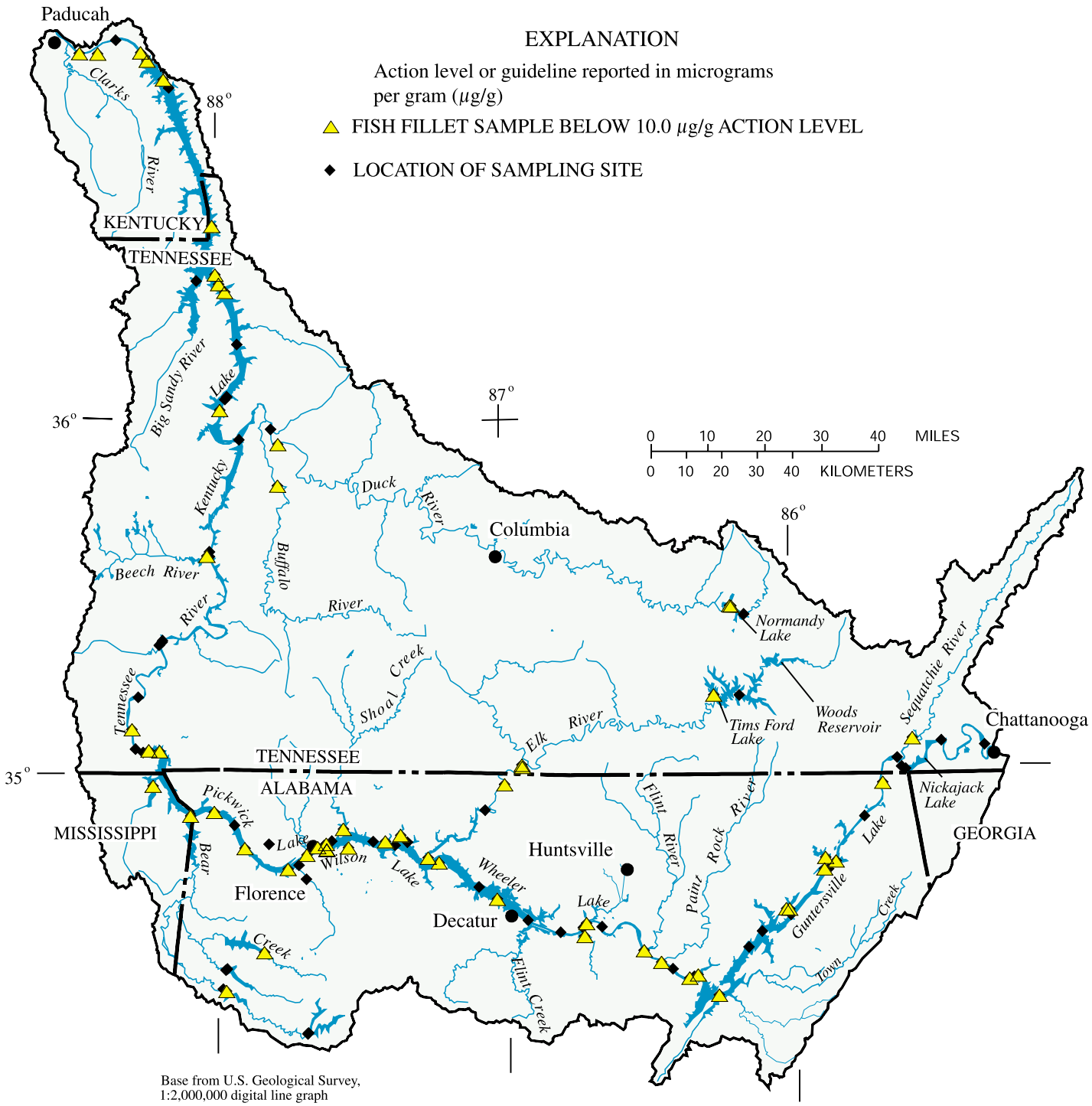

Figure 16. Location of sampling sites with detections of cadmium in fish tissue in the lower Tennessee River Basin, 1980-96.

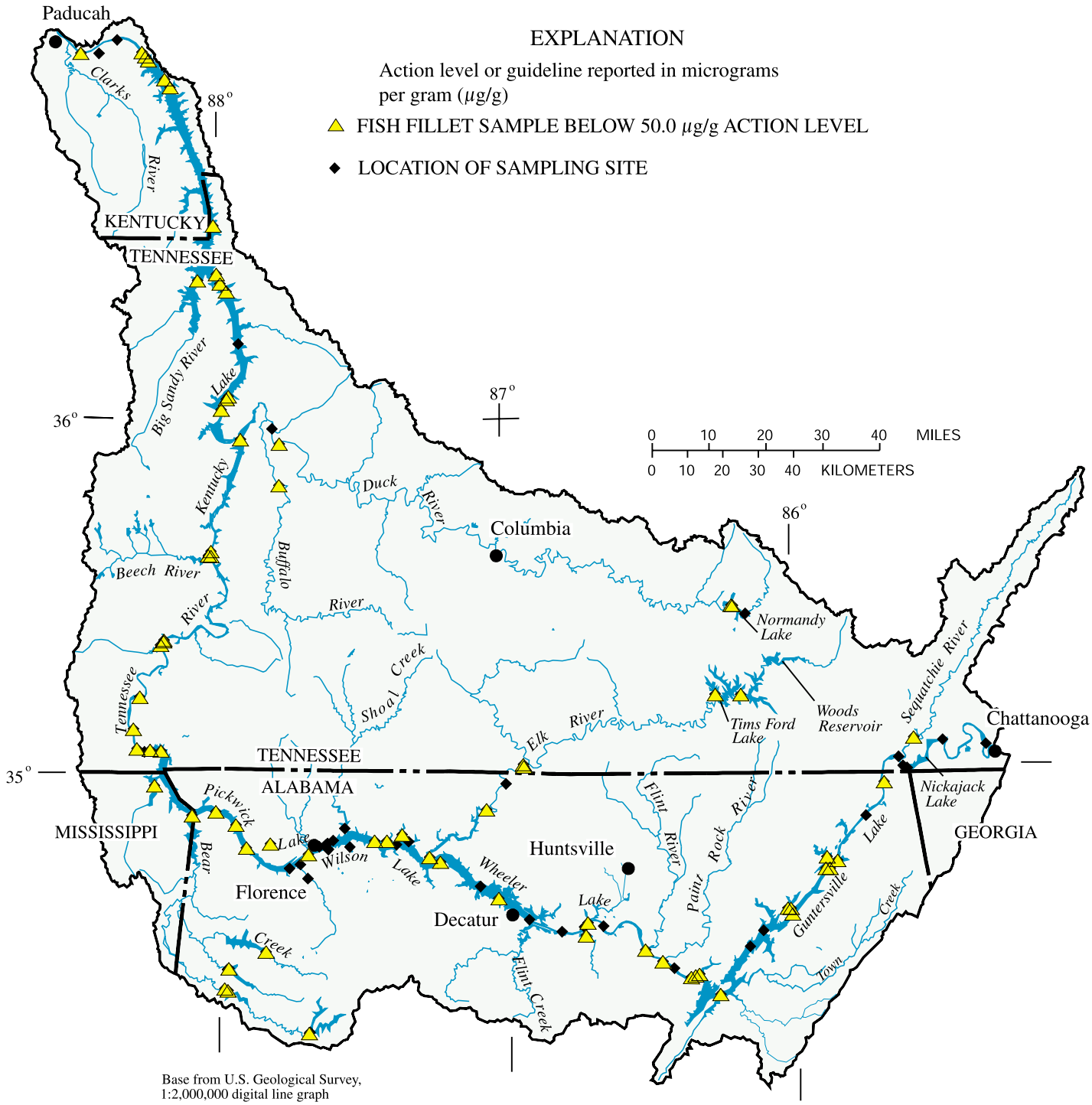

Figure 17. Location of sampling sites with detections of selenium in fish tissue in the lower Tennessee River Basin, 1980-96.

tissue samples with mercury concentrations higher than the action level; however, sampling sites where concentrations exceeded the action level were relatively localized. Generally, the highest concentrations of trace elements were found at sites located on reservoirs (Wheeler and Wilson) along the main stem of the Tennessee River. Selenium was detected in fish fillet samples from 70 of 102 sites sampled but did not exceed the 50 micrograms per gram U.S. Environmental Protection Agency screening criteria. Arsenic and cadmium were detected at 45 and 55 of the 102 sampling sites, respectively.

SELECTED REFERENCES

Alabama Department of Environmental Management, 1996, Water quality report to Congress: Montgomery, Alabama, 144 p. and appendices.

Alabama Department of Public Health, 2000, Alabama fish consumption advisories, accessed June 4, 2001, at http://www.alapubhealth.org/risk/advisory.htm

Crawford, J.K., and Luoma, S.N., 1993, Guidelines for studies of contaminants in biological tissues for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 92-494, 69 p.

Eisler, Ronald, 1986, Polychlorinated biphenyl hazards to fish, wildlife, and invertebrates: a synoptic review: U.S. Fish and Wildlife Service Biological Report 85(1.7), 72 p.

———1987, Mercury hazards to fish, wildlife, and invertebrates: a synoptic review: U.S. Fish and Wildlife Service Biological Report 85(1.10), 90 p.

Freeman, C.S., and Denton, G.M., 1997, The results of fish tissue monitoring in Tennessee 1992-1997: Tennessee Department of Environment and Conservation, 48 p.

Goodbred, S.L., Gilliom, R.J., Gross, T.S., Denslow, N.P., Bryant, W.L., and Schoeb, T.R., 1997, Reconnaissance of 17β–estradiol, 11-ketotestosterone, vitellogenin, and gonad histopathology in common carp of United States streams: potential for contaminant-induced endocrine disruption: U.S. Geological Survey Open-File Report 96-627, 47 p.

Hem, J.D., 1989, Study and interpretation of chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Kingsbury, J.A., Hoos, A.B., and Woodside, M.D., 1999, Environmental setting and water-quality issues in the lower Tennessee River Basin: U.S. Geological Survey Water-Resources Investigations Report 99-4080, 44 p.

Leiker, T.J., Madsen, J.E., Deacon, J.R., and Foreman, W.T., 1995, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—determination of chlorinated pesticides in aquatic tissue by capillary-column gas chromatography with electron-capture detection: U.S. Geological Survey Open-File Report 94-710, 42 p.

Murphy, B.R., Atchison, G.J., and McIntosh, A.W., 1978, Cadmium and zinc content of fish from an industrially contaminated lake: Journal of Fish Biology, v. 13, p. 327.

National Academy of Sciences and National Academy of Engineering, 1973, Water quality criteria, 1972: Washington D.C., U.S. Environmental Protection Agency, EPA R3-73-003, 594 p.

Nauen, C.E., 1983, Compilation of legal limits for hazardous substances in fish and fishery products: Rome, Food and Agriculture Organization of the United Nations, Circular no. 764, 102 p.

Newell, A.J., Johnson, D.W., and Allen, L.K., 1987, Niagara River biota contamination project: fish flesh criteria for piscivorous wildlife: New York State Department of Environmental Conservation Technical Report 87-3, 182 p.

Nowell, L.H., and Resek, E.A., 1994, Summary of national standards and guidelines for pesticides in water, bed sediment, and aquatic organisms and their application to water-quality assessments: U.S. Geological Survey Open-File Report 94-44, 115 p.

O'Shea, T.J., Fleming, W.J., III, and Cromartie, Eugene, 1980, DDT Contamination at Wheeler National Wildlife Refuge: Science, v. 209, p. 509-510.

Schmidt, C.J., Zapicek, J.L., and Peterman, P.H., 1990, National Contaminant Biomonitoring Program: residues of organochlorine chemicals in U.S. freshwater fish, 1976-1984: Archives of Environmental Contamination and Toxicology, v. 19, p. 748-781.

Sorenson, E.M.B., 1991, Metal poisoning in fish: Boca Raton, CRC Press, 374 p.

Tennessee Department of Environment and Conservation, 2000, Posted streams and lakes in Tennessee, accessed June 4, 2001, at http://www.state.tn.us/environment/wpc/advisory.htm

U.S. Department of Commerce, 1997, Distributional population estimates: U.S. Census Bureau, accessed August 7, 1997, at http://www.census.gov/population/www/estimates/countypop.html

U.S. Environmental Protection Agency, 1992, National study of chemical residues in fish (v. I and II): Washington, D.C., Office of Science and Technology, Standards, and Applied Science Division, EPA 823-R-92-008a (166 p.) and b (263 p.)

———1994, Water quality standards handbook (2d ed., update 1): U.S. Environmental Protection Agency, Office of Water, EPA 823-B-94-006, variously paginated.

———1995, Guidance for assessing chemical contaminant data for use in fish advisories, v. 1, Fish sampling and analysis, 2d ed.: Washington, D.C., U.S. Environmental Protection Agency, Office of Water, EPA 823-R-95-007, variously paginated.

U.S. Food and Drug Administration, 1984, Polychlorinated biphenyls (PCBs) in fish and shellfish; reduction of tolerances; final decision: Federal Register, v. 49, p. 21,514-21,520.

———1989, Compliance and Policy Guide 7141.01, Pesticide residues in food or feed—Enforcement Criteria, Attachment B, Action levels for unavoidable pesticide residues in food and feed commodities: U.S. Food and Drug Administration.

———1990, Action levels for residues of certain pesticides in food or feed: Federal Register, v. 55, p. 14,359-14,363.

Ware, G.W., 1989, The pesticide book (3rd ed.): Fresno, California, Thomson Publications, 340 p.

Williams, D.L., and Dycus, D.L., 1993, Reservoir monitoring - 1992, Fish Tissue Studies in the Tennessee Valley in 1991 and 1992: Tennessee Valley Authority, Resource Group, Water Management, Clean Water Initiative, 169 p.

Woodside, M.D., and Mitchell, R.L., III, 1998, National Water-Quality Assessment Program-Lower Tennessee River Basin: U.S. Geological Survey Fact Sheet FS-014-98, 4 p.