Phase II Assessment of Total Mercury Concentrations in Fishes from Rivers, Lakes and Reservoirs of New Jersey

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EXECUTIVE SUMMARY

In 1996-1997, the Academy of Natural Sciences of Philadelphia (ANSP) conducted a study of mercury concentrations in tissues of freshwater fish in New Jersey. This study is a follow-up of a preliminary screening study conducted in 1992-1993. The objectives of the study were to:

- Provide more extensive spatial data on mercury concentrations by sampling fish from additional sites. Sampling focused on largemouth bass and chain pickerel, species with high potential for bioaccumulation, which makes them useful for comparing bioaccumulation across lakes.

- Provide a basis of predicting mercury concentrations in fish from information on waterbody chemistry, geology, location, etc. This would be useful in defining consumption advisories and for designing future monitoring studies.

- Provide information on concentrations of mercury in species of fish commonly consumed, since higher overall risk may be associated with consumption of these species than of species which have higher concentrations but are less often consumed.

- Provide information on roles of different trophic pathways within sites on mercury bioaccumulation by sampling a variety of organisms within sites.

- Compare concentrations of mercury in fillets and the whole body of selected specimens in order to link data gathered for human risk assessment (based on fillet analyses) with data gathered for analysis of trophic uptake or risk to wildlife (based on whole body analyses).

For the 1996-1997 study, a total of 258 samples (not including QA/QC samples) of fish from 30 sites were analyzed. This included 58 largemouth bass, 58 chain pickerel, 109 large specimens of other commonly consumed species (brown and brook trout, channel and white catfishes, brown and yellow bullheads, smallmouth bass, Northern pike, sunfishes, black crappie, white perch and yellow perch), 32 samples of “forage fish” (including golden shiner, gizzard shad, alewife, chubsucker, and small specimens of sunfish, crappies, and white perch) and one sample of an aquatic insect (a backswimmer) for investigation of trophic differences in mercury bioaccumulation. Single fillets of larger fish were analyzed, while samples of forage fish included composites or individual fish, depending on the size.

Sites were sampled which had not been sampled previously. Site selection was based on a stratified random sampling design. The *a priori* stratification was based on geographical location, geological setting of the waterbody, and water chemistry (pH). The stratification was designed to represent the gradient in water chemistry from highly acidic, low alkalinity sites in the Pine Barrens through alkaline sites in carbonate regions in northern New Jersey. Separate strata were set up for large, unique lakes, and for sites in industrial regions which have known or likely histories of point source mercury contamination. The stratification was a modification of that used for the earlier (1992) study, allowing use of data from that study.

Sites were selected from strata which had shown high mercury concentrations or variability in mercury concentrations in previous studies, or for which little information was available. Priority was given to Pine Barrens sites (which had high concentrations in previous studies), sites in industrial areas (which had high potential for contamination), coldwater streams (which had not been studied before), Northern lakes (one of the most numerous types, with the potential for high variability), sites in the northwestern part of the state with geology potentially leading to high bioaccumulation, and sites marginal to the Pine Barrens (which had shown high among-site variability in mercury concentrations in the 1992 study).

The results of the follow-up study were consistent with those of the previous study. The highest mercury concentrations were in fish from Pine Barrens lakes and rivers. Sites from the northern Pine Barrens were sampled in the 1996-1997 study, while the 1992 study included mainly southern sites. The similarity of results indicates that the high concentrations occur over the entire region. As in the 1992 study, sites at the edge of the Pine Barrens were variable in mercury concentration in fish, with some sites showing levels similar to that of Pine Barrens sites.

Sites in industrial areas were variable in the extent of mercury contamination. Some, such as the upper Raritan River, showed low mercury concentrations, while relatively high concentrations were found in some sites in the northeastern part of the state.

Fish from other sites generally had low or moderate concentrations of mercury. One exception was Crater Lake (in Sussex County), sampled as a representative of lakes on sandstone ridges in the northwestern part of the state. Concentrations in fish from Crater Lake were high compared to similar-size specimens of the same species from other sites.

Concentrations were generally highest in piscivorous fish such as chain pickerel and largemouth bass. Lower concentrations were seen in other species, including many that are commonly consumed, such as white perch, yellow perch, sunfish, crappies, catfish and bullhead. Assessment of potential human health hazards from eating these species would require a risk assessment, which was beyond the scope of this study. However, concentrations in some specimens were greater than threshold defined in 1994 by the Toxics in Biota Committee which trigger advisories to restrict consumption.

Comparisons of mercury concentrations among fish from different trophic levels showed the general increase in concentrations with trophic levels, although among-species variation within trophic groups was seen. No clear difference in mercury concentrations was seen between invertebrate-eating species (e.g., sunfishes) and mainly zooplanktivorous species (golden shiner had lower concentrations while alewife had similar concentrations). White perch had lower concentrations than other invertebrate eaters. Pine Barrens sites contain several species of sunfishes which are much smaller than widespread species such as bluegill and pumpkinseed. Specimens of the small species show higher concentrations than similarly-sized specimens of other sunfish species.

This is likely related to age differences: adults (probably 1-3 years old) of the small species are similar in size to young-of-year of the other species. Since these small, but relatively old, fish are consumed by predatory fish, this difference could contribute to high bioaccumulation in predatory fish in the Pine Barrens.

Comparisons of fillet and whole body concentrations were made for 8 chain pickerel, 10 largemouth bass, and 13 specimens of 6 other species. Mercury concentration in fillets were higher than whole body concentrations in all of these samples. Ratios were variable for largemouth bass, with a median of 1.65 (i.e., fillet concentrations were about 1.65 times the whole body concentrations). Ratios were fairly consistent within the other species. Fillet concentrations were about 1.3 times greater than whole body concentrations for chain pickerel. Median ratios of fillet to whole body concentrations were 1.3-1.9 for other species.

As in previous studies, mercury concentrations within species tended to increase with the size and age of the fish. These relationships need to be considered in making detailed comparisons among sites. Three types of analyses were done to adjust for length/age relationships and compare sites:

1) Length and age adjustments were made using analysis of covariance (ANCOVA), where length or age is treated as a covariate and other factors (e.g., sampling strata) were treated as discrete treatment effects. This is similar to regressing mercury concentrations against age or length, with different intercepts for different strata. The simplest model used only stratum as a grouping factor, while more complex models used waterbody within strata.

2) Multiple linear regression was done, using length or age, and water chemistry factors for each lake. The length/age adjustment is analogous to that done for the first model, but site variation is modeled based on water chemistry variables rather than on discrete groupings of sites.

3) A combined analysis using both discrete groupings of sites and water chemistry variables was done with ANCOVA. This analysis indicates whether water chemistry explains variation in mercury concentrations within the site groupings.

These analyses were done on largemouth bass, chain pickerel and brown bullhead. For these analyses, data from the 1996-1997 study were combined with data from three other studies: the 1992-1993 study and two other studies done in 1993-1994. Together, these studies include 252 specimens of largemouth bass, 126 specimens of chain pickerel and 44 specimens of brown bullhead.

The analyses showed that much of the variation in mercury concentrations could be explained by fish size or age and by descriptors of site characteristics (stratum or water chemistry parameters). Models in which specific waterbody effects were included had very high explanatory power (90-95% of total variation). This shows that while there are consistent patterns in mercury bioaccumulation among types of lakes, that there is substantial lake-to-lake variation within a given lake type.

Concentrations of mercury in chain pickerel were the most predictable, with age providing better resolution of among-fish differences than length. For chain pickerel, either strata or water chemistry provided good models. All water chemistry parameters (pH, conductivity DOC, alkalinity, sulfate and chloride) were significant in some model. pH and conductivity (both easily measured parameters) provided good predictions, although other groups of parameters provided better predictions. The high predictability of pickerel bioaccumulation reflects the importance of the gradient from low alkalinity, high DOC, low pH sites (e.g., the Pine Barrens), to higher alkalinity, low DOC, high pH sites (e.g., some northern lakes) for this species.

Concentrations in largemouth bass were not as well explained by the models using strata and/or water chemistry. This reflects the variety of mid- to high-pH waterbodies in which largemouth bass were found, and its absence from many Pine Barrens sites. As a result, the pH/alkalinity/DOC gradient is not as well-defined, and other types of among-site differences are more important. For largemouth bass, total length provided better predictions of mercury than age. This could be due to the importance of size-related shifts in feeding habits, habitat, etc. for this species. As with chain pickerel, pH and conductivity alone provided good predictions of mercury, but the best predictions were provided by regressions including DOC, conductivity and chloride.

For brown bullhead, pH alone provided good predictions, although the best models included DOC and alkalinity.

Much of the among-site variability in bioaccumulation (especially in largemouth bass) comes from a few sites with relatively high values, which are not explained by the water chemistry parameters which are measured. Relatively high mercury concentrations were seen in fish from some lakes in industrial areas, and from relatively young reservoirs.

In 1994, NJDEP sampled fish for mercury analysis in sites which had yielded fish with relatively high mercury concentrations (above 1.0 mg/g) in the 1992-1993 study. The results of these analyses were consistent with those of the 1992-1993 study. The concentrations in largemouth bass and chain pickerel from the 1994 NJDEP study were compared with predictions from the multiple regression models derived from the combined ANSP studies. These predictions were based on the size of fish analyzed in the NJDEP study and the water quality parameters measured by ANSP in those lakes. There was good overall agreement between the NJDEP measurements and predicted values. Consistent deviations were seen for some sites. These are attributed to the inherent between-lake variation in mercury bioaccumulation and to factors promoting mercury availability not accounted for by the water quality parameters, such as historic point source contamination and high bioaccumulation in new reservoirs.

Bioaccumulation of mercury has been related to differences in water chemistry, which affect rates of methylation of mercury into methylmercury, which is more readily accumulated. The relationships of mercury bioaccumulation to parameters such as pH, alkalinity, conductivity and DOC are consistent with other studies. These parameters are intercorrelated, and the causal basis of their relationship to bioaccumulation cannot be determined from this type of comparative study. The intercorrelation makes it difficult to separate observed relationships, and differences in explanatory power can arise from differences in the temporal, spatial and measurement variability in parameters, nonlinearities in the parameter-bioaccumulation relationship, etc. DOC has been considered as a primary factor promoting bioaccumulation, based on modeling, laboratory and experimental studies. In the present study, DOC was the only parameter significantly related to bioaccumulation in all three studies when all other parameters were included in the model.

The major conclusions of these mercury studies are:

- Concentrations of mercury occur in fillets of some species of fish from a number of New Jersey freshwaters at levels which may trigger consumption advisories, based on existing risk assessments.

- Among different types of waterbodies, relatively high concentrations were seen in fish from the Pine Barrens, including rivers and ponds and sites from throughout the Pine Barrens.

- Relatively high concentrations were seen in some sites at the edge of the Pine Barrens, at some relatively new reservoirs, and at some sites in the northeastern part of the state, which may have had historical point-source contamination.

- Concentrations were lowest in coldwater streams, in some ponds and rivers in the southwestern part of the state (i.e., on the Coastal Plain outside the Pine Barrens), in the Delaware River, and in some high pH lakes in the northern part of the state.

- Among different fishes, concentrations were highest in large, piscivorous fish such as chain pickerel and largemouth bass. Relatively high concentrations of mercury may occur in individuals of these species from a variety of sites.

- Concentrations in lower trophic levels were lower than those in piscivorous fish, but clear patterns of differences among planktivores, generalized invertebrate-feeders and bottom-feeders were not found.

- Several species of sunfish which remain small throughout their lives are common in the Pine Barrens; these species can live several years and are small enough to be important forage fish throughout their lives. As a result, these may contribute to bioaccumulation in piscivores.

- Much of the variation in mercury concentrations in a species can be explained by fish size or age and by measures of lake chemistry (either categories of lake type or by measurements of water chemistry parameters). However, there is substantial variation among lakes which is not explained by the measurements made. This variation comes from some sites with high bioaccumulation due to other factors, such as in new reservoirs or in sites with historical contamination.

- For chain pickerel, mercury concentrations followed a relatively simple pattern along the pH/alkalinity/conductivity/DOC gradient. Since these factors covary, a variety of models (i.e., using different groups of parameters) can be used to explain variation in mercury bioaccumulation.

- For largemouth bass, there was also a relationship between bioaccumulation and the pH/alkalinity/conductivity/DOC gradient, but other factors were also important. This may reflect the widespread occurrence of the species in moderate and high pH/alkalinity/conductivity sites.

- Fillet concentrations of mercury were higher than estimated whole body concentrations. Relationships between fillet and whole body concentrations were generally consistent among species, with fillet concentrations 1.3-1.9 times higher than whole body concentrations.

Recommendations for future studies are made, based on the findings of this report. Areas for future work include providing more precise information on regions or taxa which are variable or currently poorly known, sampling over time to determine temporal trends, and investigation of mechanisms of bioaccumulation. Trend sampling may be particularly opportune, in order to provide information on possible decreases in mercury concentrations in fish subsequent to decreases in anthropogenic atmospheric emissions. Recommended studies include:

1) Sampling additional waterbodies and taxa for which there is no information. The most important analyses would be from lakes in the northeastern part of the state, parts of the northwestern part of the state, and in sites marginal to the Pine Barrens. Ongoing studies of mercury concentrations in eels and snapping turtles may indicate the need for more analysis of these species.

2) Periodic monitoring of mercury concentrations in a limited number of sites to determine the occurrence and time scale of expected decreases in mercury concentrations following decreases in atmospheric emissions of mercury.

3) Periodic monitoring of mercury concentrations in some sites, such as newly-impounded reservoirs and sites with former point source inputs, since these sites may follow different temporal patterns than other sites.

4) Periodic monitoring of atmospheric deposition rates would be important to determine temporal trends of deposition, which is a major factor controlling mercury concentrations in aquatic organisms.

5) More intensive sampling of chemical parameters in water to provide better estimates of seasonal and spatial variation of these parameters within lakes. This variation may affect

the reliability of prediction of mercury concentrations from spot sampling of water chemistry.

6) Analysis of additional waterbody characteristics which may improve the ability to model mercury concentrations from waterbody characteristics. Watershed information derived from GIS, such as land use, amount of wetlands in the watershed and watershed geology, may be useful for this purpose.

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INTRODUCTION

In 1992-1993, The Academy of Natural Sciences of Philadelphia (ANSP) conducted a preliminary assessment of mercury in freshwater fishes of New Jersey (ANSP 1994a). This study found concentrations of concern in fish from a number of lakes. These data were used to develop consumption advisories for recreationally caught freshwater fishes in New Jersey. Subsequently, ANSP conducted two other studies, one in 1992-1993 at several sites in Camden County (ANSP 1994b) and one in 1994 in Lakes Oradell and Tappan for the Hackensack Water Company (ANSP 1994c). These data supplement those from the preliminary assessment. In 1995, the New Jersey Department of Environmental Protection and the New Jersey Department of Health analyzed mercury in additional specimens of fish from some of the lakes which had been sampled in the 1992-1993 study. In 1995, ANSP initiated studies to address some of the issues unresolved by the preliminary assessment or other studies. Sampling for this follow-up study was done in 1996 and 1997.

Study Objectives

The main goal of this study is more thorough analysis of variation in mercury concentrations in fish among sites and within sites (Figure 1). Specific objectives are:

1) Improvement in the ability to predict mercury concentrations by refinements in the definition of sampling strata; collection of more information on potentially important physico-chemical parameters which may be correlated with mercury bioaccumulation, including pH, alkalinity, dissolved organic carbon, chloride and sulfate concentrations; analysis of ages of fish, since age can provide a more accurate covariate of bioaccumulation.

2) Sampling of fish from additional waterbodies. Fish from 28 additional sites were analyzed for the 1996-1997 study.

3) Assessment of mercury concentrations in species of fish commonly eaten by anglers (e.g., perch, catfishes and bullheads, sunfishes and crappies). Such information will be essential for subsequent risk assessment for fish consumption from different sources. Although these species may have lower concentrations than the larger piscivores (e.g., largemouth bass and chain pickerel), they may contribute more to health risks because they are more frequently caught and eaten.

4) Assessment of differences in mercury concentrations in fishes from different portions of the food web. In particular, differences in mercury concentration among different groups of forage fish (e.g., benthic feeders, zooplankton feeders) may indicate important ecological controls in mercury bioaccumulation in piscivores.

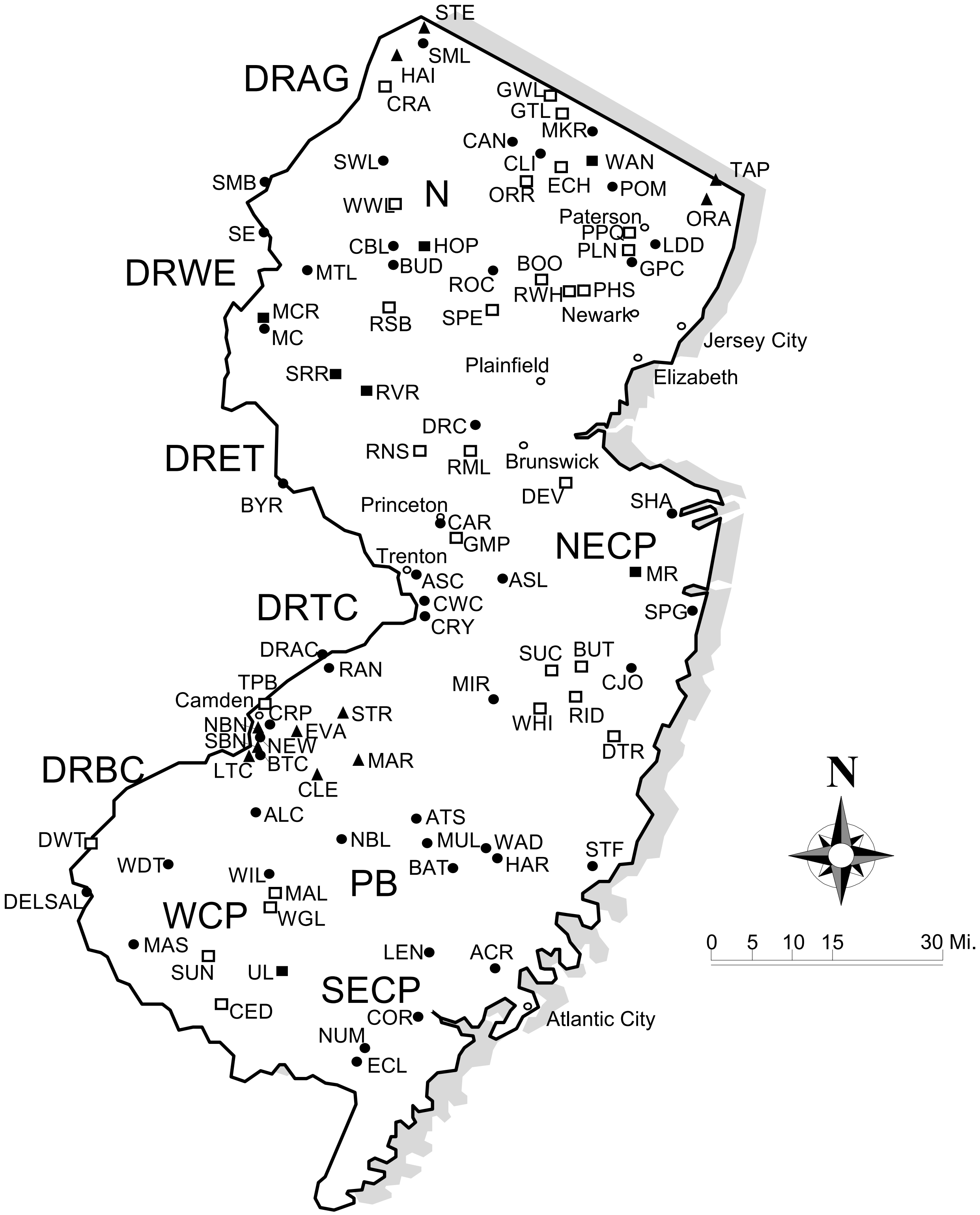

Figure 1. Location of sites (see Table 2 for key) sampled as part of ANSP surveys of mercury concentrations in fish tissues, including this (1996-1997) study (open squares), 1992-1993 screening study (closed circles), 1994 Camden County study (closed triangles in vicinity of Camden), and 1994 Hackensack Water Company study (closed triangles).

5) Combined analysis of the data from the preliminary assessment, the Camden County study, the Hackensack study, and data newly generated for this study.

6) Comparison of ANSP results with those of the 1995 NJDEP-NJDOH study. An interlaboratory comparison was done on data from one lake in 1995. The results, previously reported to the NJDEP (ANSP 1996), are reprinted as Appendix E in this report.

Factors Affecting Bioaccumulation of Mercury

The study sites, species analyzed and physico-chemical parameters measured were selected using existing information on mercury bioaccumulation. Reviews of aspects of mercury cycling can be found in Jasinski (1995), Zillioux et al. (1993), EPMAP (1994), Rudd (1995) and USEPA (1998). A short review of factors especially relevant to bioaccumulation in New Jersey freshwater fishes was presented in ANSP (1994a). As a simplification, variation in mercury concentrations in fish tissue can be related to a series of factors:

1) *Rates of input and export of mercury*. Atmospheric deposition is a major source of mercury into aquatic watersheds (EPMAP 1994, Rudd 1995). While some spatial variation in deposition occurs (Keeler et al. 1995, St. Louis et al. 1995, Pirrone et al. 1995), the long-range transport of mercury from anthropogenic and natural sources (Pacyna and Keeler 1995) reduces among-site variability. Greater variability is expected from terrestrial or direct aquatic applications. Terrestrial applications have occurred from a variety of industrial and agricultural sources, such as fungicides and paints (NOAA 1988). Most of these applications have been reduced or eliminated, but watershed inputs may still occur from historical uses. Similarly, direct aquatic inputs from industrial sources have been greatly reduced or eliminated. However, mercury can persist in sediments long after cessation of input (Rada et al. 1986). Current inputs may occur from waste treatment plants (although treatment may remove most mercury from the effluent stream, Balogh and Liang 1995), or from losses from sites contaminated by spills from mercury equipment, chlor-alkali units, etc. (Harju et al. 1995, Klein and Jacobs 1995). Chloride concentrations are typically higher in urban areas, although chloride varies with proximity to the ocean and other factors, as well. Correlations between mercury bioaccumlation and chloride concentrations, e.g., as in this study, may be due to the joint correlation with urbanization, sewage plant effluents, and other point and non-point source inputs of mercury.

   Watershed hydrology and geochemistry can affect transport of mercury into rivers and lakes. Mercury may be retained in watersheds by adsorption on clays or binding with organic complexes (Rudd 1995, Bishop et al. 1995). Transport of mercury into rivers and lakes can be facilitated by transport of particulates (Hurley et al. 1995) or DOC (Zillioux et al. 1993, Lee et al. 1995a,b, Driscoll et al. 1995, Hintelmann et al. 1995, Watras et al. 1995a). Methylmercury may be largely retained in upland soils with high infiltration of rainfall (Bishop et al. 1995). In particular, movement of DOC in groundwater is a significant pathway of methylmercury movement from wetlands into drainage lakes (Porvari and Verta

1995, Rudd 1995, Pettersson et al. 1995, Branfireun et al. 1996, St. Louis et al. 1996). Complexation of mercury with humic acids was the primary mechanism of transport of mercury out of floodplain soils of the Elbe River (Wallschlager et al. 1996). Bishop et al. (1995) found high concentrations of methylmercury in riparian sphagnum mosses, which served as a source to the downstream stream.

Inorganic mercury can be lost from waterbodies by volatilization. Increased methylation (see below) and/or binding of methylmercury by DOC may decrease the amount of inorganic mercury, resulting in lower volatilization and greater retention of mercury (Watras et al. 1995b).

2) *Rates of methylation of mercury*. Methylmercury is bioaccumulated to a greater extent than inorganic mercury. Therefore, factors increasing rates of methylation can greatly affect rates of bioaccumulation. Sulfur-reducing bacteria are a dominant methylator of mercury (Gilmour and Henry 1991, Watras et al. 1995c, Matilainen 1995). Bacterial methylation typically occurs in anoxic zones, such as near the anoxic-oxic boundary of sediments (Leermakers et al. 1995, Watras et al. 1995c) or lake waters (Slotton et al. 1995), anoxic hypolimnetic waters of stratified lakes (Verta and Matilainen 1995), wetland soils (Porvari and Verta 1995), or the interior of algal mats (Gilmour et al. 1997, Checker et al. 1998).

   On a watershed or site level, rates of methylation may depend on the extent of such sites, and the rate of methylation within the sites (Rudd 1995). For example, Watras et al. (1995b) found that mercury concentrations in water in drainage lakes were correlated with the amount of wetland in the watershed of a lake, and Hurley et al. (1995) found that methylmercury loads in Wisconsin rivers were correlated with wetland surface area. The net rate of methylation within sites may increase with temperature (Schindler et al. 1995), with sulfate (Gilmour and Henry 1991, Gilmour and Capone 1987) and DOC (Leermakers et al. 1995, Driscoll et al. 1994), which increase activity of methylating bacteria. Temporal changes in the location of the anoxic-oxic boundary (e.g., changes of groundwater levels in wetlands, seasonal shifts in the location of the hypolimnion in stratified lakes) can increase methylation by preventing depletion of bacterial substrate in static zones.

   The rate of methylation may be higher at lower pH (Xun et al. 1987), but this effect may be weak compared to other factors cited above (Watras et al. 1995d). The presence of organic acids (e.g., humic acids) may affect methylation more through the DOC effect than through direct pH effects.

3) *Factors affecting bioavailability of mercury*. Physical (e.g., adsorption) or chemical (e.g., bonding) reactions may increase or decrease bioavailability of mercury. For example, formation of mercury sulfide in high sulfide sediments may remove mercury from food chains. Partitioning of mercury or methylmercury (e.g., to DOC, clay particles, particulate organic matter) may decrease bioavailability by reducing direct uptake from water. However, these processes may increase trophic uptake by filter or deposit-feeders (Gagnon and Fisher 1997).

4) *Factors affecting bioaccumulation of mercury*. Within a site, mercury concentrations are expected to be highest in top-level predators, and this has been found in many studies (this study, Stafford and Haines 1997, Becker and Bigham 1995, Kidd et al. 1995). Mercury concentrations are also expected to be higher in long-lived fish, since depuration rates of methylmercury are relatively low. Older fish are also more likely to be more predatory. Increase in mercury concentrations with age has been observed in many studies (Morrison and Therien 1995, Allen-Gil et al. 1995). Because of the increase with age, large individuals of lower trophic levels may have higher mercury concentrations than many piscivorous species from the same site (Ward et al. 1997).

   Bioaccumulation may differ among different food webs within a site or across sites, as well. Many aquatic systems have food webs based on planktonic algal production (e.g., phytoplankton to zooplankton to zooplanktivorous fish and invertebrates to piscivorous fish) and on detritus (e.g., through detritus-feeding macroinvertebrates and protozoans). France (1995) found strong differences in the source of carbon of benthic portions of lakes (near-shore zones and bottom communities) which were based on detritus, and openwater communities, which were based on plankton.

   Many of the causal factors have multiple effects which may enhance or counteract each other. For example, DOC may enhance bioaccumulation both by stimulating of methylation or mercury and by increasing transport of methylmercury to rivers and lakes. Within rivers and lakes, binding of DOC and mercury may increase or decrease bioavailability of mercury to different consumers. Furthermore, many of the causal factors are correlated in occurrence. For example, Pine Barrens sites are characterized by high DOC (i.e., humic acids) and high amounts of wetland. Because of these effects, complex relationships between potential causal factors and mercury concentrations, as observed in this study, are to be expected.

Regulatory Thresholds

Mercury concentrations of concern may be defined by several criteria, including human health risk from consumption of fish, risk to wildlife from consumption of fish, concentrations leading to direct toxic effects in fish, and concentrations above some background level (e.g., as indicative of point source contamination). Concentrations based on human health risk have been of primary concern, e.g., as the basis for defining consumption restrictions (for commercial fisheries) or consumption advisories (for noncommercial fisheries). Criteria for protection of human health vary, due to a number of factors, including: a) assumptions about dose-human response relationships; b) assumptions about the total amount of fish consumption and the proportion of contaminated fish in the diet; c) definitions of "acceptable" risk; and d) different strategies for defining consumption advisories (e.g., setting a single threshold versus different levels for different groups of people). Human-health based thresholds have been based on fillet or muscle concentrations. Thresholds which have been used for establishing advisories include:

I. A single threshold concentration of 1.0 mg/kg (wet weight); this is used by FDA as the threshold for closing commercial fisheries and has been used for other advisories, as well; the threshold is based on assumptions of a mix of contaminated and noncontaminated fish in the diet.

II. A single threshold concentration of 0.5 mg/kg (wet weight); this is used by several jurisdictions (e.g., Wisconsin, Florida, Ontario, Sweden), as a concentration above which restricted consumption (e.g., on total number of meals per month) is advised; different rates of consumption may be advised for different groups of people (e.g., lower rates for pregnant women and children).

III. A single threshold concentration of 0.41 mg/kg (wet weight); this has been developed as a risk-based level by USEPA (1993b). This value is derived from a maximum recommended dose (0.3 $\mu g/kg\ d^{-1}$) and a daily ingestion rate (54 g d^{-1}), corrected for the fraction of days in a year of residential exposure (365/350). This value has no official status for regulation or guidance, but is suggested as a flag for further study.

IV. Multiple thresholds, to recognize higher vulnerability of children and pregnant women and lower vulnerability of other groups. In 1994, the Toxics and Biota Committee of the New Jersey DEP, DOH and DOA (Toxics and Biota Committee 1994) defined four classes of mercury concentration for each of two risk groups:

Women of reproductive age and children:
1) above 0.54 mg/kg; no consumption advised;
2) between 0.19 and 0.54 mg/kg; limited consumption (less than one meal per month) advised;
3) between 0.08 and 0.18 mg/kg; limited consumption (less than one meal per week) advised;
4) below 0.08 mg/kg; no advisories.

Others:
a. above 2.81 mg/kg; no consumption advised;
b. between 0.94 and 2.81 mg/kg; limited consumption (less than one meal per month) advised;
c. between 0.35 and 0.93 mg/kg; limited consumption (less than one meal per week) advised;
d. below 0.35 mg/kg; no advisories.

V. Wildlife-based concentrations. Toxicological models may be used to estimate fish concentrations expected to lead to toxic effects in fish-eating wildlife.

Selection of Sampling Sites

Most sites were selected using a stratified random sampling design. This design categorizes each potential waterbody into a group of strata, defines a number of sites to be selected from each stratum, and randomly selects sites for sampling from each stratum.

Stratification

The stratification was similar to that used in the 1992-1993 screening study (Table 1), with modifications based on the results of the 1992-1993 sampling. Modifications were done to: a) provide a better separation of sites with different expected levels of mercury bioaccumulation; b) retain the original design as much as possible, so that the random selection of sites for sampling in the 1992-1993 screening study would still be appropriate. By doing this, sites sampled in the 1992-1993 study, as well as those sampled in this followup study, can be analyzed together as part of a single design.

The original stratification, which was used in the 1992-1993 study, divided sites principally on geographic location, physiographic location (e.g., Coastal Plain versus upland sites) and type of waterbody (lake or river). Some strata were defined as unique, i.e., with only one member. These included the Delaware River, and eight lakes which were considered unique on the basis of size (they are the eight largest lakes in the state, seven of which were sampled in 1992), depth (e.g., maximum depths greater than 13 m in all but Union Lake), and age (Merrill Creek Reservoir was filled in 1988; Manasquan Reservoir was stocked in 1990).

The 1992-1993 study found that differences in mercury concentration could be attributed to waterbody chemistry and type of waterbody. The geographic and physiographic location were important mainly as location was correlated with water chemistry (e.g., low pH in Pine Barrens sites). The 1992-1993 strata were modified to better reflect expected differences in water chemistry. In the 1992-1993 screening study, Coastal Plain lakes were separated on the basis of location; in the modified version, rivers and lakes were separated on the basis of expected pH (5-6, 6-7, 7-8 and >8). In the 1992-1993 study, a single stratum was used for Northern lakes. For the 1995 study, Northern lakes were separated on the basis of surface geology of the immediate drainage. Lakes were separated into three classes, those with carbonate rocks in the immediate drainage, those in the Shawangunk Formation (a sandstone formation of the Northwestern part of the state; these rocks are expected to have low buffering capacity and might lead to higher bioaccumulation), and other lakes. For the 1996-1997 study, sites in industrial areas were separated into two strata, one for southern industrial lakes and rivers (e.g., in the immediate vicinity of Camden), and another for northern industrial lakes and rivers (sites in the northeastern part of the state). Sites with known point sources or identified as having likely point-source impacts in prior studies were included in these strata. These include Atlantic City Reservoir, which was identified in the 1992-1993 study; Raritan River at Neshanic Station, which was sampled by Jacangelo (1977), and sites in the Pompton-Pequannock system.

Table 1. Comparison of stratifications used in the current study and the 1992-1993 study.* indicates that the stratum was defined, but that no sites were sampled from the stratum.

1992 Strata	Number of Strata	1998 Strata	Number of Strata
Pine Barrens Rivers	1	Pine Barrens Rivers	1
Eastern Coastal Plain rivers*	1		
Western Coastal Plain rivers	1	Coastal Plain rivers	1
		Southern industrial rivers	1
Coldwater streams	1	Coldwater streams	1
Northern warmwater rivers	1	Northern warmwater rivers	1
		Northern industrial rivers	1
Brackish Coastal Plain rivers	1	Brackish Coastal Plain rivers	1
Pine Barrens lakes	1	Pine Barrens lakes	1
Western Coastal Plain lakes	1	Coastal Plain lakes (pH 5-6)	1
Northeastern Coastal Plain lakes	1	Coastal Plain lakes (pH 6-7)	1
Southeastern Coastal Plain lakes	1	Coastal Plain lakes (pH 7-8)	1
Mixed Coastal Plain lakes	1	Coastal Plain lakes (pH >8)	1
		Southern industrial lakes	1
Northern lakes	1	Northern midland lakes	1
		Northern carbonaceous lakes	1
		Northern industrial lakes	1
		Northern lakes, Shawangunk Formation	1
Unique Lakes	7	Unique lakes, non-carbonaceous	4
		Unique lakes, carbonaceous	4
Delaware River strata	5	Delaware River strata	5

For the 1996-1997 study, a stratum was designated as "Mixed Coastal Plain river", for drainages with a mix of relatively undisturbed Pine Barrens areas, agricultural or residential areas within the Pine Barrens, and areas outside the Pine Barrens. These sites were potentially intermediate in water chemistry between Pine Barrens and other Coastal Plains sites. The site selected for sampling, Ridgeway Branch, had water chemistry similar to Pine Barrens sites, and the site was classed with other Pine Barrens rivers for analysis.

Base List of Lakes

For the 1992-1993 study, a base list of waterbodies of interest was developed using NJDEPE (1992), USGS topographic maps, and county stream drainage maps. Criteria for inclusion were: a) lakes/ponds/reservoirs greater than 15 acres (6.1 ha) in area, or streams/rivers greater than 12 miles (19.3 km) in length; b) public ownership or access; c) probable presence of appropriate fish (primarily sport fish) for sampling. The base list contained 172 lakes, ponds and reservoirs, and 80 river/stream reaches (after removal of brackish ponds). This list was used as the basis for this study, as well. Boonton Reservoir was added to the list for this study, since public fishing access has been developed for this private lake.

Allocation of Sampling Sites

The effectiveness of a stratified random sampling design is affected mainly by the variability within sampling strata, which is determined by the inherent variability among sampling units, and the definition of strata, and by the precision of estimates within strata. The precision is determined by the precision of the estimates for each sampling unit (e.g., the number of fish sampled per site) and the number of units sampled within each stratum (e.g., the number of sites sampled). Note that the total number of units within a stratum affects precision only through the variability among units: a stratum containing a large number of similar sites can be assessed by sampling relatively few units (i.e., sampling a low proportion of all sites, while a stratum containing a small number of dissimilar sites may require sampling of a high proportion of sites.

For the 1992-1993 study, the numbers of sites to be sampled within each stratum (see Table 1) were selected on the basis of the likely potential for bioaccumulation, the variability within sites within the stratum, and the total number of sites within the stratum. The 1992-1993 data were used to determine numbers of additional sites in the various strata to be sampled for this study. For this study, emphasis was placed on those strata for which little data were available in 1992-1993, for which mercury bioaccumulation was potentially relatively high, and/or for which the 1992-1993 data showed high variability among sites.

Based on these criteria, the 1996-1997 sampling focused on:

1) Sites in and marginal to the Pine Barrens, since these showed the highest variability in mercury concentrations, and included some lakes with high concentrations.

2) Northern lakes, especially those in non-carbonate areas. There are a large number of these lakes and these showed variability among sites in the 1992-1993 sampling. These sites had relatively low sampling intensity (relative to the number of such sites) in the preliminary study and are likely to show higher concentrations, and many such sites have important fisheries.

3) Industrial areas in the Hudson, Passaic and Raritan drainages. While these types of sites did not show the highest concentrations in the preliminary assessment, concentrations were apparently higher than expected from water chemistry alone. Historical data indicated high mercury concentrations in the past. In addition, there may be greater frequency of consumption of fish from these areas.

4) Strata with low sample intensity in the preliminary assessment. A coldwater stream was selected for sampling, since little data was available from the 1992-1993 screening study.

Selection of Sampling Sites

Each waterbody on this list was assigned a selection number randomly. Within each stratum, sites with the lowest selection number were chosen for sampling, up to the determined number of sites. In some cases, sites originally selected for sampling were found to be unsuitable (e.g., lack of access, tidal exchange in coastal sites). In these cases, replacement sites with the next lowest selection number were chosen. In some cases (e.g. for Coastal Plain lakes, where stratification is based on pH), analysis of water chemistry indicated misclassification of lakes in the original stratification. In these cases, the lakes were reclassified, and new lakes were selected for sampling, based on selection number.

The random selection procedure was not used for the selection of some sites. Such sites include those sampled as part of other sampling programs with site-specific selection criteria, and sites selected for specific potential sources of contamination. These sites include:

1) Sites sampled as part of a 1992-1993 survey of sites in Camden County (ANSP 1994a). For this study, sites were chosen along a gradient from south Camden to the edge of the county. These sites are listed in Table 2. Some of the sites sampled for this study are not on the base list for the statewide survey, because of small size or private ownership.

2) Lake Oradell and Tappan Reservoir were sampled in 1994 as part of a study for the Hackensack Water Company (ANSP 1994b).

3) Industrial sites were picked on the basis of information on potential point sources (possibly including mercury) or to compare with earlier surveys. These sites include Lake Dundee, Cooper River Park Lake, Newton Lake, Big Timber Creek and Rancocas Creek, which were sampled in the 1992-1993 study, and all the industrial sites sampled in 1996-1997 (Table 2).

4) Some sites were selected to sample sites in parts of the state or in drainages not selected in the random site selection (Wilson Lake, Atlantic City Reservoir, Alcyon Lake), to coordinate with

Table 2. Lakes sampled in ANSP mercury sampling programs in New Jersey and code used in Figure 1.

Water body	Year Sampled	Strata	Code
New Jersey 1992-1993 Survey			
Alcyon Lake	1992	Coastal Plain Lake - pH 6 (CPL6)	ALC
Assunpink Creek - Lower	1992	Coastal Plain River (CPR)	ASC
Assunpink Lake	1992	Coastal Plain Lake - pH 7 (CPL7)	ASL
Atlantic City Reservoir	1993	Southern Industrial Lake (SINDL)	ACR
Atsion Lake	1992	Pine Barrens Lake (PBL)	ATS
Batsto Lake	1992	Pine Barrens Lake (PBL)	BAT
Big Timber Creek	1992	Southern Industrial River (SINDR)	BTC
Budd Lake	1993	Northern Midland Lake (NML)	BUD
Canistear Reservoir	1993	Northern Midland Lake (NML)	CAN
Carnegie Lake	1993	Northern Carbonate Lake (NCARB)	CAR
Clinton Reservoir	1992	Northern Midland Lake (NML)	CLI
Cooper River Park Lake*	1993	Southern Industrial River (SINDR)	CRP
Corbin City Impoundment #3	1993	Brackish Coastal Plain Lake (BCPL)	COR
Cranberry Lake	1992	Northern Carbonate Lake (NCARB)	CBL
Crosswick Creek	1993	Southern Industrial River (SINDR)	CWC
Crystal Lake	1993	Coastal Plain Lake - pH 7 (CPL7)	CRY
Delaware Raritan Canal	1993	Northern Industrial River (NINDR)	DRC
Delaware River - Above Camden (At and above Rancocas Creek)	1992	Delaware River - from Camden to Trenton (DRTS)	DRTC DRAC
Delaware River - above Easton (At Sandt's Eddy)	1992	Delaware River - from Easton to the Water Gap (DRWE)	DRWE SE
Delaware River - above Water Gap (At Smithfield Beach)	1992	Delaware River - above the Water Gap (DRAG)	DRAG SMB
Delaware River - Below Camden (At Salem)	1992	Delaware River - below Camden (DRBC)	DRBC DELSAL
Delaware River - Trenton to Easton (At Byrum)	1992	Delaware River - from Trenton to Easton (DRET)	DRET BYR
Dundee Lake	1992	Northern Industrial River (NINDR)	LDD
East Creek Lake	1992	Pine Barrens Lake (PBL)	ECL
Harrisville Lake	1992, 1993	Pine Barrens Lake (PBL)	HAR
Lake Carasaljo	1992	Coastal Plain Lake - pH 6 (CPL6)	CJO
Lake Hopatcong	1992	Unique Lake (UL)	HOP
Lake Nummy	1992	Pine Barrens Lake (PBL)	NUM
Lenape Lake	1992	Pine Barrens Lake (PBL)	LEN
Manasquan Reservoir	1993	Unique Lake (UL)	MR
Maskells Mills Lake	1993	Coastal Plain Lake - pH 5 (CPL5)	MAS
Merrill Creek	1992	Cold-water Stream (CWS)	MC
Merrill Creek Reservoir	1992	Northern Carbonate Lake - Unique Lake (NCARB-UL)	MCR
Mirror Lake	1992	Coastal Plain Lake - pH 5 (CPL5)	MIR
Monksville Reservoir	1992	Northern Midland Lake (NML)	MKR
Mountain Lake	1992	Northern Carbonate Lake (NCARB)	MTL

* Also sampled in Camden County study (see below).

Table 2 (continued). Lakes sampled in ANSP mercury sampling programs in New Jersey and code used in Figure 1.

Water body	Year Sampled	Strata	Code
New Jersey 1992-1993 Survey			
Mullica River	1993	Pine Barrens River (PBR)	MUL
New Brooklyn Lake*	1993	Coastal Plain Lake - pH 5 (CPL5)	NBL
Passaic River at Great Piece	1992	Northern Industrial River (NINDR)	GPC
Pompton Lake	1993	Northern Industrial Lake (NINDL)	POM
Rancocas Creek	1992	Coastal Plain River (CPR)	RAN
Rockaway River	1992	Northern Warm-water River (NWWR)	ROC
Round Valley Reservoir	1992, 1993	Northern Carbonate Lake - Unique Lake (NCARB-UL)	RVR
Saw Mill Lake	1992	Northern Midland Lake - Shawangunk Formation (NMLSSG)	SML
Shadow Lake	1992	Coastal Plain Lake - pH 8 (CPL8)	SHA
Spring Lake	1992	Coastal Plain Lake - pH 8 (CPL8)	SPG
Spruce Run Reservoir	1992, 1993	Northern Carbonate Lake - Unique Lake (NCARB-UL)	SRR
Stafford Forge Main Line	1992, 1993	Pine Barrens Lake (PBL)	STF
Swartswood Lake	1992	Northern Carbonate Lake (NCARB)	SWL
Union Lake	1993	Unique Lake (UL)	UL
Wading River	1992	Pine Barrens River (PBR)	WAD
Wanaque Reservoir	1992	Northern Carbonate Lake - Unique Lake (NCARB-UL)	WAN
Wilson Lake	1992	Coastal Plain Lake - pH 5 (CPL5)	WIL
Woodstown Memorial Lake	1992	Coastal Plain Lake - pH 7 (CPL7)	WDT
Camden Survey			
Clementon Lake	1993	Coastal Plain Lake - pH 6 (CPL6)	CLE
Cooper River Park Lake	1992	Southern Industrial River (SINDR)	CRP
Evans Pond	1992	Coastal Plain Lake - pH 6 (CPL6)	EVA
Haddon Lake (South Branch Newton C)	1992	Southern Industrial Lake (SINDL)	SBN
Little Timber Creek	1992	Coastal Plain River (CPR)	LTC
Marlton Lake	1992	Coastal Plain Lake - pH 6 (CPL6)	MAR
New Brooklyn Lake	1993	Coastal Plain Lake - pH 5 (CPL5)	NBL
Newton Creek (North Branch)	1993	Southern Industrial River (SINDR)	NBN
Newton Lake	1992	Southern Industrial Lake (SINDL)	NEW
Strawbridge Ponds	1992	Coastal Plain Lake - pH 6 (CPL6)	STR
Hackensack Water Company Survey			
Oradell Reservoir	1994	Northern Midland Lake (NML)	ORA
Tappan Lake	1994	Northern Midland Lake (NML)	TAP
New Jersey 1996-1997 Survey			
Boonton Reservoir	1996	Northern Midland Lake (NML)	BOO
Butterfly Bogs	1996	Pine Barrens Lake (PBL)	BUT
Cedar Lake	1996	Coastal Plain Lake - pH 6 (CPL6)	CED

Table 2 (continued). Lakes sampled in ANSP mercury sampling programs in New Jersey and code used in Figure 1.

Water body	Year Sampled	Strata	Code
New Jersey 1996-1997 Survey			
Crater Lake	1996	Northern Midland Lake - Shawangunk Formation (NMLSSG)	CRA
De Voe Lake	1996	Coastal Plain Lake - pH 6 (CPL6)	DEV
Delaware River - Above Camden (At Tacony-Palmyra Bridge)	1996	Delaware River - from Camden to Trenton (DRTS)	DRAC TPB
Delaware River - Below Camden (At Deepwater)	1996	Delaware River - below Camden (DRBC)	DRBC DWT
Double Trouble Lake	1996	Pine Barrens Lake (PBL)	DTR
Echo Lake	1996	Northern Carbonate Lake (NCARB)	ECH
Green Turtle Lake	1996	Northern Midland Lake (NML)	GTL
Greenwood Lake	1996, 1997	Unique Lake (UL)	GWL
Grovers Mill Pond	1997	Northern Midland Lake (NML)	GMP
Hainesville Pond	1996	Northern Midland Lake (NML)	HAI
Malaga Lake	1996	Coastal Plain Lake - pH 5 (CPL5)	MAL
Oak Ridge Reservoir	1997	Northern Midland Lake (NML)	ORR
Passaic River at Hatfield Swamp	1996	Northern Industrial River (NINDR)	PHS
Pompton River at Lincoln Park	1996	Northern Industrial River (NINDR)	PLN
Pompton River at Pequannock River	1997	Northern Industrial River (NINDR)	PPQ
Raritan River at Millstone Creek	1996	Northern Industrial River (NINDR)	RML
Raritan River at Neshanic Station	1996	Northern Industrial River (NINDR)	RNS
Raritan River, South branch, Clairemont stretch	1996	Cold-water Stream (CWS)	RSB
Ridgeway Branch of Tom's River	1996	Pine Barrens River (PBR)	RID
Rockaway/ Whippany Rivers	1996	Northern Industrial River (NINDR)	RWH
Speedwell Lake	1996	Northern Midland Lake (NML)	SPE
Steenykill Lake	1996	Northern Midland Lake - Shawangunk Formation (NMLSSG)	STE
Success Lake	1996	Pine Barrens Lake (PBL)	SUC
Sunset Lake	1996	Coastal Plain Lake - pH 8 (CPL8)	SUN
Wawayanda Lake	1996	Northern Midland Lake (NML)	WWL
Whitesbog Pond	1997	Pine Barrens Lake (PBL)	WHI
Willow Grove Lake	1997	Coastal Plain Lake - pH 6 (CPL6)	WGL

other sampling programs (Mountain Lake), to sample sites with new or special fishery programs (Monksville Reservoir, Boonton Reservoir), or to use specimens of interest collected for other purposes (Mirror Lake, Mullica River, Delaware and Raritan Canal, Echo Lake, Steenykill Lake).

5) The coldwater stream was selected nonrandomly, to provide the greatest likelihood of obtaining larger trout. Since most listed coldwater streams are stocked with little holdover, random selection would probably have yielded few or no trout with more than a short residence time in the stream.

Sampling Methods

Virtually all larger fish were collected by electrofishing, angling or gill netting. Most smaller fish (collected as part of the 1996-1997 study) were collected by electroshocking, seining and trapping. Most fish were collected by personnel of the Academy of Natural Sciences of Philadelphia (ANSP), and/or the New Jersey Department of Environmental Protection (NJDEPE; Division of Scientific Research, and Division of Fish, Game and Wildlife). For the 1996-1997 study, some specimens were collected by the Delaware River Basin Commission and private anglers. For the 1992-1993 screening study, additional specimens were made available by RMC, Inc. (Merrill Creek Reservoir), Tom Lloyd and Assoc. (Delaware River, below Camden) and by private anglers.

After capture, fish were placed in clean plastic bags or muffled aluminum foil, the package was sealed or taped shut, and identification information was written on an external label fixed to each package. Specimens were held on ice until transfer into a freezer. Transfers of specimen from the field to laboratory or other transfers between personnel were documented by ANSP standard chain-of-custody procedures. Samples were maintained frozen until sample preparation.

Analytical Methods

Sample Preparation

Four different tissue types were used for this study, fillets, whole body, carcass without fillets and carcass with a single fillet.

Fillets were used for all specimens for the 1992-1993 screening study, 1992-1993 Camden study and 1994 Hackensack study. Fillets were analyzed for larger specimens (i.e., those of size likely to be consumed by people) for the 1996-1997 study. Fillets were prepared with the entire fillet on one side, including the belly flap, excluding skin. This preparation (skin off, entire fillet) was chosen to provide consistent methodology for all species, to sample similar tissues from fish of different sizes, and since mercury bioaccumulated primarily in muscle tissue rather than skin or fat, exclusion of the skin does not exclude major portions of the mercury in the fish. Removal of skin is typical in analyses of mercury (in which lipophilic substances such as organochlorides are not analyzed from the same sample), e.g., Gloss et al. (1990).

Whole body samples were used for smaller specimens analyzed for the trophic comparison studies. For some small fish, composites of whole fish were used, where necessary to obtain sufficient sample material.

Carcass concentrations were analyzed to enable estimation of whole body concentrations for larger fish for the trophic comparison study. For selected specimens, the carcass was minced after removal of both fillets (for chemical analysis) and otoliths (for ageing).

Carcass with a single fillet was used to estimate whole body concentrations for specimens on which only a single fillet was removed for tissue analysis.

Specimens were partially or totally thawed, weighed, measured and filleted (for fillet preparations). Each sample was minced and mixed, and a fraction of the sample was used for digestion and analysis. All surfaces in contact with the fillet (glassware, scalpels, knives, and foil for wrapping the sample) were cleaned prior to preparation of each sample. Cleaning was done by: a) muffling at 450°C (glassware, foil), or b) rinsing in nitric acid, then double-distilled water, and solvent-cleaned in acetone (applicable to all types of equipment); or c) rinsing in hexane (new, clean disposable scalpel blades). This procedure is nearly identical to that used for the 1992-1993 screening study (ANSP 1994a), except that a dichloromethane rinse was used in the 1992 study instead of hexane or acetone. Notes were taken on the condition of each specimen, stomach contents, etc. For the 1996-1997 study, otoliths were either dissected from the specimen at the time of sample preparation, or heads were removed for subsequent dissection of otoliths. For some specimens from the 1992-1993 screening study and the 1992-1993 Camden study, heads were archived and otoliths were dissected and archived. A portion of the chain pickerel otoliths from the 1992-1993 screening study were aged, and these data were reported in ANSP (1994a). Remaining otoliths from the 1992-1994 studies were aged as part of this study.

Ageing was done by embedding whole otoliths in epoxy resin and sectioning otoliths on a mineral saw. Ages were estimated from presumed annular bands on the otolith sections.

Sample Digestion

A fraction of each minced fillet was tissumized. Sample material thawed either overnight in a refrigerator or thawed during the day at room temperature was tissumized. From this, an optimal sample size of 1.0 g (wet weight) of tissumized fish tissue was digested in 10 ml of concentrated trace metal grade nitric acid using microwave heating (CEM 1991). Digestion was carried out in closed Teflon-lined vessels employing a CEM microwave model MDS-2100 (950 watts ± 50).

The fish tissue was weighed directly into Teflon liners which were then placed into the vessels; 10 ml of nitric acid was added and the vessels were capped. The vessels were placed into a 12-position tray which was then placed on the rotating carousel of the microwave. A pressure sensing tube was connected to the control vessel, and a fiberoptic temperature probe was placed in the thermal well of the control vessel. Usually, 12 samples were digested at a time using a 5-stage heating program in which temperature was used to control the digestion as follows.

STAGE	1	2	3	4	5
POWER	25%	80%	80%	90%	90%
PRESSURE (PSI)	20	40	85	135	190
RUN TIME (MIN)	10:00	20:00	20:00	20:00	20:00
TIME @ PSI (MIN)	5:00	5:00	5:00	10:00	10:00
TEMPERATURE (°C)	100	140	170	180	190

After the heating program was completed, the vessels were allowed to cool to less than 40°C at which time the pressure within the vessels was about 40 psi. While still in the microwave cavity, pressure in the control vessel was released by slowly unscrewing the vent stem until the pressure reached zero. The fiberoptic temperature probe and pressure sensing tube were disconnected and the carousel removed to a fume hood where the pressure in the other vessels was allowed to bleed off by slowly unscrewing the vent stems.

After release of the pressure, the vessels were uncapped and the tops and sides of the liners were rinsed into the liner with double-deionized water (DDW). The digestate was then brought to 100 ml volume in a 100-ml graduated cylinder with DDW and transferred to a 125-ml Pyrex Wheaton bottle. A volume of 7 ml potassium permanganate (5%) was added to each bottle, and each was capped and allowed to stand overnight.

Sample Analysis and Quantitation

Mercury in the diluted digestate was determined by Manual Cold Vapor Atomic Absorption (USEPA 1979). Excess potassium permanganate was reduced by the addition of 3 ml of 12% sodium chloride-hydroxylamine hydrochloride solution to the Pyrex bottle. After the potassium permanganate became colorless, the samples were analyzed using a Perkin Elmer FIMS-400 Mercury Analyzer. A computer and hard copy data log was kept of all runs as a permanent record. For each sample run, standards were run at the beginning or each run, and a single standard was run after each 20 samples. Each set of standards consisted of a blank and seven concentrations (typically 0.2, 0.5, 2.0, 5.0, 10.0, 15.0, and 20.0 µg/L). Standard curves were computed by linear regression of the means of the peak heights of three runs for each of the different standards. Goodness-of-fit (e.g., linearity) was assessed by calculation of the r-value for the regression. All r-values were greater than 0.995, the New Jersey threshold (values were typically greater than 0.999). The peak heights of the samples were then compared to the standard curve to calculate total mercury, by using the parameters of the linear regression for the standard curve. In some cases, the calculated amount of mercury was greater than the highest standard used in that run. In those cases, the sample was analyzed in another run, using smaller amounts of tissue to maintain the peak height within the calibrated range. In these cases, only the data from runs within the calibrated range were used for analysis. These were transformed to mg/kg wet weight, taking into account the weight of fish tissue digested.

Physico-Chemical Data

A set of measurements was taken at each of the 1996-1997 sampling sites, the two 1994 Hackensack sites, most of the 1992-1993 screening study sites, and most of the 1992-1993 Camden County sampling sites. pH, conductivity, and water temperature were measured in the field. Dissolved organic carbon (DOC), Sulfate (SO_4), Chloride (Cl), and alkalinity were measured in the laboratory.

Specific analytical methods are summarized in Table 3 for this study. For the 1996-1997 sites, measurements and water samples were taken either at the time of fish collecting, or on separate trips. The 1992-1994 sites were revisited in order to take water samples and measurements. Measurements of pH were done as part of the 1992-1993 screening study, using Orion SA250 pH meters (ANSP 1994a). Additional pH data were taken from USGS 1991 and 1992 surface sampling data (USGS 1991a,b, 1992), from RMC (1992, Merrill Creek Reservoir), Wagner (1979, Round Valley Reservoir) and unpublished data taken by several groups: C. Goulden (ANSP) at Round Valley Reservoir; Newark Water District at Clinton and Canistear reservoirs; North Jersey Water District at Wanaque and Monksville reservoirs; and NJDEP at Atlantic City Reservoir. Mean pH values were taken from these external sources (mean of all measurements for partial records, mean of monthly means for daily measurements). Sulfate concentrations are expressed as mg sulfate/kg.

For analysis of correlation among physico-chemical variables, only data taken at the same time were used. For correlation of physico-chemical variables with mercury data, the mean of all observations of each parameter was used, e.g., means of pH values from the 1992-1993 screening study and the 1996-1997 resampling were used.

Measurements and samples were taken about 10 cm below the water surface, usually near the shore of the waterbody. In a few cases, water samples were taken, held on ice, and measurements of pH and conductivity were taken within 12 hours of collection. DOC samples were usually filtered at the time of sample collection. In a few cases, water samples were taken, held on ice, and filtering was done within 12 hours of collection.

Statistical Analysis

Two basic statistical approaches were used to assess differences in mercury concentrations among specimens and sites. The first estimates mean mercury concentrations within discrete units (strata, and waterbodies within strata). The second estimates mercury concentrations as functions of the physico-chemical parameters. For both approaches, it is necessary to account for the increase in mercury with increasing age/size of fish.

Adjustments for size and species of fish. Adjustments for size and species of fish were made to provide more powerful comparisons between waterbodies and groups of waterbodies. A re-

Table 3. Analytical methods and procedures for chemical analysis of water.

pH: Reported as standard pH units; determined by electrometric method with a Fisher Accumet 1001 meter. U.S. EPA, 1983; Method 150.1.

Conductance: Reported as µS; determined by YSI SCT meter or equivalent. U.S. EPA, 1983; Method 120.1.

Temperature: Reported as degrees Celsius (^oC); determined by thermometer or thermistor method, pre-calibrated using a YSI meter. U.S. EPA, 1983; Method 170.1.

Total Alkalinity: Reported as mg/L $CaCO_3$; determined by titration with 0.02 N sulfuric acid to the potentiometric end point (pH 4.5). U.S. EPA, 1983; Method 310.1.

Dissolved Chloride: Reported as mg Cl/L; determined by the titrimetric mercuric nitrate method. U.S. EPA, 1983; Method 325.3.

Dissolved Sulfate: Reported as mg/L SO_4^-; determined by the automated methylthymol blue method. U.S. EPA, 1993a; Method 375.2.

Dissolved (<0.7 µm filtered) Organic Carbon (DOC): Reported as mg C/L; determined on a Dohrmann Envirotech DC-80, utilizing ultra-violet oxidation conversion to carbon dioxide followed by infrared detection. Dohrmann, 1981, U.S. EPA, 1983; Method 415.2., and Wangersky, 1993.

gression of mercury concentration against age, total length or total weight of the specimen was made for each species. Within species, different regressions were made for each stratum. (In general, too few specimens were analyzed from each site to allow accurate site-specific mercury-length regressions.) The regression models were used to calculate a predicted concentration based on specimen length, weight or age, stratum and waterbody. These regressions also allow calculation of a predicted mercury concentration at a standardized age or size. The regressions were calculated using analysis of covariance (ANCOVA), in PROC GLM (SAS 1985). Regressions were of the form:

$$\ln(\text{mercury concentration}) = I + B_{\text{stratum}} + D_{\text{waterbody nested within stratum}}\ C^* \ln(\text{total length})$$

where I is an intercept fit by the model, B_{group} is a "treatment" effect, fit for each stratum, D is a "nested treatment" effect estimating the deviation of each lake from the average within the stratum, and C is a slope fit by the model. The model in ln(mercury concentration) and ln(total length) is equivalent to the power function:

Mercury concentration = $[\exp(I+B_{group} + D)(\text{total length})^{C}$

This model fits the same power C for all groups, and varies the multiplier.

Statistical analyses were done using the GLM procedure in SAS (SAS 1985). Calculations of predicted Hg concentrations were calculated from parameters derived from the SAS runs, using EXCEL.

Comparison of strata and waterbodies. The mercury concentrations of waterbodies and strata were compared by using ANCOVA, as explained in the previous section. Statistical models were written, which estimate mercury concentrations within strata, and in waterbodies within each stratum, after adjustment for the length or age of individual specimens.

Relationship between mercury concentration and physico-chemical parameters. Multiple regression was used to estimate mercury concentrations as functions of the physico-chemical parameters after adjusting for size or age of fish. These models are of the form:

$\ln[Hg] = A + B_{A/S}*\ln(TL \text{ or } Age) + C_1*P_1 + ... C_n *P_n$

where TL is total length, and the P_i are physico-chemical parameters.

The regression models were formed in three ways:

1) *Stepwise regression was used to identify groups of parameters with significant effect.* This procedure sequentially adds parameters with significant correlations with the dependent variable (ln[mercury concentration]), starting with those with the most significant relationships. After each new variable is added, variables previously included are retested, and any variables which are no longer significant are removed.

These models were done using PROC REG in SAS (1985). Models used pH, alkalinity, ln(DOC), ln(conductivity), ln(Cl) and ln(SO4) as potential independent variables, as well as ln(total length), ln(total weight) or ln(age).

Multiple regression is sensitive to correlation among the independent parameters. Since there were correlations among many of the physico-chemical variables, the results must be interpreted carefully. With high correlation among a pair of variables, either variable (but not both) may explain the dependent variables, and which independent variable appears as significant or the most significant will depend on the order in which variables are added, and significance can be sensitive to small changes in the values of the independent and dependent variables. Alternately, both variables may appear significant due to nonlinear relationships between the independent variable and a dependent variable. Fitting a line to the nonlinear relationship can create a pattern of residuals which is fit by a second independent variable which is correlated with the first.

To check for these effects, the slope of the relationships between ln[Hg] and each significant parameter was checked. If the sign of the slope was opposite that expected from known relationships, the relationship was assumed to be an artifact and the model was rerun excluding that parameter. For example, pH and DOC are highly positively correlated. Mercury concentrations typically increase with decreasing pH or DOC, i.e., there is a negative relationship between ln[Hg] and both parameters. If a regression model fits a significant negative relationship with pH and a significant positive relationship to DOC after fitting the pH regression, it is assumed that the DOC relationship is an artifact, and DOC is removed from the model. For these comparisons, it was assumed that the relationship between ln[Hg] should be negative with pH, DOC, alkalinity, conductivity, and sulfate. No a priori direction for the relationship with chloride was assumed.

2) *Reduced regression with parameters assumed to be most important*. Multiple linear regression was done using pH, ln(DOC) and a size/age variable (ln(TL), ln(TW) or ln(age). These regressions were done, since pH and DOC have been established as correlating significantly with mercury bioaccumulation in many systems.

3) *Reduced regression with most easily measured parameters.* One of the goals of the analyses is to determine relationships which can be used to predict mercury concentrations, which can be used in setting advisories or selecting sites for further study. It would be especially advantageous if these predictions could be done using easily collected predictor variables.

   Regressions were done using only ln(TL), pH, and ln(conductivity). Length is routinely measured, while ageing of specimens requires additional preparation and analysis, while pH and conductivity can be measured in the field with meters. Reasonable accuracy can be obtained with inexpensive meters. The other parameters require more complex field collection procedures, as well as laboratory analysis for quantification.

Corbin City Impoundment was excluded from all the regression analyses. This site is brackish, with extreme values of several parameters (very high conductivity, chloride and sulfate). Inclusion of this site could obscure relationships between mercury concentrations and water chemistry among other sites.

Estimation of Whole Body Concentrations

Estimates of bioaccumulation among trophic levels are most meaningful with respect to whole body concentrations. However, fillet concentrations were measured on most larger fish, because of their relevance to human health. For selected specimens of largemouth bass, chain pickerel and brown bullhead, measurements of carcass concentrations were made as well, allowing estimation of whole body concentrations as:

$$C_{whole} = (C_{fillet} * W_{fillet} + C_{carcass} * C_{weight})/(\text{Total weight})$$

Data recording errors on a few specimens necessitated special handling. The carcass weight of one specimen was not measured. The carcass weight of two other specimens was entered incorrectly, as evident from the relative fillet, carcass and total body weights. Among all specimens other than these, the fillet plus carcass weight was between 91% and 98% of the total body weight (excepting one specimen with a value of 87%), with an average of 95%. The difference presumably represents fluid and other tissue lost from the fillet and/or carcass prior to weighing. For these three specimens, the carcass weight was estimated from the total weight and fillet weight, assuming that fillet and carcass weight would total 95% of the total body weight.

RESULTS

Results of 1996-1997 Study

Mercury concentrations differed among species and strata (Table 4, Appendix Table A-1, Appendix B). The 1996-1997 data showed similar patterns to the 1992-1993 screening study results. Among species, mercury concentrations were highest in piscivores (e.g., largemouth bass and chain pickerel). Among strata, mercury concentrations were highest in the Pine Barrens and adjacent waters. The Pine Barrens sites sampled in 1996-1997 included sites in the northern part of the Pine Barrens, while the 1992-1993 sites were mainly in the central and southern Pine Barrens. Thus, the 1996-1997 results show consistent patterns throughout the Barrens. Two of the sites with low to moderate pH (Malaga Lake and Willow Grove Lake) had concentrations as high or higher than those in the Pine Barrens sites. Both of these sites are near the edge of the Pine Barrens. Fish from the other moderate pH sites (Cedar Lake in southern New Jersey and De Voe Lake in central New Jersey) had moderate mercury concentrations. Moderate concentrations were seen in bass from some of the sites in the northern part of the state. Several of these are rivers with current or former industrial use, such as the Rockaway, Passaic, lower Raritan and Pompton rivers, but moderate concentrations were also seen in some larger reservoirs (Boonton and Oak Ridge reservoirs) and in large individual bass from other lakes (e.g., Greenwood Lake and Grovers Mill Pond). Moderate concentrations were seen in brown bullhead and yellow perch from Crater Lake in Sussex County. This is notable, since these species have low concentrations in most sites. Concentrations were low in many of the higher pH sites (e.g., Sunset Lake, Hainesville Pond, Echo Lake) and some riverine sites (e.g., the upper Raritan). Concentrations tended to increase with age and length of fish, so quantitative comparisons of concentrations among sites or species need to adjust for these differences. These adjustments are discussed below, incorporating data from the previous ANSP studies into the 1996-1997 data, to increase reliability of analyses.

The Toxics in Biota Committee of NJDEP, DOH and DOA has developed guidelines for consumption advisories (Toxics in Biota Committee 1994, Stern 1993). These guidelines define mercury concentration categories, based on recommended maximal frequencies of consumption for higher risk people (pregnant women, women planning pregnancy and young women) and lower risk people. The proportions of fish in these advisory groups for each lake is summarized in Table 5. For the lower risk groups, most fish fell in the unrestricted category, with predatory and Pine Barren fish falling into restricted categories. For the higher risk group, most fish fell into some restricted category, with some species (sunfish, brown bullhead, trout) usually in the unrestricted category.

Correlation among Physico-chemical Parameters and Variation among Sites

As part of the 1996-1997 study, measurements of a suite of physico-chemical parameters was measured in each of the 1996-1997 study lakes, as well as most of the lakes previously studied (ANSP 1994a, b, c). These analyses form a basis for interpreting observed differences in mercury bioaccumulation among sites and strata. They also allow a separate analysis of bioaccumulation-

Table 4. Average and range of mercury concentrations in fish from ANSP studies. Type indicates sample type (individual or composite), Sa is the tissue used (fillet or whole body), and N is the number of samples analyzed.

						Total Length (cm)		**Age (years)**		**Hg Concentration (mg/kg wet weight)**	
Water Body	**Species**	**Year**	**Type**	**Sa**	**N**	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**
Coastal Plain Lake - pH 5 (CPL5)											
Malaga Lake	*Esox niger*	1996	Ind	F	5	32.50	29.3 - 36.2	2.6	2 - 4	0.99	0.73 - 1.38
Malaga Lake	*Micropterus salmoides*	1996	Ind	F	1	32.40	32.4	3.0	3	0.95	0.95
Coastal Plain Lake - pH 6 (CPL6)											
Cedar Lake	*Ameiurus nebulosus*	1996	Ind	F	1	31.50	31.5	6.0	6	0.06	0.06
Cedar Lake	*Esox niger*	1996	Ind	F	3	54.07	47.9 - 64.7	4.3	3 - 6	0.43	0.24 - 0.76
Cedar Lake	*Micropterus salmoides*	1996	Ind	F	3	41.43	39.0 - 43.8	5.0	3 - 6	0.48	0.25 - 0.61
De Voe Lake	*Ameiurus nebulosus*	1996	Ind	F	1	27.00	27.0	5.0	5	0.09	0.09
De Voe Lake	*Esox niger*	1996	Ind	F	3	44.33	41.5 - 48.5	4.3	3 - 5	0.22	0.14 - 0.27
De Voe Lake	*Micropterus salmoides*	1996	Ind	F	3	34.10	31.7 - 36.5	2.7	2 - 3	0.18	0.07 - 0.26
Willow Grove Lake	*Ameiurus catus*	1997	Ind	F	1	43.00	43.0	9.0	9	0.17	0.17
Willow Grove Lake	*Ameiurus natalis*	1997	Ind	F	2	29.25	28.0 - 30.5	4.5	4 - 5	0.87	0.82 - 0.91
Willow Grove Lake	*Ameiurus nebulosus*	1997	Ind	F	2	32.70	32.4 - 33.0	4.0	4 - 4	0.25	0.23 - 0.28
Willow Grove Lake	*Esox niger*	1997	Ind	F	5	42.76	31.0 - 53.0	3.4	2 - 4	1.09	0.76 - 1.29
Willow Grove Lake	*Micropterus salmoides*	1997	Ind	F	1	33.20	33.2	3.0	3	1.68	1.68
Coastal Plain Lake - pH 8 (CPL8)											
Sunset Lake	*Dorosoma cepedianum*	1996	Ind	F	1	31.80	31.8	-	-	0.04	0.04
Sunset Lake	*Esox niger*	1996	Ind	F	1	30.70	30.7	2.0	2	0.09	0.09
Sunset Lake	*Lepomis gibbosus*	1996	Ind	F	1	9.40	9.4	-	-	0.04	0.04
Sunset Lake	*Lepomis gibbosus*	1996	Comp	W	2	6.10	5.6 - 6.5	-	-	0.03	-
Sunset Lake	*Lepomis macrochirus*	1996	Ind	F	2	10.00	8.8 - 11.2	2.0	2 - 2	0.04	0.03 - 0.05
Sunset Lake	*Lepomis macrochirus*	1996	Comp	W	35	-	2.2 - 3.4	-	-	0.03	-
Sunset Lake	*Lepomis macrochirus*	1996	Comp	W	37	-	2.3 - 3.3	-	-	0.02	-
Sunset Lake	*Lepomis macrochirus*	1996	Comp	W	30	-	2.4 - 3.5	-	-	0.01	-
Sunset Lake	*Micropterus salmoides*	1996	Ind	F	5	37.20	22.5 - 53.0	3.8	2 - 9	0.30	0.10 - 0.69
Sunset Lake	*Morone americana*	1996	Comp	W	3	5.33	5.0 - 5.5	-	-	0.05	-
Sunset Lake	*Morone americana*	1996	Comp	W	3	5.47	5.4 - 5.5	-	-	0.04	-
Sunset Lake	*Notemigonus crysoleucas*	1996	Comp	W	14	-	3.0 - 5.7	-	-	0.01	-
Sunset Lake	*Notemigonus crysoleucas*	1996	Comp	W	11	-	4.3 - 5.8	-	-	0.01	-
Sunset Lake	*Pomoxis nigromaculatus*	1996	Comp	W	2	5.05	4.8 - 5.3	-	-	0.02	-
Sunset Lake	*Pomoxis nigromaculatus*	1996	Comp	W	4	4.13	4.1 - 4.2	-	-	0.02	-

Table 4 (continued). Average and range of mercury concentrations in fish from ANSP studies. Type indicates sample type (individual or composite), Sa is the tissue used (fillet or whole body), and N is the number of samples analyzed.

						Total Length (cm)		Age (years)		Hg Concentration (mg/kg wet weight)	
Water Body	**Species**	**Year**	**Type**	**Sa**	**N**	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**
Cold-water Stream (CWS)											
Raritan River, South Br., Clairemont stretch	*Salmo trutta*	1996	Ind	F	3	17.73	16.6 - 19.6	2.0	2 - 2	0.01	0.00 - 0.01
Raritan River, South Br., Clairemont stretch	*Salvelinus fontinalis*	1996	Ind	F	1	16.20	16.2	2.0	2	0.02	0.02
Delaware River - below Camden (DRBC)											
Delaware River - Below Camden	*Ictalurus punctatus*	1996	Ind	F	4	47.88	43.5 - 50.0	7.8	5 - 9	0.16	0.02 - 0.40
Delaware River - Below Camden	*Morone americana*	1996	Ind	F	4	21.03	19.1 - 22.9	4.5	3 - 6	0.10	0.07 - 0.16
Delaware River - from Camden to Trenton (DRTS)											
Delaware River - Above Camden	*Ictalurus punctatus*	1996	Ind	F	2	46.35	44.5 - 48.2	11.0	11 - 11	0.16	0.12 - 0.21
Delaware River - Above Camden	*Morone americana*	1996	Ind	F	2	19.00	18.9 - 19.1	6.0	5 - 7	0.13	0.12 - 0.15
Northern Carbonaceous Lake (NCARB)											
Echo Lake	*Micropterus salmoides*	1996	Ind	F	4	32.20	29.0 - 35.0	4.0	4 - 4	0.15	0.12 - 0.17
Northern Industrial River (NINDR)											
Passaic River at Hatfield Swamp	*Ameiurus natalis*	1996	Ind	F	1	21.40	21.4	4.0	4	0.11	0.11
Passaic River at Hatfield Swamp	*Lepomis gibbosus*	1996	Ind	F	2	12.50	12.4 - 12.6	3.0	3 - 3	0.09	0.08 - 0.09
Passaic River at Hatfield Swamp	*Lepomis macrochirus*	1996	Ind	F	1	18.90	18.9	4.0	4	0.19	0.19
Passaic River at Hatfield Swamp	*Micropterus salmoides*	1996	Ind	F	3	27.50	23.0 - 36.0	3.7	2 - 7	0.31	0.17 - 0.53
Passaic River at Hatfield Swamp	*Pomoxis nigromaculatus*	1996	Ind	F	4	19.25	18.1 - 20.0	5.8	4 - 7	0.26	0.21 - 0.32
Pompton River at Lincoln Park	*Esox lucius*	1996	Ind	F	3	45.47	27.8 - 66.6	2.7	2 - 3	0.39	0.17 - 0.59
Pompton River at Lincoln Park	*Esox niger*	1996	Ind	F	1	22.70	22.7	2.0	2	0.23	0.23
Pompton River at Lincoln Park	*Micropterus salmoides*	1996	Ind	F	2	35.45	35.4 - 35.5	7.5	7 - 8	0.59	0.50 - 0.68
Pompton River at Lincoln Park	*Perca flavescens*	1996	Ind	F	2	22.50	21.0 - 24.0	3.0	3 - 3	0.23	0.21 - 0.26
Pompton River at Pequannock River	*Ambloplites rupestris*	1997	Ind	F	3	20.77	19.2 - 22.0	4.0	3 - 5	0.58	0.54 - 0.68
Pompton River at Pequannock River	*Ameiurus natalis*	1997	Ind	F	1	26.20	26.2	7.0	7	0.80	0.80
Pompton River at Pequannock River	*Erimyzon oblongus*	1997	Ind	W	3	9.27	8.2 - 9.8	1.0	1 - 1	0.06	0.05 - 0.07
Pompton River at Pequannock River	*Lepomis auritus*	1997	Ind	F	2	14.75	13.7 - 15.8	5.0	3 - 7	0.37	0.32 - 0.41
Pompton River at Pequannock River	*Lepomis gibbosus*	1997	Ind	W	3	9.47	9.1 - 9.7	1.0	1 - 1	0.14	0.12 - 0.16
Pompton River at Pequannock River	*Lepomis gibbosus*	1997	Ind	F	2	14.3	14.1 - 14.5	2.5	2 - 3	0.57	0.35 - 0.78
Pompton River at Pequannock River	*Lepomis gibbosus*	1997	Comp	W	3	5.33	4.9 - 5.6	-	-	0.11	-
Pompton River at Pequannock River	*Micropterus dolomieu*	1997	Ind	F	4	29.90	25.4 - 36.8	5.0	4 - 6	0.96	0.57 - 1.14

Table 4 (continued). Average and range of mercury concentrations in fish from ANSP studies. Type indicates sample type (individual or composite), Sa is the tissue used (fillet or whole body), and N is the number of samples analyzed.

						Total Length (cm)		**Age (years)**		**Hg Concentration (mg/kg wet weight)**	
Water Body	**Species**	**Year**	**Type**	**Sa**	**N**	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**
Pompton River at Pequannock River	*Micropterus salmoides*	1997	Ind	F	2	39.40	39.0 - 39.8	7.5	7 - 8	1.17	0.99 - 1.36
Pompton River at Pequannock River	*Pomoxis nigromaculatus*	1997	Ind	F	1	19.30	19.3	2.0	2	0.24	0.24
Raritan River at Millstone Creek	*Ameiurus nebulosus*	1996	Ind	F	2	26.45	25.4 - 27.5	4.5	4 - 5	0.07	0.06 - 0.07
Raritan River at Millstone Creek	*Ictalurus punctatus*	1996	Ind	F	1	39.80	39.8	-	-	0.15	0.15
Raritan River at Millstone Creek	*Micropterus salmoides*	1996	Ind	F	4	37.68	32.5 - 44.9	6.8	5 - 12	0.37	0.33 - 0.46
Raritan River at Neshanic Station	*Ambloplites rupestris*	1996	Ind	F	1	15.00	15.0	3.0	3	0.09	0.09
Raritan River at Neshanic Station	*Ameiurus natalis*	1996	Ind	F	2	16.75	16.3 - 17.2	2.5	2 - 3	0.07	0.06 - 0.08
Raritan River at Neshanic Station	*Lepomis auritus*	1996	Ind	F	2	15.80	15.7 - 15.9	2.5	2 - 3	0.12	0.09 - 0.15
Raritan River at Neshanic Station	*Micropterus dolomieu*	1996	Ind	F	1	20.70	20.7	2.0	2	0.18	0.18
Raritan River at Neshanic Station	*Micropterus salmoides*	1996	Ind	F	1	18.20	18.2	2.0	2	0.11	0.11
Rockaway River near Whippany	*Lepomis macrochirus*	1996	Ind	F	1	14.50	14.5	2.0	2	0.12	0.12
Rockaway River near Whippany	*Micropterus salmoides*	1996	Ind	F	1	39.80	39.8	9.0	9	0.92	0.92
Rockaway River near Whippany	*Pomoxis nigromaculatus*	1996	Ind	F	1	17.90	17.9	6.0	6	0.21	0.21
Northern Midlands Lake (NML)											
Boonton Reservoir	*Ameiurus catus*	1996	Ind	F	1	40.00	40.0	15.0	15	0.54	0.54
Boonton Reservoir	*Ameiurus nebulosus*	1996	Ind	F	2	31.65	30.5 - 32.8	6.0	5 - 7	0.02	0.01 - 0.02
Boonton Reservoir	*Micropterus salmoides*	1996	Ind	F	3	40.57	35.0 - 45.1	6.3	5 - 8	0.58	0.33 - 0.81
Green Turtle Lake	*Esox niger*	1996	Ind	F	3	39.80	28.1 - 46.6	1.7	1 - 2	0.13	0.11 - 0.15
Green Turtle Lake	*Micropterus salmoides*	1996	Ind	F	3	28.13	23.6 - 34.7	3.0	2 - 5	0.24	0.17 - 0.32
Green Turtle Lake	*Perca flavescens*	1996	Ind	F	2	22.70	20.8 - 24.6	7.5	5 - 10	0.09	0.09 - 0.10
Grovers Mill Pond	*Ameiurus nebulosus*	1997	Ind	F	2	32.60	32.2 - 33.0	9.5	9 - 10	0.24	0.08 - 0.40
Grovers Mill Pond	*Enneacanthus gloriosus*	1997	Comp	W	6	6.02	5.6 - 6.5	-	-	0.05	-
Grovers Mill Pond	*Enneacanthus gloriosus*	1997	Comp	W	3	6.40	6.1 - 6.9	-	-	0.03	-
Grovers Mill Pond	*Enneacanthus gloriosus*	1997	Comp	W	8	4.86	4.5 - 5.3	-	-	0.02	-
Grovers Mill Pond	*Esox niger*	1997	Ind	F	4	36.05	35.2 - 37.2	2.5	2 - 3	0.15	0.12 - 0.18
Grovers Mill Pond	*Lepomis gibbosus*	1997	Ind	W	6	9.80	8.7 - 10.8	1.0	1 - 1	0.01	0.01 - 0.02
Grovers Mill Pond	*Lepomis gibbosus*	1997	Comp	W	2	6.15	6.0 - 6.3	-	-	0.01	-
Grovers Mill Pond	*Micropterus salmoides*	1997	Ind	F	5	34.32	28.0 - 41.5	4.2	3 - 6	0.35	0.25 - 0.47
Grovers Mill Pond	*Notemigonus crysoleucas*	1997	Ind	W	5	19.18	17.0 - 21.1	4.0	4 - 4	0.01	-0.01 - 0.04
Hainesville Pond	*Esox niger*	1996	Ind	F	3	37.47	36.5 - 39.3	3.0	3 - 3	0.14	0.14 - 0.15
Hainesville Pond	*Micropterus salmoides*	1996	Ind	F	3	30.87	30.3 - 31.3	3.0	3 - 3	0.19	0.13 - 0.23

Table 4 (continued). Average and range of mercury concentrations in fish from ANSP studies. Type indicates sample type (individual or composite), Sa is the tissue used (fillet or whole body), and N is the number of samples analyzed.

						Total Length (cm)		Age (years)		Hg Concentration (mg/kg wet weight)	
Water Body	**Species**	**Year**	**Type**	**Sa**	**N**	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**
Oak Ridge Reservoir	*Ameiurus natalis*	1997	Ind	F	1	24.50	24.5	4.0	4	0.25	0.25
Oak Ridge Reservoir	*Ameiurus nebulosus*	1997	Ind	F	2	33.75	33.0 - 34.5	4.0	4 - 4	0.02	0.02 - 0.02
Oak Ridge Reservoir	*Esox niger*	1997	Ind	F	4	35.40	25.0 - 58.0	1.8	1 - 3	0.28	0.24 - 0.30
Oak Ridge Reservoir	*Lepomis auritus*	1997	Ind	W	3	10.83	10.6 - 11.1	3.0	3 - 3	0.04	0.03 - 0.05
Oak Ridge Reservoir	*Lepomis gibbosus*	1997	Ind	W	3	9.67	9.3 - 9.9	1.0	1 - 1	0.03	0.02 - 0.05
Oak Ridge Reservoir	*Lepomis macrochirus*	1997	Ind	W	4	9.50	9.0 - 10.4	1.0	1 - 1	0.04	0.03 - 0.05
Oak Ridge Reservoir	*Micropterus dolomieu*	1997	Ind	F	1	40.20	40.2	4.0	4	0.49	0.49
Oak Ridge Reservoir	*Micropterus salmoides*	1997	Ind	F	4	43.83	36.8 - 48.0	7.5	4 - 11	0.65	0.38 - 0.89
Oak Ridge Reservoir	*Notemigonus crysoleucas*	1997	Ind	W	2	13.85	9.6 - 18.1	2.0	0 - 4	0.02	-0.03 - 0.06
Oak Ridge Reservoir	*Perca flavescens*	1997	Ind	W	2	17.50	16.7 - 18.3	2.0	2 - 2	0.04	0.04 - 0.04
Speedwell Lake	*Ameiurus nebulosus*	1996	Ind	F	1	21.00	21.0	4.0	4	0.01	0.01
Speedwell Lake	*Lepomis macrochirus*	1996	Ind	F	2	19.00	18.3 - 19.7	6.5	6 - 7	0.12	0.12 - 0.13
Speedwell Lake	*Micropterus salmoides*	1996	Ind	F	3	32.03	27.5 - 36.1	3.7	2 - 5	0.28	0.10 - 0.38
Wawayanda Lake	*Esox niger*	1996	Ind	F	6	39.55	35.0 - 42.4	3.5	3 - 4	0.32	0.25 - 0.44
Northern Midlands Lake - Shawangunk Formation (NMLSSG)											
Crater Lake	*Ameiurus nebulosus*	1996	Ind	F	1	30.00	30.0	10.0	10	0.39	0.39
Crater Lake	*Perca flavescens*	1996	Ind	F	3	23.13	19.9 - 27.9	10.3	8 - 13	0.44	0.29 - 0.58
Steenykill Lake	*Micropterus salmoides*	1996	Ind	F	6	27.90	26.5 - 29.6	2.2	2 - 3	0.18	0.15 - 0.22
Pine Barrens Lake (PBL)											
Butterfly Bogs	*Ameiurus nebulosus*	1996	Ind	F	1	30.60	30.6	3.0	3	0.08	0.08
Butterfly Bogs	*Esox niger*	1996	Ind	F	1	33.90	33.9	4.0	4	0.78	0.78
Double Trouble Lake	Corixidae	1996	Comp	W	many	-	-	-	-	0.16	-
Double Trouble Lake	*Ameiurus natalis*	1996	Ind	F	3	27.00	26.1 - 28.3	9.3	8 - 12	1.03	0.82 - 1.18
Double Trouble Lake	*Enneacanthus chaetodon*	1996	Comp	W	15	-	3.0 - 4.4	-	-	0.10	-
Double Trouble Lake	*Enneacanthus chaetodon*	1996	Comp	W	3	-	5.9 - 6.2	-	-	0.16	-
Double Trouble Lake	*Enneacanthus chaetodon*	1996	Comp	W	3	-	5.9 - 6.7	-	-	0.20	-
Double Trouble Lake	*Enneacanthus chaetodon*	1996	Comp	W	3	-	5.9 - 6.4	-	-	0.18	-
Double Trouble Lake	*Enneacanthus chaetodon*	1996	Comp	W	12	-	3.4 - 4.5	-	-	0.11	-
Double Trouble Lake	*Erimyzon oblongus*	1996	Ind	F	2	25.15	22.3 - 28.0	4.5	3 - 6	0.38	0.25 - 0.52
Double Trouble Lake	*Esox niger*	1996	Ind	W	1	11.20	11.2	0.0	0	0.28	0.28
Double Trouble Lake	*Esox niger*	1996	Ind	F	1	18.10	18.1	2.0	2	0.74	0.74
Double Trouble Lake	*Esox niger*	1996	Ind	F	4	48.60	37.7 - 57.6	9.8	7 - 11	1.84	1.24 - 2.30

Table 4 (continued). Average and range of mercury concentrations in fish from ANSP studies. Type indicates sample type (individual or composite), Sa is the tissue used (fillet or whole body), and N is the number of samples analyzed.

						Total Length (cm)		Age (years)		Hg Concentration (mg/kg wet weight)	
Water Body	**Species**	**Year**	**Type**	**Sa**	**N**	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**
Success Lake	*Esox niger*	1996	Ind	F	8	33.30	27.5 - 40.0	4.0	3 - 6	0.93	0.63 - 1.64
Whitesbog Pond	*Esox niger*	1997	Ind	F	5	32.18	23.0 - 39.6	2.0	2 - 2	0.71	0.43 - 1.02
Pine Barrens River (PBR)											
Ridgeway Branch of Tom's River	*Ameiurus nebulosus*	1996	Ind	F	4	25.45	22.8 - 27.0	7.0	3 - 11	0.83	0.17 - 1.57
Ridgeway Branch of Tom's River	*Esox niger*	1996	Ind	F	1	36.00	36.0	4.0	4	1.22	1.22
Unique Lake (UL)											
Greenwood Lake	*Alosa pseudoharengus*	1996-7	Ind	W	4	15.70	15.0 - 16.8	-	-	0.05	0.05 - 0.07
Greenwood Lake	*Lepomis macrochirus*	1996-7	Ind	W	4	13.25	13.0 - 13.6	3.0	3 - 3	0.02	0.01 - 0.03
Greenwood Lake	*Micropterus salmoides*	1996-7	Ind	F	5	35.64	31.4 - 40.0	4.2	3 - 7	0.24	0.15 - 0.40
Greenwood Lake	*Morone americana*	1996-7	Ind	W	2	17.70	17.2 - 18.2	2.0	2 - 2	0.00	-0.01 - 0.00
Greenwood Lake	*Morone americana*	1996-7	Ind	F	2	18.75	18.3 - 19.2	2.0	2 - 2	0.01	0.00 - 0.02

Table 5. Percentages of fish within concentration groupings used for consumption advisories by the state Toxics and Biota Committee. **High Risk**: Pregnant Women, Women Planning Pregnancy Within a Year and Young Children 1: < 0.08ppm; 2: 0.08 - 0.18 ppm; 0.19 - 0.54 ppm; > 0.54 ppm. **Normal Risk**: Other Adults and Adolescents 1: < 0.35ppm; 2: 0.35 - 0.93 ppm; 0.94 - 2.81 ppm; > 2.81 ppm.

				High Risk				**Normal Risk**			
Water Body	**Species**	**Yr.**	**N**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Coastal Plain Lake - pH 5 (CPL5)											
Malaga Lake	*Esox niger*	96	5	-	-	-	100	-	40	60	-
Malaga Lake	*Micropterus salmoides*	96	1	-	-	-	100	-	-	100	-
Coastal Plain Lake - pH 6 (CPL6)											
Cedar Lake	*Ameiurus nebulosus*	96	1	100	-	-	-	100	-	-	-
Cedar Lake	*Esox niger*	96	3	-	-	67	33	67	33	-	-
Cedar Lake	*Micropterus salmoides*	96	3	-	-	33	67	33	67	-	-
De Voe Lake	*Ameiurus nebulosus*	96	1	-	100	-	-	100	-	-	-
De Voe Lake	*Esox niger*	96	3	-	33	67	-	100	-	-	-
De Voe Lake	*Micropterus salmoides*	96	3	-	33	67	-	100	-	-	-
Willow Grove Lake	*Ameiurus catus*	97	1	-	100	-	-	100	-	-	-
Willow Grove Lake	*Ameiurus natalis*	97	2	-	-	-	100	-	100	-	-
Willow Grove Lake	*Ameiurus nebulosus*	97	2	-	-	100	-	100	-	-	-
Willow Grove Lake	*Esox niger*	97	5	-	-	-	100	-	20	80	-
Willow Grove Lake	*Micropterus salmoides*	97	1	-	-	-	100	-	-	100	-
Coastal Plain Lake - pH 8 (CPL8)											
Sunset Lake	*Esox niger*	96	1	-	100	-	-	100	-	-	-
Sunset Lake	*Lepomis gibbosus*	96	1	100	-	-	-	100	-	-	-
Sunset Lake	*Lepomis macrochirus*	96	2	100	-	-	-	100	-	-	-
Sunset Lake	*Micropterus salmoides*	96	5	-	40	40	20	60	40	-	-
Cold-water Stream (CWS)											
Raritan River, South Br., Clairemont Stretch	*Salmo trutta*	96	3	100	-	-	-	100	-	-	-
Raritan River, South Br., Clairemont Stretch	*Salvelinus fontinalis*	96	1	100	-	-	-	100	-	-	-
Delaware River - below Camden (DRBC)											
Delaware River - Below Camden	*Ictalurus punctatus*	96	4	50	25	25	-	75	25	-	-
Delaware River - Below Camden	*Morone americana*	96	4	25	75	-	-	100	-	-	-

Table 5 (continued). Percentages of fish within concentration groupings used for consumption advisories by the state Toxics and Biota Committee. **High Risk**: Pregnant Women, Women Planning Pregnancy Within a Year and Young Children 1: < 0.08ppm; 2: 0.08 - 0.18 ppm; 0.19 - 0.54 ppm; > 0.54 ppm. **Normal Risk**: Other Adults and Adolescents 1: < 0.35ppm; 2: 0.35 - 0.93 ppm; 0.94 - 2.81 ppm; > 2.81 ppm.

				High Risk				**Normal Risk**			
Water Body	**Species**	**Yr.**	**N**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Delaware River - from Camden to Trenton (DRTS)											
Delaware River - Above Camden	*Ictalurus punctatus*	96	2	-	50	50	-	100	-	-	-
Delaware River - Above Camden	*Morone americana*	96	2	-	100	-	-	100	-	-	-
Northern Carbonate Lake (NCARB)											
Echo Lake	*Micropterus salmoides*	96	4	-	100	-	-	100	-	-	-
Northern Carbonate Lake - Unique Lake (NCARB-UL)											
Northern Industrial River (NINDR)											
Passaic River at Hatfield Swamp	*Ameiurus natalis*	96	1	-	100	-	-	100	-	-	-
Passaic River at Hatfield Swamp	*Lepomis gibbosus*	96	2	-	100	-	-	100	-	-	-
Passaic River at Hatfield Swamp	*Lepomis macrochirus*	96	1	-	-	100	-	100	-	-	-
Passaic River at Hatfield Swamp	*Micropterus salmoides*	96	3	-	33	67	-	67	33	-	-
Passaic River at Hatfield Swamp	*Pomoxis nigromaculatus*	96	4	-	-	100	-	100	-	-	-
Pompton River at Lincoln Park	*Esox lucius*	96	3	-	33	33	33	33	67	-	-
Pompton River at Lincoln Park	*Esox niger*	96	1	-	-	100	-	100	-	-	-
Pompton River at Lincoln Park	*Micropterus salmoides*	96	2	-	-	50	50	-	100	-	-
Pompton River at Lincoln Park	*Perca flavescens*	96	2	-	-	100	-	100	-	-	-
Pompton River at Pequannock River	*Ambloplites rupestris*	97	3	-	-	33	67	-	100	-	-
Pompton River at Pequannock River	*Ameiurus natalis*	97	1	-	-	-	100	-	100	-	-
Pompton River at Pequannock River	*Erimyzon oblongus*	97	3	67	33	-	-	100	-	-	-
Pompton River at Pequannock River	*Lepomis auritus*	97	2	-	-	100	-	50	50	-	-
Pompton River at Pequannock River	*Lepomis gibbosus*	97	5	-	60	20	20	60	40	-	-
Pompton River at Pequannock River	*Micropterus dolomieu*	97	4	-	-	-	100	-	25	75	-
Pompton River at Pequannock River	*Micropterus salmoides*	97	2	-	-	-	100	-	-	100	-
Pompton River at Pequannock River	*Pomoxis nigromaculatus*	97	1	-	-	100	-	100	-	-	-
Raritan River at Millstone Creek	*Ameiurus nebulosus*	96	2	50	50	-	-	100	-	-	-
Raritan River at Millstone Creek	*Ictalurus punctatus*	96	1	-	100	-	-	100	-	-	-
Raritan River at Millstone Creek	*Micropterus salmoides*	96	4	-	-	100	-	50	50	-	-

Table 5 (continued). Percentages of fish within concentration groupings used for consumption advisories by the state Toxics and Biota Committee. **High Risk**: Pregnant Women, Women Planning Pregnancy Within a Year and Young Children 1: < 0.08ppm; 2: 0.08 - 0.18 ppm; 0.19 - 0.54 ppm; > 0.54 ppm. **Normal Risk**: Other Adults and Adolescents 1: < 0.35ppm; 2: 0.35 - 0.93 ppm; 0.94 - 2.81 ppm; > 2.81 ppm.

				High Risk				Normal Risk			
Water Body	**Species**	**Yr.**	**N**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Raritan River at Neshanic Station	*Ambloplites rupestris*	96	1	-	100	-	-	100	-	-	-
Raritan River at Neshanic Station	*Ameiurus natalis*	96	2	50	50	-	-	100	-	-	-
Raritan River at Neshanic Station	*Lepomis auritus*	96	2	-	100	-	-	100	-	-	-
Raritan River at Neshanic Station	*Micropterus dolomieu*	96	1	-	100	-	-	100	-	-	-
Raritan River at Neshanic Station	*Micropterus salmoides*	96	1	-	100	-	-	100	-	-	-
Rockaway River near Whippany	*Lepomis macrochirus*	96	1	-	100	-	-	100	-	-	-
Rockaway River near Whippany	*Micropterus salmoides*	96	1	-	-	-	100	-	100	-	-
Rockaway River near Whippany	*Pomoxis nigromaculatus*	96	1	-	-	100	-	100	-	-	-
Northern Midland Lake (NML)											
Boonton Reservoir	*Ameiurus catus*	96	1	-	-	100	-	-	100	-	-
Boonton Reservoir	*Ameiurus nebulosus*	96	2	100	-	-	-	100	-	-	-
Boonton Reservoir	*Micropterus salmoides*	96	3	-	-	33	67	33	67	-	-
Green Turtle Lake	*Esox niger*	96	3	-	100	-	-	100	-	-	-
Green Turtle Lake	*Micropterus salmoides*	96	3	-	33	67	-	100	-	-	-
Green Turtle Lake	*Perca flavescens*	96	2	-	100	-	-	100	-	-	-
Grovers Mill Pond	*Ameiurus nebulosus*	97	2	-	50	50	-	50	50	-	-
Grovers Mill Pond	*Esox niger*	97	4	-	100	-	-	100	-	-	-
Grovers Mill Pond	*Lepomis gibbosus*	97	5	100	-	-	-	100	-	-	-
Grovers Mill Pond	*Micropterus salmoides*	97	5	-	-	100	-	40	60	-	-
Grovers Mill Pond	*Notemigonus crysoleucas*	97	5	100	-	-	-	100	-	-	-
Hainesville Pond	*Esox niger*	96	3	-	100	-	-	100	-	-	-
Hainesville Pond	*Micropterus salmoides*	96	3	-	33	67	-	100	-	-	-
Oak Ridge Reservoir	*Ameiurus natalis*	97	1	-	-	100	-	100	-	-	-
Oak Ridge Reservoir	*Ameiurus nebulosus*	97	2	100	-	-	-	100	-	-	-
Oak Ridge Reservoir	*Esox niger*	97	4	-	-	100	-	100	-	-	-
Oak Ridge Reservoir	*Lepomis auritus*	97	3	100	-	-	-	100	-	-	-
Oak Ridge Reservoir	*Lepomis gibbosus*	97	3	100	-	-	-	100	-	-	-

Table 5 (continued). Percentages of fish within concentration groupings used for consumption advisories by the state Toxics and Biota Committee. **High Risk**: Pregnant Women, Women Planning Pregnancy Within a Year and Young Children 1: < 0.08ppm; 2: 0.08 - 0.18 ppm; 0.19 - 0.54 ppm; > 0.54 ppm. **Normal Risk**: Other Adults and Adolescents 1: < 0.35ppm; 2: 0.35 - 0.93 ppm; 0.94 - 2.81 ppm; > 2.81 ppm.

				High Risk				**Normal Risk**			
Water Body	**Species**	**Yr.**	**N**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Oak Ridge Reservoir	*Lepomis macrochirus*	97	4	100	-	-	-	100	-	-	-
Oak Ridge Reservoir	*Micropterus dolomieu*	97	1	-	-	100	-	-	100	-	-
Oak Ridge Reservoir	*Micropterus salmoides*	97	4	-	-	25	75	-	100	-	-
Oak Ridge Reservoir	*Notemigonus crysoleucas*	97	2	100	-	-	-	100	-	-	-
Oak Ridge Reservoir	*Perca flavescens*	97	2	100	-	-	-	100	-	-	-
Speedwell Lake	*Ameiurus nebulosus*	96	1	100	-	-	-	100	-	-	-
Speedwell Lake	*Lepomis macrochirus*	96	2	-	100	-	-	100	-	-	-
Speedwell Lake	*Micropterus salmoides*	96	3	-	33	67	-	33	67	-	-
Wawayanda Lake	*Esox niger*	96	6	-	-	100	-	67	33	-	-
Northern Midland Lake - Shawangunk Formation (NMLSSG)											
Crater Lake	*Ameiurus nebulosus*	96	1	-	-	100	-	-	100	-	-
Crater Lake	*Perca flavescens*	96	3	-	-	67	33	33	67	-	-
Steenykill Lake	*Micropterus salmoides*	96	6	-	50	50	-	100	-	-	-
Pine Barrens Lake (PBL)											
Butterfly Bogs	*Ameiurus nebulosus*	96	1	-	100	-	-	100	-	-	-
Butterfly Bogs	*Esox niger*	96	1	-	-	-	100	-	100	-	-
Double Trouble Lake	*Ameiurus natalis*	96	3	-	-	-	100	-	33	67	-
Double Trouble Lake	*Erimyzon oblongus*	96	2	-	-	100	-	50	50	-	-
Double Trouble Lake	*Esox niger*	96	6	-	-	17	83	17	17	67	-
Success Lake	*Esox niger*	96	8	-	-	-	100	-	63	38	-
Whitesbog Pond	*Esox niger*	97	3	-	-	33	67	-	100	-	-
Pine Barrens River (PBR)											
Ridgeway Branch of Tom's River	*Ameiurus nebulosus*	96	4	-	25	25	50	25	25	50	-
Ridgeway Branch of Tom's River	*Esox niger*	96	1	-	-	-	100	-	-	100	-
Unique Lake (UL)											
Greenwood Lake	*Lepomis macrochirus*	96-7	4	100	-	-	-	100	-	-	-
Greenwood Lake	*Micropterus salmoides*	96-7	5	-	40	60	-	80	20	-	-
Greenwood Lake	*Morone americana*	96-7	4	100	-	-	-	100	-	-	-

chemistry relationships, which can be used to predict mercury concentrations in different types of sites. These analyses are presented later, incorporating mercury data from the previous ANSP studies.

There was high correlation among the physico-chemical parameters (Tables 6-7), largely reflecting the gradient from soft, low pH sites (e.g., Pine Barrens sites) through hard, high pH sites. Corbin City Impoundment was not included in the correlation analysis, since its extreme values for several parameters (e.g., conductivity, chloride and sulfate) would affect overall correlations among other sites. DOC was negatively correlated with pH, decreasing with increasing pH up to a pH of about 6.5, with little apparent relationship at higher pH's. Alkalinity was 0 for the low pH sites and tended to increase with increasing pH. However, there were also low-alkalinity sites of moderate to high pH, such as Assunpink Lake, Saw Mill Pond, Crater Lake, Steenykill Lake, Clinton Reservoir and Split Rock Reservoir. This pattern is related to geological setting, with most of these sites located in sandstone, metamorphic or igneous rocks in the northern part of the state. Conductivity showed high correlation with pH and alkalinity, being lowest in the Pine Barrens and low alkalinity sites. Chloride concentrations tend to vary both with location (e.g., higher near the coast, and northern areas where road salting is more frequent) and land use (higher in urban areas). Chloride concentrations were lowest in sites in the northwestern part of the state (especially Crater Lake). Sulfate concentrations were relatively low in a few lakes in or near the Pine Barrens (e.g., Atlantic City Reservoir), in northwestern lakes, and in some northern lakes (e.g., Green Turtle Pond, Clinton Reservoir, Split Rock Reservoir). Sulfate was highest in the southern Coastal Plain streams and ponds.

Concentrations of Mercury in Fish Most Likely to Be Consumed

Analysis focused on chain pickerel and largemouth bass, since these species are likely to have high bioaccumulation. However, many fish of these species which are caught may be released instead of being consumed. Other species with lower mercury concentrations, but higher frequency of consumption, might pose greater human health risks. Additional analyses were targeted at species more commonly consumed by people. These fish include catfish, bullheads, and a variety of "pan fish", including white and yellow perch, crappies, and sunfish.

In general, catfish (white and channel) bioaccumulate mercury more slowly than piscivores such as bass and pickerel (e.g., ANSP 1994a). However, because these species are long-lived, moderately high concentrations were found in some specimens from this study (Table 3) or from the previous studies (ANSP 1994a,b c; Appendix Table A-2). Concentrations greater than 0.50 mg/kg wet weight were found in a large specimen of white catfish from Boonton Reservoir 0.54 mg/kg wet weight), and in two specimens analyzed in the 1992-1993 screening study (0.72 mg/kg wet weight in a very large channel catfish from the Delaware and Raritan Canal and 0.58 mg/kg wet weight in a large white catfish from Budd Lake). Other observed values (mostly from specimens from the Delaware River and tributaries) were less than 0.30 mg/kg wet weight.

Yellow bullhead were collected mainly from low pH sites, while brown bullhead were more typical of higher pH sites. The two species were collected together at few sites (Oak Ridge

Table 6. Results of water chemistry analyses, by lake.

Waterbody	Avg. pH	Date	pH	Temp., H_2O (°C)	Conductivity (µmhos)	DOC (mg / L)	Alkalinity (mg / L)	Chloride (mg / L)	Sulfate (mg / L)
Alcyon Lake	6.82	7/18/96	7.11	25.7	159.3	3.91	22.55	23.44	12.38
Assunpink Creek - Lower	6.97	11/20/96	7.02	9.1	170	4.88	29.59	25	18.76
Assunpink Lake	7.19	11/20/96	6.88	7.3	85	3.04	3.12	13.54	18.26
Atlantic City Reservoir	5.62	8/22/96	5.30	23.8	46	7.24	2	10.64	4.56
Atlantic City Reservoir	5.62	8/22/96	6.46	26.4	63.4	4.62	2.94	14.58	4.31
Atsion Lake	4.48	7/18/96	4.33	26.8	56.7	27.84	0	8.33	11.56
Atsion Lake	4.48	7/21/96	4.28		57	32.8	0		
Batsto Lake	4.72	7/18/96	4.53	25.6	51.3	15.1	0	8.33	7.2
Big Timber Creek	7.18	12/18/96	7.05	9.4	149	4.62	25.96	16.67	16.87
Boonton Reservoir	7.35	11/27/96	7.35	12.3	190	4	37	32.78	10.74
Budd Lake	8.60	12/12/96	8.64	4.0	210	5.07	31.37	50	10.14
Butterfly Bogs Pond	4.63	11/6/96	5.05	11.5	62				
Butterfly Bogs Pond	4.63	7/15/96	4.21	24.0	68	22.41	0	12.24	8.62
Canistear Reservoir	7.47	10/28/96	7.36	12.6		6.47	24.51	10.5	7.15
Lake Carasaljo	6.77	11/6/96	6.48	9.9	91	7.36	7.29	16.84	11.87
Carnegie Lake	7.40	11/20/96	7.00	8.8	185	4.46	28	27.78	19.27
Cedar Lake	6.51	10/23/96	6.51	13.9	81	4.19	8.82	11.22	9.11
Cranberry Lake	8.08	12/11/96	7.25	3.5	120	4.78	28.12	21.02	9.59
Clementon Lake	6.72	8/22/96	7.13	25.0	96	2.96	10.78	13.02	9.73
Clinton Reservoir	7.11	10/28/96	7.01	14.8		4.58	7	4.5	6.26
Cooper River Park Lake	6.65	12/18/96	6.98	8.4	117.3	5.83	19.39	13.54	14.87
Corbin City Impoundment #3	6.35	7/18/96	6.02	30.1	4000	15.44	4.9	1375	144.09
Crater Lake	6.92	6/24/96	7.01	21.9	20	1.67	5	0.83	8.1
Crater Lake	6.92	12/11/96	6.82	2.3	24	2.23	3.06	1.63	7.78
Crosswick Creek	7.44	11/20/96	7.28	5.9	142	3.09	32.29	14.29	15.91
Crystal Lake	7.27	11/20/96	7.20	6.2	167	3.23	29	23.4	19.41
Delaware River - Below Camden	7.27	10/24/96	7.14	13.9	174	4.32	32	16.83	16.78
Delaware River - Camden to Trenton	7.28	11/20/96	7.32	5.4	125	2.59	30	13.54	13.95
Delaware River - Trenton to Easton	8.19	11/3/96	7.83	7.3	154	6.36	40.62	12.24	17.25
Delaware River - Easton to Water Gap	7.35	12/12/96	6.92	6.0	104	2.34	26	10.47	10.85

Table 6 (continued). Results of water chemistry analyses, by lake.

Waterbody	Avg. pH	Date	pH	Temp., H_2O (°C)	Conductivity (µmhos)	DOC (mg / L)	Alkalinity (mg / L)	Chloride (mg / L)	Sulfate (mg / L)
Delaware River - above Water Gap	7.53	6/21/96	7.19		130	2.62	14	9.68	8.05
Delaware River - above Water Gap	7.53	12/11/96	7.03	5.8	60	2.28	11	8.51	7.67
Delaware Raritan Canal	7.90								
Devoe Lake (Spotswood)	6.15	7/22/96	6.15	24.1	138	3.85	2.04	22.96	23.08
Double Trouble Pond	4.96	11/6/96	4.96	12.0	39	5.92	0	5.85	4.56
Dundee Lake	7.70	10/29/96	7.39	12.2	189	9.41	36	32.5	13.93
East Creek Lake	4.96	7/18/96	4.49	31.0	51	17.96	0	8.85	7.09
Echo Lake	7.68	10/28/96	7.68	14.0		7.11	20	14.5	8.66
Evans Pond	6.86	12/18/96	6.94	10.0	182	5.23	26.6	23.13	24.66
Green Turtle Lake	6.42	11/1/96	6.42	9.8	74	2.87	11.22	13.46	6.78
Greenwood Lake	7.09	11/1/96	7.09	10.2	148	3.3	26.02	31.12	8.51
Grovers Mill Pond	5.95	11/20/96	5.95	8.4	160	2.46	14	27.6	15.06
Haddon Lake	7.16	12/18/96	6.90	10.3	211	1.88	31.25	25	19.15
Hainesville Pond	7.16	6/23/96	7.23	21.1	190	6.05	59	25	5.49
Hainesville Pond	7.16	12/11/96	7.08	2.8	63	2.85	17.35	6.91	8.05
Harrisville Lake	4.31	7/18/96	4.39	27.1	47.5	8.43	0	6.25	5.07
Lake Hopatcong	7.59	12/11/96	7.44	3.8	220	3.54	30	51.63	13.95
Lenape Lake	5.03	7/18/96	4.40	25.0	58.6	24.04	0	10.2	9.83
Little Timber Creek	7.16	12/18/96	7.10	9.9	267	3.71	47.96	22.56	39.04
Malaga Lake	4.98	10/23/96	4.98	16.1	47	14.98	0.51	10.2	9.27
Manasquan Reservoir	7.15	11/6/96	6.89	15.2	107	5.35	11	16.5	14.04
Marlton Lake	6.65								
Mary Elmer Lake	8.29	7/17/96	8.29	30.1	107	6.55	13	9.5	10.64
Maskells Mills Lake	5.31	7/17/96	5.62	27.8	66	8.22	1.96	10.94	8.19
Merrill Creek	7.68								
Merrill Creek Reservoir	7.36	12/12/96	7.04	6.2	107	2.23	26.47	9.44	13.78
Mirror Lake	5.18	11/7/96	5.90	12.9	39	8.34	0.98	7.35	8.54
Monksville Reservoir	7.43	10/29/96	7.48	12.9	130	3.65	21.57	23.98	8.33
Mountain Lake	8.20	12/12/96	7.23	4.9	220	2.82	101	14.29	12.78
Mullica River	4.59	7/18/96	4.43	25.7	56.3	26.32	0	10.64	10.68

Table 6 (continued). Results of water chemistry analyses, by lake.

Waterbody	Avg. pH	Date	pH	Temp., H_2O (°C)	Conductivity (µmhos)	DOC (mg / L)	Alkalinity (mg / L)	Chloride (mg / L)	Sulfate (mg / L)
New Brooklyn Lake	5.60	8/22/96	5.34	21.4	56	18.7	2.94	11.46	8.18
Newton Creek (North Branch)	7.31	12/18/96	7.19	9.2	194	3.29	48.04	14.02	19.71
Newton Lake	7.93	12/18/96	6.88	8.5	125	3.01	22.12	10.11	15.24
Lake Nummy	4.27	7/18/96	4.19	27.1	59.3	24.21	0	8.16	7.89
Oak Ridge Reservoir	7.41	10/28/96	7.42	14.3		5.39	29.59	20.1	8.08
Oak Ridge Reservoir	7.41	5/21/97	7.39	16.9	100	3.22	40.2	18.7	8.06
Oradell Reservoir	7.39	10/31/96	7.39	10.5	270	4.63	64.29	49	13.32
Passaic River at Hatfield Swamp	7.01	7/24/96	7.01	22.0	308	10.86	58	50	17.22
Passaic River at Great Piece	7.29	10/31/96	6.87	13.6	210	10.22	42.86	36	16.42
Pompton Lake	8.64	8/22/96	9.22		428	6.22	68	75.54	14.17
Pompton River at Lincoln Park	7.28	10/31/96	7.28	12.3	230	3.74	43.88	38.5	13.29
Pompton River at Pequannock River	7.40	10/31/96	7.38	12.2	188	4.58	40.82	40.82	13.41
Pompton River at Pequannock River	7.40	5/21/97	7.42	13.7	195	3.55	36.9	39	12.72
Rancocas Creek	6.92	11/20/96	7.06	6.5	140	6.18	18	20.31	21.78
Ridgeway Branch of Tom’s River	5.16	7/28/96				19.9	0	10.42	11
Ridgeway Branch of Tom’s River	5.16	11/6/96	5.16	10.3	52				
Raritan River at Millstone Creek	7.49	7/23/96	7.49	20.8	234	5.16	56.12	29.59	16.43
Raritan River at Neshanic Station	7.05	12/12/96	7.05	6.4	181	2.01	36.73	27.17	11.69
Raritan River, S. Branch, Clairemont Stretch	8.34	7/23/96	8.34	20.9	250	3.1	62.24	27.34	18.27
Rockaway River	7.35	11/27/96	7.08	12.6	149	5.19	28.43	25.53	10.57
Rockaway, Whippany Rivers	7.42	7/24/96	7.42	21.1	411	4.5	71.57	66.85	24.86
Round Valley Reservoir	8.00	12/13/96	7.51	7.3	110	1.95	32.69	10.42	13.54
Saw Mill Lake	6.90	12/11/96	6.80	1.3	26	2.58	1.92	2.13	7.08
Shadow Lake	7.93	11/6/96	6.90	11.3	220	6.95	25.5	33.16	23.89
Speedwell Lake	7.34	7/22/96	7.34	19.0	350	4.37	50	55.85	16.13
Spring Lake	8.04	11/6/96	7.19	11.7	182	7.03	23.96	33.85	11.18
Split Rock Reservoir	6.92	10/28/96	6.92	16.0	25	5.26	7	6	5.44
Spruce Run Reservoir	7.94	12/12/96	6.96	5.8	130	2.1	21.57	17.44	14.04
Stafford Forge Main Line	4.64								
Steenykill Lake	7.19	12/11/96	7.19	2.1	153	4.23	7	39.58	7.16

Table 6 (continued). Results of water chemistry analyses, by lake.

Waterbody	Avg. pH	Date	pH	Temp., H_2O (°C)	Conductivity (µmhos)	DOC (mg / L)	Alkalinity (mg / L)	Chloride (mg / L)	Sulfate (mg / L)
Strawbridge Ponds	6.82	12/18/96	6.78	9.8	223	3.06	17.35	25	44.14
Success Lake	4.37	11/7/96	4.37	19.8	44	13.72	0	8.33	7.47
Sunset Lake	8.84	7/17/96	8.84	30.0	162	4.95	14.71	18	15.37
Sunset Lake	8.84	10/22/96			150	6.33	14.42	20.41	15.59
Swartswood Lake	7.87	12/11/96	7.29	4.1	149	4.52	44.9	17.05	9.63
Tappan Lake	8.01	11/29/96	8.01	5.3	300	5.79	71.87	58.7	13.18
Union Lake	6.74	7/18/96	6.82	28.7	89.2	7.69	7	15.62	7.4
Wading River	4.35	7/18/96	4.21	25.3	53.8	14.02	0	6.5	8.69
Wanaque Reservoir	7.78	10/29/96	7.67	12.9	137	2.87	24	26.02	10.19
Wawayanda Lake	7.87	10/29/96	7.87	10.9	186	8.1	43.14	31.5	7.32
Whitesbog Pond	3.79	7/10/96	3.79		84	42.93	0	7.98	12.2
Whitesbog Pond	3.79	11/6/96	3.79	12.3	67	29.81	0	5.63	11.18
Willow Grove Lake	6.02	7/17/96	6.10	30.1	63	17.42	5	10.5	7.96
Willow Grove Lake	6.02	10/24/96	5.47	13.9	61	11.29	3.5	11.46	8.64
Willow Grove Lake	6.02	5/8/97	6.50	17.0	45	10.32	3	9.7	8.44
Wilson Lake	5.98	7/18/96	5.60	26.5	56.6	14.79	2.94	9.18	8.59
Woodstown Memorial Lake	7.01	7/17/96	7.02	28.9	240	9.95	33	25	27.38

Table 7. Correlations among physico-chemical parameters. Pearson correlations are shown above the diagonal, and Spearman rank correlations are shown below the diagonal. For this analysis, only measurements taken at the same time are included.

	Ave pH	pH	ln(alkalinity)	ln(DOC)	ln(chloride)	ln(sulfate)	ln(conductivity)
Ave pH	1.0	0.96	0.88	-0.69	0.37	0.30	0.54
pH	0.88	1.0	0.88	-0.69	0.50	0.36	0.63
ln(alkalinity)	0.76	0.82	1.0	-0.62	0.66	0.51	0.82
ln(DOC)	-0.49	-0.46	-0.43	1.0	-0.12	-0.21	-0.29
ln(chloride)	0.49	0.57	0.71	-0.13	1.0	0.47	0.89
ln(sulfate)	0.33	0.28	0.50	-0.18	0.53	1.0	0.68
ln(conductivity)	0.62	0.67	0.84	-0.23	0.89	0.70	1.0

Reservoir in this study, and Batsto Lake and Rockaway River in the 1992-1993 screening study). Concentrations in yellow bullhead were much higher than those in brown bullheads at Oak Ridge Reservoir and Rockaway River at the latter two sites (accounting for age differences), but were similar at Batsto Lake. High concentrations in yellow bullheads (greater than 0.80 mg/kg wet weight) were seen in Pine Barren lakes, Willow Grove Lake, and the Pompton River at the mouth of the Pequannock River. A concentration of 0.25 mg/kg wet weight was found in one specimen from Oak Ridge Reservoir. High concentrations in brown bullhead were found only in specimens from Ridgeway Branch, a Pine Barrens site. Otherwise, concentrations greater than 0.12 mg/kg (between 0.18 and 0.47 mg/kg wet weight) were found in other relatively low pH sites (Willow Grove Lake, sampled in this study, and Maskell's Mill Pond and Batsto Lake, which were sampled in the 1992-1993 screening study), Grovers Mill Pond, Crater Lake and some sites sampled in the 1992 study (Little Timber Creek and Haddon Lake in the Delaware Drainage and Lake Dundee, an impoundment of the Passaic River). These higher values for both species are in the range for which consumption advisories for all people were generated in 1994, and many specimens are in the range for which consumption advisories for low risk groups (i.e., concentrations greater than 0.08 mg/kg wet weight) would be considered.

Three species of sunfish (bluegill, redbreast sunfish, and pumpkinseed), as well as rock bass, were analyzed from various sites. In general, concentrations were low, except for fish from industrial areas. For example, relatively high concentrations were found in rock bass (up to 0.58 mg/kg wet weight), redbreast sunfish (up to 0.41 mg/kg wet weight), and pumpkinseed (up to 0.78 mg/kg wet weight) from the Pompton River at the mouth of the Pequannock River and bluegill from the Passaic River in Hatfield Swamp (up to 0.19 mg/kg wet weight).

Concentrations in crappies appeared to be less variable than those of sunfish. Low concentrations (maximum of 0.13 mg/kg wet weight) were seen in the Delaware tributary sites, which were sampled in the 1992-1993 screening study (Newton Lake, Cooper River Park Lake, and Big Timber Creek). Average concentrations of 0.20-0.25 mg/kg wet weight and maximum observed concentrations of 0.21-0.32 mg/kg wet weight were seen in Northern industrial areas (sites in the Passaic, Pompton and Rockaway rivers), and Coastal Plain lakes (Maskells Mill Pond, Alcyon Lake, and Strawbridge Pond, which were sampled in the 1992-1994 studies). Concentrations in all fish analyzed were less than those triggering advisories for low risk people, but fish from most sites might trigger advisories for high risk groups.

White and yellow perch were not widespread in collections. White perch typically showed relatively low concentrations (site averages less than or equal to 0.13 mg/kg wet weight and maximum observed concentration of 0.19 mg/kg wet weight). Moderately high concentrations were seen in old yellow perch from Crater Lake (0.29-0.58 mg/kg), and from the Pompton River at Lincoln Park (0.21 to 0.26 mg/kg wet weight).

Brook, brown and rainbow trout were collected from a few sites. Concentrations were typically low, especially in small trout, which were probably stocked fish with short residence times in the wild. Moderate concentrations were found in rainbow trout (and large lake trout) from Merrill Creek Reservoir in 1992.

Relationship Between Filet and Carcass Concentrations

Separate analyses of fillet and carcass material were done on 33 samples (8 chain pickerel, 10 largemouth bass, 2 brown bullhead, 9 sunfish, crappies and rock bass, 2 chubsuckers, and 2 white perch). These were used to estimate whole body concentrations, and ratios of fillet to whole body concentrations (Table 8). Mercury was not detected in either tissue of the two white perch analyzed. For the other samples, whole body concentrations were lower than fillet concentrations. The ratio of fillet to whole body concentration ranged from 1.17 to 2.18. Mean values for each species are given in Table 8; because of the skewed distribution of ratio estimates, ranges and medians may be more useful. The ratios tended to be lower for chain pickerel (range 1.17-1.42 , median = 1.33) and creek chubsucker (range 1.33-1.35, median=1.34) than the other species (1.46 for black crappie, 1.47 for rock bass, 1.65 for pumpkinseed, 1.86 for brown bullhead, and 1.88 for bluegill) . Ratios for largemouth bass were variable (range 1.19-2.18; median = 1.65), although ratios for 8 of the 10 specimens were between 1.49 and 1.77.

Variation in Mercury Concentrations among Trophic Groups

Analyses of fish from several trophic levels were done on specimens from seven sites. These include sites in the Pine Barrens (Double Trouble), Coastal Plain (Sunset Lake), upland lakes (Grovers Mill Pond, Oak Ridge Reservoir, and Greenwood Lake), and industrial rivers (Passaic River at Hatfield Swamp, and Pompton River at the mouth of the Pequannock). Comparisons of concentrations were based on whole body concentrations, since these are probably more relevant to bioaccumulation ratios, and since fillet samples would have been difficult to obtain on some smaller specimens. The geometric means of the ratios of fillet to whole body (see previous section and Table 9) were used to estimate whole body concentrations for specimens on which only fillet analyses were done. The species and sizes of fish analyzed depended on occurrence at the sites. Trophic groups included piscivores (largemouth bass and chain pickerel), probable omnivores (brown and yellow bullhead), and invertebrate feeders (sunfish, crappies, rock bass, yellow perch, white perch, golden shiner, alewife, and creek chubsucker). These invertebrate feeders differ in feeding habits. Golden shiner and alewife are principally zooplanktivores; golden shiner may eat some algae as well. White perch and yellow perch typically eat a variety of macroinvertebrates, and may eat zooplankton and small fish, as well. Rock bass typically eat macroinvertebrates, especially crayfish, but may eat small fish, as well. The sunfish mainly eat macroinvertebrates, but may eat zooplankton. Crappies typically eat a mix of macroinvertebrates and zooplankton, but may eat small fish. The chubsucker feeds on macroinvertebrates in benthic habitats.

The comparisons of mercury concentrations among trophic groups within lakes (Table 9) shows the general pattern of higher concentrations in piscivores, but there is considerable among-species variation within trophic groups. For example golden shiners (mainly zooplanktivorous) had low concentrations in the three lakes from which it was analyzed. Alewife, the other zooplanktivore, had concentrations similar to that of sunfish from the same lake. White perch tended to have lower concentrations than sunfish, yellow perch or other mixed invertebrate feeders.

Table 8. Mercury concentrations in whole body and fillets from specimens with multiple mercury analyses. Fields are estimated whole body concentration of mercury (EWC, mg/kg wet weight), concentration in one or both fillets (FilC), concentration in carcass or carcass and one fillet (CcC), length of the fish (LTL, in cm), weight of the fish (LNW, in g), sample weight of the fillet(s) (FillW), sample weight of the carcass or carcass and one fillet (CcW), estimated ratio of the fillet concentration to whole body concentration (RFW), ln(RFW), and proportion of carcass plus fillet sample weights to total body weight (Psmp). The whole body mercury concentration (EWC) is estimated from the carcass and fillet concentrations weighted by the sample weights of each tissue type. Since the quantitated mercury concentration in fillets and carcass of white perch from Greenwood Lake was negative, no meaningful estimate of RFW could be obtained.

Station	Age	LTL	EWC	CcC	FillC	RFW	Ln(RFW)	Psmp	LNW	CcW	FilW
Chain pickerel											
Double Trouble	2	18.1	0.536	0.465	0.743	1.39	0.326	0.94	29.5	20.7	7.13
Whitesbog	2	23.0	0.337	0.309	0.433	1.28	0.250	0.95	70.3	51.8	15.1
	2	32.5	0.647	0.617	0.758	1.17	0.159	0.98	181.6	140.6	37.5
	2	34.3	0.592	0.551	0.737	1.25	0.220	0.97	229.9	174.5	48.8
Grover's Mill Pond	2	35.2	0.112	0.098	0.160	1.42	0.353	0.95	262.3	191.7	57.5
	3	35.3	0.088	0.079	0.121	1.37	0.316	0.96	268.2	202.1	55.9
	2	36.5	0.125	0.111	0.175	1.40	0.339	0.96	248.9	186.8	51.0
	3	37.2	0.132	0.125	0.157	1.19	0.174	0.95	268.2	200.7	55.1
Largemouth bass											
Grover's Mill Pond	4	28.0	0.316	0.279	0.470	1.49	0.398	0.93	318.3	239.5	56.8
	3	31.3	0.114	0.086	0.249	2.18	0.781	0.97	530.2	424.1	88.2
Greenwood Lake	3	31.4	0.118	0.096	0.208	1.77	0.570	0.96	406.2	315.8	75.8
	3	34.3	0.120	0.104	0.179	1.49	0.400	0.96	525.6	398.3	106.7
Grover's Mill Pond	4	35.0	0.230	0.201	0.364	1.58	0.460	0.97	616.6	490.9	104.3
	4	35.8	0.173	0.147	0.296	1.72	0.540	0.96	674.4	537.1	112.0

Table 8 (continued). Mercury concentrations in whole body and fillets from specimens with multiple mercury analyses. Fields are estimated whole body concentration of mercury (EWC, mg/kg wet weight), concentration in one or both fillets (FilC), concentration in carcass or carcass and one fillet (CcC), length of the fish (LTL, in cm), weight of the fish (LNW, in g), sample weight of the fillet(s) (FillW), sample weight of the carcass or carcass and one fillet (CcW), estimated ratio of the fillet concentration to whole body concentration (RFW), ln(RFW), and proportion of carcass plus fillet sample weights to total body weight (Psmp). The whole body mercury concentration (EWC) is estimated from the carcass and fillet concentrations weighted by the sample weights of each tissue type. Since the quantitated mercury concentration in fillets and carcass of white perch from Greenwood Lake was negative, no meaningful estimate of RFW could be obtained.

Station	Age	LTL	EWC	CcC	FillC	RFW	Ln(RFW)	Psmp	LNW	CcW	FilW
Greenwood Lake	4	36.2	0.090	0.073	0.154	1.72	0.540	0.95	708.6	537.4	138.5
	4	36.3	0.140	0.114	0.241	1.72	0.540	0.97	750.0	573.8	150.2
Greenwood Lake	7	40.0	0.263	0.233	0.398	1.51	0.412	0.98	921.6	732.7	166.2
Grover's Mill Pond	6	41.5	0.328	0.315	0.391	1.19	0.175	0.97	1242.6	996.4	209.1
Brown bullhead											
Grover's Mill Pond	10	32.2	0.246	0.223	0.398	1.62	0.482	0.92	512.1	411.6	61.5
	9	33.0	0.038	0.028	0.079	2.10	0.740	0.95	488.0	375.7	86.9
Pumpkinseed											
Sunset	.	9.4	0.030	0.021	0.042	1.43	0.357	0.91	15.6	8.48	5.70
Passaic at Hatfield Swamp	3	12.4	0.050	0.042	0.084	1.69	0.525	0.95	51.0	39.5	8.80
	3	12.6	0.056	0.048	0.092	1.65	0.503	0.95	45.7	35.6	7.70
Bluegill											
Sunset	.	8.8	0.016	0.008	0.029	1.83	0.603	0.87	14.8	8.06	4.88
	2	11.2	0.027	0.020	0.052	1.93	0.658	0.92	23.0	16.7	4.60

Table 8 (continued). Mercury concentrations in whole body and fillets from specimens with multiple mercury analyses. Fields are estimated whole body concentration of mercury (EWC, mg/kg wet weight), concentration in one or both fillets (FilC), concentration in carcass or carcass and one fillet (CcC), length of the fish (LTL, in cm), weight of the fish (LNW, in g), sample weight of the fillet(s) (FillW), sample weight of the carcass or carcass and one fillet (CcW), estimated ratio of the fillet concentration to whole body concentration (RFW), ln(RFW), and proportion of carcass plus fillet sample weights to total body weight (Psmp). The whole body mercury concentration (EWC) is estimated from the carcass and fillet concentrations weighted by the sample weights of each tissue type. Since the quantitated mercury concentration in fillets and carcass of white perch from Greenwood Lake was negative, no meaningful estimate of RFW could be obtained.

Station	Age	LTL	EWC	CcC	FillC	RFW	Ln(RFW)	Psmp	LNW	CcW	FilW
Black crappie											
Passaic at Hatfield Swamp	6	18.1	0.202	0.178	0.295	1.46	0.378	0.95	113.8	85.6	22.4
	7	18.9	0.218	0.189	0.321	1.47	0.387	0.95	103.2	76.2	21.6
Rock bass											
Pompton at Pequannock R.	3	19.2	0.360	0.315	0.543	1.51	0.410	0.92	191.3	141.1	35.1
	4	21.1	0.375	0.336	0.535	1.43	0.356	0.93	205.8	154.8	37.5
Creek chubsucker											
Double Trouble	3	22.3	0.184	0.165	0.249	1.35	0.299	0.95	150.2	109.8	33.2
	6	28.0	0.391	0.352	0.521	1.33	0.289	0.93	278.1	200.6	59.2
White perch											
Greenwood Lake	2	18.3	-0.0048	-0.007	0.004	.	.	0.95	79.6	61.3	14.3
	2	19.2	-0.0045	-0.010	0.019	.	.	0.95	88.7	68.0	16.6

Table 9. Estimated average whole body concentrations of mercury (mg/kg wet weight) in specimens from sites with analyses of large and forage fishes. Whole body concentrations estimated from whole body samples, from separate fillet and carcass samples, or from fillet samples and average ratios of fillet to whole body concentrations (see text). Waterbodies are: Double Trouble (DT), Grover's Mill Pond (GMP), Greenwood Lake (GWL), Oak Ridge Reservoir (ORR), Passaic River at Hatfield Swamp (PHS), Pompton River at the mouth of the Pequannock River (PPQ), Sunset Lake (SUN), and Whitebog (WHI).

Species	Presumed Age	WATERBODY							
		DT	GMP	GWL	ORR	PHS	PPQ	SUN	WHI
Piscivores									
Chain pickerel	All	1.08	0.11	-	0.22	-	-	0.069	0.56
	0	0.28							
	1				0.20				
	2-3	0.54	0.11		0.23			0.069	
	7	0.95							
	10-11	1.57							
Largemouth bass	All	-	0.23	0.15	0.40	0.19	0.73	0.19	-
	2					0.12		0.084	
	3-4		0.21	0.12				0.17	
	6-8		0.33	0.26		0.33	0.73		
	9							0.43	
Smallmouth bass	All	-	-	-	0.30	-	0.59	-	-
Forage Fish (feed mainly on macroinvertebrates; possibly some zooplankton and fish)									
Rock bass	4-5	-	-	-	-	-	0.41	-	-
Yellow perch	2	-	-	-	0.036	-	-	-	-
White perch	All	-	-	-0.006	-	-	-	0.044	-
Black crappie	All	-	-	-	-	0.18	0.16	0.023	-
	1-2						0.16	0.023	
	4-7					0.18			
Forage fish (feed mainly on macroinvertebrates; some zooplankton)									
Redbreast sunfish	All	-	-	-	0.044	-	0.23	-	-
Pumpkinseed	All	-	0.013	-	0.033	0.053	0.21	0.028	-
	0		0.012				0.11		
	1		0.013		0.033		0.14		

Table 9 (continued). Estimated average whole body concentrations of mercury (mg/kg wet weight) in specimens from sites with analyses of large and forage fishes. Whole body concentrations estimated from whole body samples, from separate fillet and carcass samples, or from fillet samples and average ratios of fillet to whole body concentrations (see text). Waterbodies are: Double Trouble (DT), Grover's Mill Pond (GMP), Greenwood Lake (GWL), Oak Ridge Reservoir (ORR), Passaic River at Hatfield Swamp (PHS), Pompton River at the mouth of the Pequannock River (PPQ), Sunset Lake (SUN), and Whitebog (WHI).

Species	**Presumed Age**	**WATERBODY**							
		DT	**GMP**	**GWL**	**ORR**	**PHS**	**PPQ**	**SUN**	**WHI**
	2						0.22		
	3					0.053	0.49		
Bluegill	All	-	-	0.017	0.041	0.10	-	0.020	-
	0								
	1				0.041				
	3			0.017					
	4					0.10			
Creek chubsucker	All	0.29	-	-	-	-	0.060	-	-
Black-banded sunfish	All	0.15	-	-	-	-	-	-	-
	a. 1-2	0.10							
	a. 3	0.18							
Bluespotted sunfish	a. 2-3	-	0.036	-	-	-	-	-	-
Forage fish (mainly zooplankton)									
Golden shiner	All	-	0.0078	-	0.016	-	-	0.0085	-
	0-1				-0.025			0.0085	
	4				0.056				
Alewife	All	-	-	0.052	-	-	-	-	-
Insect									
Corixidae		0.16	-	-	-	-	-	-	-
Omnivores									
Yellow bullhead	Adult	0.56	-	-	0.14	0.058	0.43	-	-
Brown bullhead	Adult	-	0.14	-	0.012	-	-	-	-

Concentrations in forage species vary with age of fish. As a result, differences in growth rates of forage fish will affect mercury concentrations in food of predators. For example, the *Enneacanthus* sunfish (black-banded and blue-spotted sunfish) are small species, with maximum sizes of about 8 cm (Jenkins and Burkhead 1994). Examination of scales of some of the *Enneacanthus* indicated that the larger fish (6-7 cm) were 3 years old. These fish are comparable in size to young-of-year or yearling *Lepomis* sunfishes (bluegill, pumpkinseed, and redbreast sunfish), crappies, and perch. *Enneacanthus* are expected to have higher mercury concentrations than *Lepomis* of the same size, because of these age differences alone. This pattern was seen for Grovers Mill Pond, where both blue-spotted and pumpkinseed sunfishes were analyzed.

Joint Analysis of 1992-1997 Data

The 1996-1997 study was designed as a supplement to the earlier studies, i.e., sampling priorities were chosen to fill data gaps and provide larger sample sizes for important strata. Thus, joint analysis of all the data provides the best description of statewide patterns of mercury concentrations in fishes. In this section, two types of analyses of statewide patterns are discussed. The first describes among-strata variation in mercury concentrations and variation among waterbodies within strata. Since the strata are defined on the basis of water chemistry, the among-strata comparisons analyze effects of water chemistry on mercury bioaccumulation by comparison of discrete chemistry classes. The second type of analyses directly use water chemistry data to explain among site variation in mercury concentration.

Mercury concentrations increase with the size and age of fish. Differences in the age and size distribution of fish in samples from different lakes must be accounted for in making comparisons across sites. For all analyses, the relationships between age, length or weight and mercury concentration are modeled by linear regression. Where significant relationships are found, comparisons among sites are done after adjusting for the age or size. This allows comparison of mercury concentration among sites of a standard-sized or standard-age fish.

Adjustment for Fish Size and Comparison among Strata and Sites

In general, mercury concentrations increased with the size and age of the fish (Figs. 2-8), so that size adjustment is needed for among-site comparisons. Adjustment among strata was done using analysis of covariance (ANCOVA), with ln(age) or ln(total length) as a covariate, and strata as a discrete (treatment) effect. Sites were nested within strata, to assess variation within strata. This is equivalent to fitting a linear regression between ln(mercury concentration) and ln(age) or ln(size), and comparing strata after adjusting for the linear relationship. Analyses were done for largemouth bass, chain pickerel, and brown bullhead, the three species with moderate-large sample sizes across a number of sites. Because of differences among unique lakes, each unique lake was treated as a separate stratum. Similar analyses of the 1992-1993 screening study data indicated no heterogeneity of slopes of the mercury-size relationships among strata, so only a single slope was estimated for each species.

Figure 2. Log normalized mercury concentration (ppm) vs ln (Age) for largemouth bass in Pine Barrens and low pH Coastal Plain Lakes.

There were highly significant relationships between ln[Hg] and ln(age) for all three species ($p < 0.0001$). There were also highly significant relationships between ln[Hg] and ln(total length) for largemouth bass and chain pickerel ($p < 0.0001$), but not for brown bullhead. There were highly significant differences among strata for all three species. For chain pickerel, regression using ln(age) was much better than regression using ln(total length), based on model r^2. For largemouth bass, model fit using ln(total length) was slightly better ($r^2 = 0.91$ for model with ln(total length), strata and site nested within strata) than that using ln(age) ($r^2=0.89$ for the analogous model).

Strata and sites were compared by using the statistical models to predict average mercury concentrations of a standard-aged (age 3) or standard-sized fish (33.4 cm largemouth bass, i.e., the average size of a 3-year old fish). Predictions were made for each stratum and for each site (Table 10). The prediction for each stratum was calculated as the average predicted ln(Hg) among all sites within the stratum, i.e., all sites were weighted equally in calculating the average. Two sets of predictions were made using length. The first used only the specimens for which ages were also available. This set provides the best comparison of age-adjustment versus length-adjustment. The second set uses all specimens of bass. This provides more accurate length-adjustment, since it is based on more specimens.

For chain pickerel (Table 10), adjusted concentrations decreased along the gradient from the Pine Barrens to more alkaline sites. The highest concentrations were seen in Pine Barrens rivers and lakes and Union Lake, other Coastal Plain sites had intermediate values, and the lowest concentrations were found in northern lakes and rivers, and in Sunset Lake (a eutrophic lake in Southern New Jersey). There was considerable variation among strata, especially in those with higher concentrations. Although they had higher pH, Willow Grove Lake and Lake Malaga had adjusted concentrations typical of Pine Barrens lakes. Wanaque and Monksville reservoirs also had relatively high concentrations.

Largemouth bass showed similar patterns (Table 10), although there were fewer specimens from the low pH sites (where bass are relatively uncommon). Relatively high adjusted concentrations were seen in Atlantic City Reservoir, Manasquan Reservoir, Union Lake, Wanaque Lake and the Pine Barrens and pH 5 Coastal Plain lakes. Intermediate concentrations were seen in northern lakes and Coastal Plain lakes outside the Pine Barrens. The lowest concentrations were seen in higher pH sites (including sites with adjacent carbonate rocks), small Coastal Plain lakes and rivers, and the Delaware River sites. Several sites had high concentrations relative to their strata. As with chain pickerel, bass from Willow Grove Lake and Malaga Lake had adjusted concentrations similar to those of Pine Barrens lakes. Other such sites were Atlantic City Reservoir, Pompton-Lincoln Park (based on age-adjustment), Clinton Reservoir and Monksville Reservoir.

For many strata and individual sites, size-adjusted and age-adjusted concentrations were similar. However, the two types of adjustments produced very different values for some sites, e.g., Union Lake, Marlton Lake, Evans Lake, Pompton-Pequannock, and Rockaway-Whippany, where age-adjusted concentrations were lower than size-adjusted concentrations, and Manasquan Reservoir, Pompton-Lincoln Park, where age-adjusted concentrations were higher. Higher age-adjusted concentrations would be expected from sites where fish grow more slowly than average (i.e., where

Table 10. Station and strata averages of adjusted mercury concentrations (ppm) for chain pickerel, brown bullhead and largemouth bass. Mercury concentrations are adjusted by age (standardized to a three year old fish) for all three species. In addition, mercury concentrations are adjusted to total length (standardized to a 33.4-cm fish) for large mouth bass. Total length adjustments were done using only those fish used in the age adjustment and using all fish.

	Age		Total Length		Total Length (All)	
	Strata	**Lake**	**Strata**	**Lake**	**Strata**	**Lake**
Chain Pickerel						
Pine Barrens River (PBR)	1.27					
Mullica River		1.63				
Ridgeway Branch of Tom's River		0.98				
Wading River		0.81				
Unique Lake (UL)	1.08					
Union Lake		1.08				
Pine Barren Lake (PBL)	0.94					
East Creek Lake		1.83				
Harrisville Lake		1.37				
Lake Nummy		1.36				
Stafford Forge Main Line		0.98				
Batsto Lake		0.86				
Whitesbog Pond		0.84				
Double Trouble Lake		0.80				
Success Lake		0.73				
Butterfly Bogs		0.63				
Lenape Lake		0.63				
Unique Lake (UL)	0.75					
Wanaque Reservoir		0.75				
Coastal Plain Lake - pH 5 (CPL5)	0.60					
Malaga Lake		1.11				
Wilson Lake		0.84				
New Brooklyn Lake		0.73				
Mirror Lake		0.38				
Maskells Mill Lake		0.30				
Coast Plain Lake - pH 7 (CPL7)	0.40					
Assunpink Lake		0.40				
Coastal Plain Lake - pH 6 (CPL6)	0.35					
Willow Grove Lake		1.00				
Clementon Lake		0.39				
Cedar Lake		0.30				
Lake Carasaljo		0.28				
De Voe Lake		0.17				
Northern Midland Lake (NML)	0.28					
Monksville Reservoir		0.71				
Oak Ridge Reservoir		0.46				
Wawayanda Lake		0.28				

Table 10 (continued). Station and strata averages of adjusted mercury concentrations (ppm) for chain pickerel, brown bullhead and largemouth bass. Mercury concentrations are adjusted by age (standardized to a three year old fish) for all three species. In addition, mercury concentrations are adjusted to total length (standardized to a 33.4-cm fish) for large mouth bass. Total length adjustments were done using only those fish used in the age adjustment and using all fish.

	Age		Total Length		Total Length (All)	
	Strata	Lake	Strata	Lake	Strata	Lake
Green Turtle Lake		0.21				
Grovers Mill Pond		0.18				
Hainesville Pond		0.14				
Northern Warmwater River (NWWR)	0.27					
Rockaway River		0.27				
Unique Lake (UL)	0.27					
Lake Hopatcong		0.27				
Northern Carbonate Lake (NCARB)	0.21					
Cranberry Lake		0.33				
Swartswood Lake		0.14				
Coastal Plain Lake - pH 8 (CPL8)	0.12					
Sunset Lake		0.12				
Brown Bullhead						
Pine Barren River (PBR)	0.22					
Ridgeway Branch of Tom' River		0.22				
Coastal Plain Lake - pH 5 (CPL5)	0.17					
Maskells Mill Lake		0.17				
Pine Barren Lake (PBL)	0.10					
Batsto Lake		0.12				
Butterfly Bogs		0.08				
Coastal Plain Lake - pH 6 (CPL6)	0.06					
Willow Grove Lake		0.17				
De Voe Lake		0.05				
Cedar Lake		0.02				
Northern Industrial River (NINDR)	0.05					
Lake Dundee		0.06				
Raritan River at Millstone Creek		0.04				
Coastal Plain Lake - pH 7 (CPL7)	0.03					
Crystal Lake		0.03				
Northern Midland Lake - Shawangunk Formation (NMLSSG)	0.03					
Crater Lake		0.08				
Saw Mill Lake		0.01				
Northern Warm-water River (NWWR)	0.03					
Rockaway River		0.03				
Southern Industrial Lake (SINDL)	0.03					
Haddon Lake (South Branch Newton)		0.03				

Table 10 (continued). Station and strata averages of adjusted mercury concentrations (ppm) for chain pickerel, brown bullhead and largemouth bass. Mercury concentrations are adjusted by age (standardized to a three year old fish) for all three species. In addition, mercury concentrations are adjusted to total length (standardized to a 33.4-cm fish) for large mouth bass. Total length adjustments were done using only those fish used in the age adjustment and using all fish.

	Age		**Total Length**		**Total Length (All)**	
	Strata	**Lake**	**Strata**	**Lake**	**Strata**	**Lake**
Coastal Plain River (CPR)	0.02					
Little Timber Creek		0.02				
Southern Industrial River (SINDR)	0.02					
Big Timber Creek		0.03				
Crosswick Creek		0.03				
Newton Creek, North Branch		0.02				
Northern Midland Lake (NML)	0.01					
Grovers Mill Pond		0.04				
Boonton Reservoir		0.01				
Oak Ridge Reservoir		0.01				
Speedwell Lake		0.00				
Largemouth Bass						
Unique Lake (UL)	2.66		1.78		1.70	
Manasquan Reservoir		2.66		1.78		1.70
Unique Lake (UL)	1.17		1.25		1.23	
Union Lake		1.17		1.25		1.23
Pine Barrens Lake (PBL)	0.65		1.08		1.09	
Batsto Lake		0.65		1.08		1.09
Coastal Plain Lake - pH 5 (CPL5)	0.63		0.62		0.65	
Malaga Lake		0.95		1.02		1.03
Maskells Mill Lake		0.72		0.57		0.60
Mirror Lake		0.36		0.42		0.45
Unique Lake (NCARB-UL)	0.57		0.55		0.52	
Wanaque Reservoir		0.57		0.55		0.52
Northern Warm-water River (NWWR)	0.50		0.74		0.79	
Rockaway River		0.50		0.74		0.79
Southern Industrial Lake (SINDL)	0.49		0.49		0.47	
Atlantic City Reservoir		4.36		3.40		3.28
Haddon Lake (South Branch Newton)		0.35		0.37		0.36
Newton Lake		0.08		0.09		0.09
Unique Lake (NCARB-UL)	0.42		0.52		0.49	
Merrill Creek Reservoir		0.42		0.52		0.49
Coastal Plain Lake - pH 6 (CPL6)	0.37		0.46		0.46	
Willow Grove Lake		1.68		1.70		1.71
Marlton Lake		0.66		1.07		1.02
Lake Carasaljo		0.43		0.50		0.47
Alcyon Lake		0.36		0.61		0.64

Table 10 (continued). Station and strata averages of adjusted mercury concentrations (ppm) for chain pickerel, brown bullhead and largemouth bass. Mercury concentrations are adjusted by age (standardized to a three year old fish) for all three species. In addition, mercury concentrations are adjusted to total length (standardized to a 33.4-cm fish) for large mouth bass. Total length adjustments were done using only those fish used in the age adjustment and using all fish.

	Age		**Total Length**		**Total Length (All)**	
	Strata	**Lake**	**Strata**	**Lake**	**Strata**	**Lake**
Clementon Lake		0.33		0.33		0.33
Cedar Lake		0.32		0.28		0.26
Evans Pond		0.23		0.47		0.54
Strawbridge Ponds		0.17		0.24		0.26
De Voe Lake		0.17		0.15		0.15
Northern Industrial River (NINDR)	0.36		0.47		0.48	
Pompton River at Lincoln Park		0.79		0.52		0.50
Raritan River at Neshanic Station		0.55		0.40		0.51
Passaic River at Great Piece		0.44		0.50		0.50
Passaic River at Hatfield Swamp		0.40		0.43		0.47
Passaic River - Lake Dundee		0.36		0.38		0.40
Pompton River at Pequannock River		0.29		0.81		0.75
Rockaway River near Whippany		0.21		0.63		0.58
Raritan River at Millstone Creek		0.19		0.29		0.27
Unique Lake (NCARB-UL)	0.34		0.26		0.26	
Spruce Run Reservoir		0.34		0.26		0.26
Northern Industrial Lake (NINDL)	0.33		0.37		0.36	
Pompton Lake		0.33		0.37		0.36
Northern Midland Lake (NML)	0.32		0.37		0.29	
Clinton Reservoir		0.54		0.60		0.59
Monksville Reservoir		0.53		0.62		0.61
Canistear Reservoir		0.39		0.38		0.35
Oak Ridge Reservoir		0.33		0.35		0.31
Boonton Reservoir		0.32		0.36		0.33
Grovers Mill Pond		0.27		0.33		0.33
Green Turtle Lake		0.25		0.35		0.37
Speedwell Lake		0.22		0.26		0.27
Hainesville Pond		0.19		0.22		0.23
Northern Midland Lake - Shawangunk Formation (NMLSSG)	0.22		0.26		0.28	
Steenykill Lake		0.22		0.26		0.28
Coastal Plain Lake - pH 8 (CPL8)	0.20		0.20		0.21	
Spring Lake						0.24
Sunset Lake		0.23		0.21		0.20
Shadow Lake		0.17		0.19		0.19
Northern Carbonate Lake (NCARB)	0.20		0.25		0.24	
Mountain Lake		0.29		0.31		0.29
Carnegie Lake		0.24		0.30		0.28
Echo Lake		0.12		0.16		0.16

Table 10 (continued). Station and strata averages of adjusted mercury concentrations (ppm) for chain pickerel, brown bullhead and largemouth bass. Mercury concentrations are adjusted by age (standardized to a three year old fish) for all three species. In addition, mercury concentrations are adjusted to total length (standardized to a 33.4-cm fish) for large mouth bass. Total length adjustments were done using only those fish used in the age adjustment and using all fish.

		Age		Total Length		Total Length (All)	
		Strata	Lake	Strata	Lake	Strata	Lake
Coastal Plain Lake - pH 7 (CPL7)		0.19		0.24		0.23	
	Assunpink Lake		0.30		0.27		0.26
	Woodstown Memorial Lake		0.19		0.27		0.27
	Crystal Lake		0.13		0.18		0.18
Unique Lake (UL)		0.18		0.19		0.19	
	Greenwood Lake		0.18		0.19		0.19
Southern Industrial River (SINDR)		0.17		0.16		0.17	
	Crosswick Creek		0.31		0.22		0.24
	Cooper River Park Lake		0.13		0.15		0.16
	Big Timber Creek		0.12		0.12		0.13
Unique Lake (UL)		0.17		0.23		0.22	
	Lake Hopatcong		0.17		0.23		0.22
Unique Lake - Unique Lake (NCARB-UL)		0.15		0.23		0.23	
	Round Valley Reservoir		0.15		0.23		0.23
Coastal Plain River (CPR)		0.14		0.20		0.24	
	Assunpink Creek - Lower		0.14		0.20		0.24
Delaware River (DRET)		0.14		0.15		0.14	
	From Trenton to Eaton		0.14		0.15		0.14
Delaware River (DRTS)		0.13		0.14		0.15	
	From Camden to Trenton		0.13		0.14		0.15

a fish of average size is older than average), and vice versa. Several of the sites with lower age-adjusted concentrations were represented by a few, small specimens, so the differences between the two adjustments may reflect statistical uncertainty in extrapolation.

Brown bullhead showed similar patterns among strata (Table 10), although concentrations were low and there was little resolution among most strata. The highest concentrations were in Pine Barrens and Coastal Plain pH 5 sites. As with bass and pickerel, concentrations were relatively high in Willow Grove Lake.

The slopes of the mercury-age or mercury-length relationships can be used to predict mercury concentrations in a fish from the adjusted values in Table 10. For example, if the mercury concentration in a 3-year old fish is X and the slope of the ln(Hg)-ln(age) relationship is b_{age}, then the predicted mercury concentration in a fish of age N is:

$$\mathrm{Pred}\ (Hg_{age\ N}) = Hg_{age\ 3} + b_{age}*(\ln N - \ln 3).$$

Analogously:

$$\mathrm{Pred}\ (Hg_{size\ Y}) = Hg_{33.4\ cm} + b_{TL}*(\ln N - \ln 33.4).$$

The calculated slopes of the regressions are shown in Table 11. Estimates depend on the exact model used. For largemouth bass, the length slope was 2.60 for a model with strata and site, but 2.70 for a model with strata only. In the next section, models using physico-chemical parameters are calculated (Table 11-15), which also provide estimates of the ln(Hg)-ln(age) and ln(Hg)-ln(TL) relationships. These are similar to those derived from the models using site and stratum. For example, the length slope from the best model for largemouth bass is 2.62. For chain pickerel, the age slope from the model with strata and site is 0.74, that for strata only is 0.61 and the best model using physico-chemical parameters is 0.66.

Correlation of Mercury Concentrations with Physico-chemical Parameters

The regressions showed clear relationships between mercury concentrations in fish and water chemistry (Tables 11-15). For regressions involving a single parameter and age or length (Table 12), pH, conductivity, alkalinity or DOC were highly significant. The strength of the relationships was approximately similar among the parameters (based on the r^2), although there were some differences. Conductivity was the best single predictor for largemouth bass (age or length models) and chain pickerel (age models), and pH was the best predictor for brown bullhead (age models). The significant relationships with all four parameters reflects the high correlation among these parameters (Table 7).

The multiple regression models (stepwise and specification of several parameters) improved model fit, especially for largemouth bass and brown bullhead. Linear regressions with physico-chemical parameters, along with age or length (see above), explained a substantial part of the variation in mercury concentrations: the r^2 for the best stepwise models were 0.78, 0.61 and 0.56 for

Table 11. Summary of ANCOVA or ANOVA statistical analyses of mercury concentrations (as ln[mercury concentration, mg/kg wet weight]) as functions of strata, lakes nested within strata, age or total length (cm) as a covariate, and physico-chemical parameters as covariates..N is the number of specimens. N varies among analyses, since not all specimens were aged and physico-chemical data are not present for all sites. r^2 is the correlation coefficient for the entire model. Entries for separate terms show the p-value associated with each effect. P-values are for type III effects (only one value shown) or type I/type III (where two values shown). Ns indicates a non-significant effect.

	Largemouth Bass		**Chain Pickerel**	**Brown Bullhead**
	Age	**TL(all)**	**Age**	**Age**
Number of Specimens	**210**	**252**	**119**	**41**
Age or TL, Strata and station nested within strata				
r^2	0.90	0.90	0.95	0.93
Slope of ln(Hg)-ln(Age or TL)	0.74	2.60	0.74	1.35
Age or TL	0.0001	0.0001	0.0001	0.001
Strata	0.0001	0.0001	0.0001	0.0001
Sta(Str)	0.0001	0.0001	0.0001	0.01
Age or TL, and strata				
r^2	0.38	0.48	0.71	0.73
Slope of ln(Hg)-ln(Age or TL)	0.61	2.70	0.61	1.78
Age or TL	0.0001	0.0001	0.0001	0.0002
Strata	0.0001	0.0001	0.0001	0.0001
Age or TL, strata, and pH				
r^2	0.43	0.54	0.71	0.80
Age or TL	0.0001	0.0001	0.0001	0.0036
Strata	0.0001	0.0001	0.0001/0.0014	0.0001/0.011
pH	0.0001	0.0001	ns	0.0040
Age or TL, strata, and ln(DOC)				
r^2	0.46	0.52	0.74	0.74
Age or TL	0.0001	0.0001	0.0001	0.0002
Strata	0.0001	0.0001	0.0001	0.0001/ns
DOC	0.0001	0.0001	0.0012	ns

Table 11 (continued). Summary of ANCOVA statistical analyses of mercury concentrations (as ln[mercury concentration, mg/kg wet weight]) as functions of strata, lakes nested within strata, age or total length (cm) as a covariate, and physico-chemical parameters as covariates..N is the number of specimens. N varies among analyses, since not all specimens were aged and physico-chemical data are not present for all sites. r^2 is the correlation coefficient for the entire model. Entries for separate terms show the p-value associated with each effect. P-values are for type III effects (only one value shown) or type I/type III (where two values shown). Ns indicates a non-significant effect.

	Largemouth Bass		**Chain Pickerel**	**Brown Bullhead**
	Age	**TL(all)**	**Age**	**Age**
Number of Specimens	**210**	**252**	**119**	**41**
Age or TL, strata, and ln(conductivity)				
r^2	0.52	0.61	0.75	0.81
Age or TL	0.0001	0.0001	0.0001	0.0001
Strata	0.0001	0.0001	0.0001/ 0.0035	0.0001
Conductivity	0.0001	0.0001	0.0001	0.0025
Age or TL, strata, and alkalinity				
r^2	0.43	0.56	0.71	0.80
Age or TL	0.0001	0.0001	0.0001	0.0079
Strata	0.0001	0.0001	0.0001	0.0001/ 0.0011
Alkalinity	0.0001	0.0001	ns	0.0042

Table 12. Summary of analyses of mercury concentrations as functions of fish length or age, and physico-chemical parameters. Unless otherwise labeled, entries are the type III p-values associated with each effect. The column TL is for models using total length, and only specimens for which ages are also available; TL(all) used all specimens.

Model	**Largemouth Bass**			**Chain Pickerel**			**Brown Bullhead**		
	Age	**TL**	**TL(all)**	**Age**	**TL**	**TL(all)**	**Age**	**TL**	**TL (all)**
N	**228**	**228**	**235-252**	**116-118**	**116-118**	**126**	**41**	**41**	**44**
1. Best models from stepwise linear regression									
r^2	0.46	0.56	0.52	0.78	0.71	0.69	0.61	0.48	
Slope of age or TL	0.84	2.75	2.62	0.66		1.30	1.34		
Age or TL	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	ns	
pH	x	x	x	x	0.06	x	x	x	
DOC	0.0066	0.0002	0.0005	0.0001	0.0001	0.0001	0.0005	0.04	
Alkalinity	sign	sign	x	x	0.0041	0.0001	0.008	0.0001	
Conductivity	0.0001	0.0001	0.0001	0.05	x	x	x	x	
Sulfate	x	x	x	0.0002	0.02	0.0001	sign	x	
Chloride	0.0001	0.0001	0.0001	0.003	0.03	0.10	x	x	
2. With Waterbody Type (WType). Only models with significant waterbody effects shown.									
r^2	0.48								0.58
Age or TL	0.0001								ns
WType	0.003								0.04
DOC	0.0002								0.09
Conductivity	0.0001								
Chloride	0.0001								
Alkalinity									0.0001

Table 13. Summary of analyses of mercury concentrations as functions of fish length or age, and physico-chemical parameters. Unless otherwise labeled, entries are the type III p-values associated with each effect. The column TL is for models using total length, and only specimens for which ages are also available; TL(all) used all specimens.

Model	**Largemouth Bass**			**Chain Pickerel**			**Brown Bullhead**		
	Age	**TL**	**TL(all)**	**Age**	**TL**	**TL(all)**	**Age**	**TL**	**TL (all)**
N	**213-228**	**213-228**	**235-252**	**116-118**	**116-118**	**126**	**41**	**41**	**44**
3. Reduced model with easily measured parameters									
r^2		0.40	0.40		0.62	0.64		0.45	0.48
Slope of ln(Hg)- ln(TL)		2.92	2.84		1.34	1.47			
TL		0.0001	0.0001		0.0001	0.0001		ns	ns
pH		ns	ns		0.0003	0.0001		0.0001	.0001
Conductivity		0.02	0.0002		0.0001	0.0001		0.09	0.09
4. Model with pH and DOC specified									
r^2	0.26	0.44	0.41	0.67	0.60	0.61	0.62		
Age/size	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0007		
pH	0.0015	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001		
DOC	0.0001	0.0001	0.0001	0.0001	0.0001	0.0027	0.03		
5. Model with pH, DOC and waterbody type (Wtype). Only models with significant waterbody type terms shown.									
r^2	0.36		0.43				0.62		
Age or TL	0.0001		0.0001				0.0001		
Wtype	0.0001		0.004				0.07		
pH	0.0002		0.0001				0.0001		
DOC	0.0001		0.0001				0.001		

Table 14. Summary of analyses of mercury concentrations as functions of fish length or age, and physico-chemical parameters. Unless otherwise labeled, entries are the type III p-values associated with each effect. The column TL is for models using total length, and only specimens for which ages are also available; TL(all) used all specimens.

Model	**Largemouth Bass**			**Chain Pickerel**			**Brown Bullhead**		
	Age	**TL**	**TL(all)**	**Age**	**TL**	**TL(all)**	**Age**	**TL**	**TL (all)**
N	**213-228**	**213-228**	**235-252**	**116-118**	**116-118**	**126**	**41**	**41**	**44**
6. Models with single physico-chemical parameter									
r^2	0.22		0.37	0.62		0.58	0.56		0.43
Age or TL	0.0001		0.0001	0.0001		0.0001	0.0007		ns
pH	0.0004		0.0001	0.0001		0.0001	0.0001		0.0001
r^2	0.22		0.36	0.62		0.50	0.53		0.32
Age or TL	0.0001		0.0001	0.0001		0.0001	0.0001		ns
DOC	0.0001		0.0001	0.0001		0.0001	0.0001		0.0001
r^2	0.22		0.38	0.57		0.45	0.46		0.45
Age or TL	0.0001		0.0001	0.0001		0.0001	0.12		ns
Alkalinity	0.0002		0.0001	0.0001		0.0001	0.0001		0.0001
r^2	0.28		0.40	0.68		0.58	0.28		0.31
Age or TL	0.0001		0.0001	0.0001		0.0001	ns		0.05
Conductivity	0.0001		0.0001	0.0001		0.0001	0.0084		0.0002
7. Models with pH only									
r^2	NA	0.03	0.03	0.45	0.43	NA	0.41	NA	0.44
pH	NA	0.01	0.005	0.0001	0.0001	NA	0.0001	NA	0.0001

Table 15. Summary of analyses of mercury concentrations as functions of fish length or age, and physico-chemical parameters. Unless otherwise labeled, entries are the type III p-values associated with each effect. The column TL is for models using total length, and only specimens for which ages are also available; TL(all) used all specimens.

Model	**Largemouth Bass**			**Chain Pickerel**			**Brown Bullhead**		
	Age	**TL**	**TL(all)**	**Age**	**TL**	**TL(all)**	**Age**	**TL**	**TL (all)**
N	**213-228**	**213-228**	**235-252**	**116-118**	**116-118**	**126**	**41**	**41**	**44**
8. Models with single physico-chemical parameter and waterbody type. Only models with significant waterbody terms shown.									
r^2	0.32								
Age or TL	0.0001								
Waterbody type 1-3	0.0014								
Conductivity	0.0001								
r^2	0.32		0.37			0.52			
Age or TL	0.0001		0.0001			0.0001			
Waterbody type 1-3	0.0001		0.02			0.03			
DOC	0.0001		0.0001			0.0001			
r^2	0.26						0.54		0.55
Age or TL	0.0001						0.09		ns
Waterbody type 1-3	0.002						0.01		0.005
Alkalinity	0.004						0.0001		0.0001
r^2	0.29	0.23							
Age or TL	0.0001	0.0001							
Waterbody type L/R	0.0001	0.06							
pH	0.0001	0.0002							

chain pickerel, brown bullhead and largemouth bass, respectively. Among the different parameters, DOC was significant in all of the final stepwise models (Table 12). Conductivity, alkalinity, chloride and sulfate were significant in models for one or two of the three species. pH was not significant in the final models for any species, although it was significant by itself for all species.

Models were run using the three most easily measured variables, total length, pH and conductivity. For largemouth bass, the r^2 for this model was 0.40 compared to 0.52 for the best stepwise model (using all data). This reflects the complexity of the stepwise model for bass, which included DOC and chloride as well as conductivity. For chain pickerel, the “simple” model had an r^2 of 0.64, which was similar to the best stepwise model using length (0.69), but less than that of the best overall model (0.78), which included age instead of length. For brown bullhead, the “simple” model was nearly as good as the equivalent model using length, but not as good as the best overall model, which included age.

The differences among the species in the apparent relationships with the physico-chemical parameters partly reflects the range of sites at which the species occurred. The chain pickerel occurred in many low pH sites, as well as some higher pH lakes. It was not present in collections from most rivers outside the Pine Barrens or in many lakes. As a result, mercury concentrations for pickerel can be modeled reasonably well along a single softwater to hardwater gradient. This gradient can be modeled by any of the four parameters (pH, DOC, alkalinity and conductivity), although other parameters (e.g., sulfate and chloride) improve the relationship.

Largemouth bass and brown bullhead were not found in the sites with the lowest pH, alkalinity, and conductivity, and in few low pH lakes. They were found in a variety of other sites, including many rivers, lakes, urban areas, etc. As a result, the softwater to hardwater gradient was not as strong and single parameter models were not as good as they were for chain pickerel. Concentrations of mercury were generally low for brown bullhead (often near detection levels), so analytical variability may contribute to the low r^2 for models for this species.

These models can be used to predict tissue concentrations of mercury based on water quality parameters. For the best stepwise models (including only terms with slopes consistent with bioaccumulation relationships) and for the models using easily measured parameters, models are:

Largemouth bass
$\ln(Hg) = 2.82 + 0.84*\ln(Age)+0.32*\ln(DOC)-1.85*\ln(Cond)+1.23*\ln(Cl)$ $r^2=0.46$
$\ln(Hg) = -7.04 + 2.75*\ln(TL) +0.39*\ln(DOC)-1.54*\ln(Cond)+0.89*\ln(Cl)$ $r^2=0.52$
$\ln(Hg) = -7.71+ 2.84*\ln(TL) -0.092*pH -0.55*\ln(Cond)$ $r^2=0.40$

Chain pickerel
$\ln(Hg) = -0.90+0.66*\ln(Age)+0.39*\ln(DOC)-0.59*\ln(Cond) -0.84*\ln(SO4)+0.61*\ln(Cl)$ $r^2=0.78$
$\ln(Hg) = -4.39+1.30*\ln(TL) +0.45*\ln(DOC)-0.029*\ln(Alk+1)-1.11*\ln(SO4)+0.30*\ln(Cl)$ $r^2=0.69$
$\ln(Hg) = -1.44+1.47*\ln(TL) -0.27*pH -0.70*\ln(Cond)$ $r^2=0.64$

The physico-chemical parameters do not necessarily show differences between rivers and lakes, which may affect mercury bioaccumulation. To investigate this, waterbody type was used as an explanatory variable along with the other physico-chemical variables. Waterbody type was significant for few models, and contributed little to explanatory power. Waterbody type was designated by two methods. For the first method, three types were designated: rivers (given a value of 1), narrow, run-of-river impoundments (given a value of 2), and lakes (given a value of 3). This variable was used as a regression variable. The second method divided rivers (value of 'R') and lakes (value of 'L'), and this variable was used as a class variable. Waterbody type (1-3) was significant in a stepwise model for largemouth bass (with age) and for brown bullhead (with length), but these models were not much better than corresponding models without waterbody type.

The physico-chemical parameters were also used to improve models using the pre-defined sampling strata (Table 11). Single parameters were used as covariates within models with fish size (age or length) as a covariate and strata as a class variable. The analyses show that the physico-chemical parameters explain some of the variation in mercury concentrations within strata. For example, the model for largemouth bass using age and strata had an r^2 of 0.38, while that using length, strata and conductivity had an r^2 of 0.52. The improvement was least for chain pickerel, reflecting the good separation of the primary softwater-hardwater gradient by the different strata. For chain pickerel, pH and alkalinity effected no model improvement, since the strata were designed on the basis of pH variation. Conductivity and DOC did improve model fit somewhat. These variables can explain deviation of sites like Willow Grove Lake, which had mercury concentrations higher than that of other sites in its stratum. Willow Grove Lake has DOC and conductivity near or similar to that of Pine Barrens sites, although its pH was higher (Table 6).

Comparison With Previous Studies of Mercury in New Jersey Fish

Data on mercury in New Jersey and nearby areas are available from several sources and are summarized in Appendix C. Jacangelo (1977) reported results of a study focusing on mercury contamination in New Jersey. Study sites are predominantly in rivers, streams and some small lakes and impoundments. Most samples are from industrial regions, especially in the northeastern part of the state. This emphasis reflects the main concern at that time with point source discharges during that period. As a result, little sampling was done in the larger lakes and acidic sites which showed highest concentrations in the present study. A variety of fish were sampled, with a high proportion of suckers and sunfish. Relatively few large piscivores were collected, although some large pickerel and moderate-sized bass were analyzed. Many samples were composites of fish of roughly similar sizes. Results are somewhat difficult to interpret since there is often relatively large variation among samples within sites, often not clearly related to size of fish. Precise information on date and location of sampling are not given so that some variability may reflect between-year or local spatial variation. In addition, the accuracy and precision of measurement are difficult to assess.

Jacangelo (1977) noted greater frequencies of high mercury concentrations in the industrial rivers in the northeastern part of the state. High concentrations are seen, for example, in the Passaic, Pompton, Pequannock, Rockaway and Whippany rivers in the Passaic Drainage, the Swimming River, and the Millstone, Neshanic, North Branch Raritan and South Branch Raritan rivers in the Raritan Drainage. In general, concentrations were low in a variety of fish from Round Valley Reservoir, the upper Delaware River, and a number of small ponds and tributaries. These results parallel those seen in comparisons of comparable sites in the 1992-1993 screening study.

Concentrations in several of the sites in the Passaic Drainage were higher than expected on the basis of pH group. However, the 1971-1975 analyses show relatively high levels in fish expected to have relatively low bioaccumulation, e.g., moderate-sized sunfish (especially bluegill and pumpkinseed), white suckers, small goldfish, carp and white perch. Relatively high concentrations (up to 0.41 mg/kg wet weight) were found in small (presumably young-of-year) alewife and blueback herring from the lower Delaware River. However, there was large variability among herring, with other samples showing very low concentrations. It is plausible that the differences between the earlier and present survey reflect decreases in mercury bioaccumulation related to decreasing discharges. However, without better information on precise site locations, etc., and directly comparable data it is difficult to rule out other explanations (e.g., selection of known "hot spots" in earlier studies).

Ellis et al. (1980) reported on analyses of a suite of metals in New Jersey fish. Sampling was predominantly in estuarine waters, although it included some freshwater sites mainly in the Delaware River. Data summaries are coarse, without separation of data from individual stations, size classes, etc. The main target species, striped bass, eel, white perch and sunfish, were not analyzed in this study, so relatively little direct comparison is possible. As in the present study, concentrations in catfish (presumably channel or white catfish) from the Delaware River were low. Higher concentrations were seen in the Raritan, Passaic and lower Hudson regions. Like Jacangelo, high concentrations were noted in some sunfish samples from the Raritan and Passaic drainages.

Additional data on fish from the Delaware River are available from small datasets from NYDEC (1981), ANSP (1974, 1985), and USFWS (1983). These indicate low concentrations of mercury in a variety of smaller species from the lower river (e.g., black crappie, brown bullhead, white sucker) and in adult American shad from the upper river.

Spotts and Rice (1992) analyzed mercury in fish from 12 Pennsylvania lakes. Lakes were selected which had pHs less than 7. However, it is difficult to compare these results with those from the present study, since pH data were not compiled (C. Rice, pers. comm.), although data on these lakes may be available. Average concentrations near or greater than 0.5 mg/kg were seen in chain pickerel from Lake Jean and Lake Black Moshannon and largemouth bass from Sunfish Pond. Data on reservoirs in the upper Delaware Basin are available from NYDEC (1981). Data from Onandaga Lake (NYDEC 1981, 1987), an intensively-studied lake with known point source contamination, are also presented in Appendix C.

Comparison With NJDEP 1994 Study of Mercury in New Jersey Fish

In February 1994, the 1992-1993 ANSP screening study identified mercury concentrations in fish from 55 freshwater lakes, rivers and reservoirs throughout the state. Mercury concentrations in fish collected from 15 of the 55 New Jersey water bodies tested exceeded the U.S. Food and Drug Administration (FDA) 1.0 ppm tolerance level for the protection of human health. As a result, in March 1994 the NJDEP and NJDHSS jointly issued an interim public health notice to all anglers not to eat any largemouth bass, *Micropterus salmoides,* chain pickerel, *Esox niger* or yellow bullhead, *Ameiurus natalis*, from those waterways. The list of the 15 water bodies includes Carnegie Lake (Mercer County), Manasquan Reservoir (Monmouth County), East Creek Lake and Lake Nummy

(Cape May County), New Brooklyn Lake (Camden County), Wilson Lake (Gloucester County), Batsto Lake, Harrisville Lake, Wading River and the Mullica River (Burlington County), Atlantic City Reservoir (Atlantic County), Monksville Reservoir and Wanaque Reservoir (Passaic County), Union Lake (Cumberland County), and Merrill Creek Reservoir (Warren County).

In April 1994, NJDEP resampled the15 water bodies under the interim public health notice and the results are reported in Appendix D. The objective of this project was to provide the department with additional data to confirm the findings of the 1992-1993 ANSP study. The data were also used in the design of the 1996-1997 ANSP followup study and will be used in future consumption advisories. The NJDEP project included collection of fishes of four trophic levels, including one forage group at each waterbody. A total of 15 gamefish species and 5 forage fish species were represented in this study. All of the gamefish species sampled are considered important for recreational sport fishing and are known to be consumed by New Jersey anglers**.** The inclusion of these three higher trophic levels and forage fish species in the study design provided varying perspectives of intra- and inter- specific relationships of mercury bioaccumulation in the aquatic system. Where applicable, all gamefish were either at or exceeded the legal size limit established by NJDFGW regulation. Where no species size limit regulation existed, fish sampled were of a size considered “typical” of those taken by anglers for consumption.

Overall, the data generated through this project paralleled the findings of the 1992-1993 ANSP study, where typically the largest specimen of gamefish sampled exhibited the highest mercury concentration. As in the 1992-1993 ANSP study, largemouth bass and chain pickerel were targeted as the top trophic level (TL-1) species at each of the 15 waterbodies. These two species are functionally piscivorous (fish eating) predators, though their diet also consists of invertebrates and amphibians and were identified to have elevated mercury tissue concentrations. Other TL-1 species sampled include smallmouth bass, brown trout, walleye and lake trout. Walleye and lake trout were collected from two separate lakes and each represents a unique top trophic level fishery at that waterbody. White perch, yellow perch, black crappie, bluegill, mud sunfish, and pumpkinseed sunfish comprise the TL-2 trophic level. These species are typically smaller omnivorous gamefish, feeding primarily upon a variety of invertebrates, insects and other fish. The TL-3 group included catfishes and bullheads, which are omnivorous demersal species. These species are widely distributed throughout the state and have similar feeding patterns as TL-2 species, but their diet may also include freshwater mollusks and vegetative matter. The TL-3 species most often collected were brown bullhead, yellow bullhead, white catfish and channel catfish. The TL-2 and the TL-3 species have the highest *per capita* consumption rate by anglers among New Jersey freshwater fish (NJDFGW, pers. Comm.). Forage fish samples consist of minnow, sucker, and herring species or, where applicable, juvenile specimens of white perch or mud sunfish. The common forage species sampled in this project were alewife, golden shiner, American eel and creek chubsucker.

The highest mean mercury concentrations (Appendix D) identified in the top trophic level species were in largemouth bass (1.078 mg/g wet weight) and chain pickerel (0.777 mg/g wet weight). The mean results for other top trophic level gamefish include walleye (0.737 mg/g wet weight), lake trout (0.503 mg/g wet weight) and smallmouth bass (0.406 mg/g wet weight).The highest mean value for lower trophic level gamefish were identified in mud sunfish (1.01 mg/g wet weight) from Harrisville Lake. The results for other species within this trophic level include yellow perch (0.588 mg/g wet weight), white perch (0.453 mg/g wet weight), pumpkinseed sunfish (0.386 mg/g wet weight), black crappie (0.254 mg/g wet weight) and bluegill sunfish (0.234 mg/g wet weight). Mean mercury concentration in bottom dwelling species include yellow bullhead (0.545 mg/g wet weight), brown bullhead (0.221 mg/g wet weight), white catfish (0.300 mg/g wet weight), channel catfish (0.225 mg/g wet weight), and American eel (1.496 mg/g wet weight from Atlantic City Reservoir). Forage species were analyzed as whole body individual or five-fish composite samples. The results revealed mean mercury concentrations in composite samples of golden shiner at (0.368 mg/g wet weight) and (0.107 mg/g wet weight) in individual samples. Mean mercury levels in other forage species include American eel (0.302 mg/g wet weight), creek chubsucker (0.228 mg/g wet weight), alewife (0.132 mg/g wet weight) and juvenile white perch (0.052 mg/g wet weight).

In July 1994, prior to the completion of this NJDEP project, the NJDEP/DHSS rescinded the interim public health notice on the 15 waterbodies for a more comprehensive fish consumption advisory. The NJDEP/DHSS reviewed and statistically evaluated the initial ANSP (1994a) data, and a detailed, risk-based consumption advisory was developed and ultimately adopted. The new consumption advisory recommended restrictive consumption frequencies of both largemouth bass and chain pickerel, for the general population and a high risk sub-group, on both a statewide, regional and lake specific basis (NJDEP 1994).

Collections of chain pickerel and largemouth bass from the same sites in both the NJDEP 1994 and the 1992-1993 ANSP studies allow more detailed comparison of mercury concentrations (Table 16). The observed mercury concentrations for the 1994 NJDEP study were adjusted to the standard size of 33.4 cm, allowing comparison with the adjusted values from the 1992-1993 studies (Table 10 and Table 16). The adjustments were done using the slopes (1.30 for chain pickerel and 2.60 for largemouth bass) of the ln(Hg)- ln(total length) relationships derived in the ANCOVA model including ln(total length), strata and waterbody which were developed for the various ANSP New Jersey studies (see above). The adjusted mercury concentration for a fish of size L is:

$$\text{Adj Hg}_{33.4} = \text{HG}_{L} + \text{Slope}*(\ln(33.4)-\ln(L)).$$

The average adjusted mercury concentrations were generally similar for the lakes sampled in both studies (Table 16), with a few exceptions. For chain pickerel, the averages for the 1994 NJDEP studies at Wilson Lake were higher than 1992-1993 results, while the 1994 averages at Lake Nummy, Wanaque Reservoir and the Mullica River were lower. The difference for the Mullica River may reflect the sampling site. The occurrence of white perch in the 1994 NJDEP samples suggests that sampling occurred in the lower river, while the 1992-1993 sample was taken from the more acid reach below Atsion. For largemouth bass, the average for the 1994 NJDEP analyses at Manasquan Reservoir were considerably lower than the 1992-1993 results.

Table 16. Station averages of adjusted mercury concentrations (ppm) for chain pickerel and largemouth bass for taxa sampled in both the 1992-1993 ANSP screening study and the 1994 NJDEP followup study. Mercury concentrations are adjusted to total length (standardized to a 33.4-cm fish) for largemouth bass. For the 1992-1993 data, adjustments were done using all fish (see Table 10). For the 1994 NJDEP data, adjustments were done using the slope of the ln(Hg)-ln(TL) relationship developed using all ANSP samples.

		NJDEP 1994		**ANSP 1992-1993**	
		Total Length	**N**	**Total Length (all specimens)**	**N**
Largemouth Bass					
Unique Lake (UL)					
	Manasquan Reservoir	0.88	5	1.70	7
Unique Lake (UL)					
	Union Lake	1.48	4	1.23	6
Pine Barrens Lake (PBL)					
	Batsto Lake	1.01	5	1.09	3
Unique Lake (NCARB-UL)					
	Wanaque Reservoir	0.38	5	0.52	6
Southern Industrial Lake (SINDL)					
	Atlantic City Reservoir	2.47	5	3.28	6
Unique Lake (NCARB-UL)					
	Merrill Creek Reservoir	0.55	5	0.49	3
Northern Midland Lake (NML)					
	Monksville Reservoir	0.53	4	0.61	3
Northern Carbonate Lake (NCARB)					
	Carnegie Lake	0.20	5	0.28	6
Chain Pickerel					
Pine Barrens River (PBR)					
	Mullica River	0.47	5	0.94	1
	Wading River	0.62	5	0.73	5
Unique Lake (UL)					
	Union Lake	0.80	4	0.70	1
Pine Barren Lake (PBL)					
	East Creek Lake	0.98	5	1.20	9
	Harrisville Lake	1.46	5	1.29	5
	Lake Nummy	0.57	5	1.28	1
	Batsto Lake	0.54	5	0.53	1
Unique Lake (UL)					
	Wanaque Reservoir	0.21	6	0.38	2
Coastal Plain Lake - pH 5 (CPL5)					
	Wilson Lake	0.92	6	0.66	4
	New Brooklyn Lake	0.35	5	0.41	5

DISCUSSION AND CONCLUSIONS

The results of the 1996-1997 are generally in concordance with the results of the preliminary assessment (ANSP 1994). Major findings are:

1) *Relatively high concentrations in fishes from the Pine Barrens.* The sites selected for the 1992-1993 screening study were generally in the southern Pine Barrens. The present study analyzed fish from more northern sites as well (Butterfly Bog, Lake Success, Ridgeway Branch, Double Trouble). These showed consistent patterns across the Pine Barrens.

2) *Variable concentrations in sites adjacent to the Pine Barrens, with some sites having relatively high concentrations*. This pattern was seen in the sites sampled in the 1996-1997 study as well, with relatively high concentrations in some sites (e.g., Willow Grove Lake), and lower concentrations in others (e.g., Cedar Lake). Much of this variation is explained by differences in water chemistry. For example, although pH in Willow Grove lakes was higher than that of most Pine Barrens sites, other parameters were similar.

3) *Elevated concentrations in sites in industrial areas in the Northeastern part of the state.* Several sites in the Passaic drainage (Passaic River, Pompton River, Rockaway and Whippany Rivers) were sampled in the 1996-1997 study. These showed higher concentrations than would be expected on the basis of water chemistry.

4) *Variable concentrations in Piedmont-montane lakes*. There was a general relationship between water chemistry and mercury concentrations in fish in these lakes, with higher concentrations in sites with igneous and metamorphic geology, and lower concentrations in sites with carbonaceous rocks in the immediate drainage. Relatively high concentrations were seen in fish from Crater Lake, a site located in the Shawangunk sandstone. However, there was much site-to-site variation not explained by simple geological patterns.

The stratification of New Jersey waterbodies was modified for the 1996-1997 study, to better separate chemical conditions which are expected to affect bioaccumulation. The amount of among-site variation explained by the stratification indicates its general validity. As noted above, there is still substantial variation among sites within strata, particularly within Piedmont-Montane lakes (Northern-midland lakes) and in sites adjacent to the Pine Barrens. Inclusion of water chemistry and strata in models of mercury concentrations shows that some of the within-stratum variation can be explained by differences in water chemistry. This effect has three components:

a) Given the continuous nature of variation in bioaccumulation, the strata define rather arbitrary distinctions along gradients of water chemistry. Thus, variation within strata partly reflects variation in the chemical factors used to define the strata;
b) Sites may have been misclassified. The strata were defined largely on the basis of pH. pH will vary temporally, and values measured at a single time may not be fully representative of long term conditions, which affect bioaccumulation.

c) A variety of factors, which are not encompassed by the stratification, may affect bioaccumulation, so these can create within-stratum variation in mercury. For example, Willow Grove Lake was similar in most water chemistry parameters to Pine Barrens lakes, but had a higher pH. Mercury concentrations in fish from the lake were similar to those of Pine Barrens lakes, and higher than those of similar pH.

Originally, a stratum was designated for a few streams in the Pine Barrens with mixed agricultural and forest land uses, since the water chemistry of these sites may differ from that of Pine Barrens sites. One site from this stratum, Ridgeway Branch, was selected for sampling. However, its water chemistry was similar to that of other Pine Barrens sites, and it was reclassified as a Pine Barrens site. Given the small number of streams in this group and the possibility of spatial variation in water chemistry, inferences about these sites should be based on reach-specific chemical measurements.

Analyses of mercury from fillets (muscle tissue) and carcasses of the same specimens allowed estimation of whole body concentrations and comparisons (Table 14). Among the eight species analyzed, median ratios of fillet to whole body concentrations for each species ranged from 1.33 to 1.88. Goldstein et al. (1996) compared muscle and fillet concentrations in carp and channel catfish from the Red River of the North, in Minnesota. They found consistent ratios within each of the two species and similar muscle-whole body regressions between the two species. They fit ln(whole body concentration) to ln(muscle concentration), producing slightly nonlinear relationships for the two species. Their regressions corresponded to average muscle/whole body ratios of 2.34 for carp and 1.51 for channel catfish.

The analyses of relationships between mercury concentrations and physico-chemical parameters were done to allow prediction of mercury concentration in unsampled sites. This could allow assessments of potential bioaccumulation based on relatively simple water sampling in sites where fish sampling and tissue analysis have not been done. The analyses indicated that a substantial amount of the among-site variation can be explained by simple measurements. pH and conductivity, which can be measured easily in the field, provided good explanatory power. Measurements of alkalinity and DOC increase model fit in several models, and chloride and sulfate were also important for some comparisons.

The results of these regression analyses demonstrate relationships between mercury bioaccumulation and general gradients in alkalinity/pH/conductivity which are concordant with other studies on mercury bioaccumulation (Wiener et al. 1990, Lathrop et al. 1989, Wren and MacCrimmon 1983, Gloss et al. 1990, Sorensen et al. 1990). DOC was also a significant correlate of mercury, as noted in other studies (e.g., Watras et al. 1995b,d) The analyses and others (Parks et al. 1994, Price 1995) also indicate relationships with parameters, such as sulfate and chloride, not strongly correlated with the alkalinity/pH/conductivity gradient. Correlations between mercury bioaccumulation and chloride concentrations, e.g., as in this study, may be due to the joint correlation with urbanization, sewage plant effluents, and other point and non-point source inputs of mercury. However, the importance of each variable in the analyses does not necessarily indicate the relative causal importance of that variable to mercury bioaccumulation. There are several statistical and geochemical factors which affect these relationships:

1) *The analyses are based on small numbers of measurements of each parameter* (usually one measurement). Tissue concentrations reflect mercury bioaccumulation integrated over long time periods. They may be affected by average conditions of important causal factors, or by episodic extreme conditions. These long term averages or episodic extremes may not be well-measured by a few, single point-in-time water samples. Other parameters may be more closely correlated with these long-term average or extreme events, providing better predictive power. For example, a parameter correlated with a causal factor, but showing less temporal variation, may be a better predictor of average values than the a single measurement of the causal factor. For example, pH may show diel variations of several units due to productivity/respiration cycles, decreasing the reliability of a few measurements to estimate typical site levels. Typical values of some parameters may indicate the vulnerability to extreme variation in another parameter. For example, pH fluctuations are expected to be greater in low alkalinity sites, so alkalinity may be a good predictor of extreme values.

2) *Similar arguments apply to spatial variation within sites.* Mercury bioaccumulation may be regulated by factors within sediments, adjacent wetlands, deep water, etc. (Rudd 1995, Watras et al. 1995c), which may not be well measured by surface water measurements.

3) *Relationships between bioaccumulation and chemical parameters may be nonlinear*. Without specific nonlinear models to fit, linear modeling is appropriate to determine general relationships. However, deviations from linearity may appear as model noise.

4) *Many of the parameters are highly correlated.* Thus, results of the analyses are sensitive to small changes in the parameters, the order of introduction of each variable into regression models, etc.

5) *The strength of correlations will depend on the range of values of different, measured parameters among the lakes sampled or from which a given species was caught.* For example, chain pickerel were caught in many low pH lakes and a few higher-pH lakes. Mercury concentrations in pickerel were strongly related to the single gradient relating to pH/alkalinity/DOC/conductivity. Models for largemouth bass were more complex, partly because of the rarity of bass at the low pH sites, and the variety of moderate-pH sites at which bass were caught.

6) *The strength of correlations will depend on the variation in types of sites sampled and the variation in parameters not measured.* For example, patterns of mercury transport and methylation may differ between seepage and drainage lakes (Driscoll et al. 1994), or between shallow lakes and deeper lakes which stratify. Within each type of lake, there may be strong correlations with a single or with a few parameters. However, these relationships may be obscured when date from different types of lakes are analyzed together.

7) *Many of the causal factors have multiple effects which may enhance or counteract each other*. For example, DOC may enhance bioaccumulation both by stimulating of methylation or mercury and by increasing transport of methylmercury to rivers and lakes. Within rivers and lakes, binding of DOC and mercury may increase or decrease bioavailability of mercury to different consumers. Furthermore, many of the causal factors are correlated in occurrence. For example, Pine Barrens sites are characterized by high DOC (i.e., humic acids) and high amounts of wetland. Because of these effects, complex relationships between potential causal factors and mercury concentrations, as observed in this study, are to be expected.

One of the goals of relating mercury concentrations to water chemistry was to provide a tool for screening lakes for potential mercury problems or for setting advisories on lakes from which no fish have been analyzed. The high correlations suggest that water chemistry data are informative about the likely level of mercury bioaccumulation. The size (length or age) adjusted site means (Table 6) were used as an index of mercury bioaccumulation to investigate simple contingency models (Tables 17, 18). For chain pickerel and largemouth bass, observed relationships between adjusted mercury concentrations and chemical parameters were used to categorize sites on the basis of pairs of water chemistry parameters. Cutpoints between levels of chemical parameters were chosen visually from graphs of relationships. For chain pickerel (Table 17), these categorizations separated lakes of high and low adjusted mercury concentrations. For example, pH and conductivity could be used to separate most lakes, although a few sites (Union Lake, Monksville Reservoir and Wanaque Reservoir) with moderate conductivity and pH had relatively high adjusted mercury concentrations. The success of the categorization is consistent with the high correlations between mercury and the pH, alkalinity, and conductivity gradient found in the regression models. The categorization for largemouth bass (Table 18) was not as good, with water chemistry groups containing fish of a range of adjusted mercury concentrations. This is also consistent with the results of the regression analyses, which found lower total correlation and relationships with a number of parameters. Some sites probably had historical mercury sources which would not be reflected by the water chemistry parameters, so a perfect separation is not expected. These analyses suggest that site water chemistry can provide a good, but not perfect, estimate of the likelihood of high mercury concentrations. Based on this, a monitoring strategy could be sample three types of sites: those identified by water chemistry as having a high probability of high mercury concentrations; sites with other factors which could result in high mercury (e.g., new reservoirs, historical point sources), and sites which are particularly important for fisheries.

In this study, mercury concentrations were contrasted in different species of forage fish in several lakes. Species included zooplanktivores (e.g., golden shiner and alewife), and invertebrate feeders (e.g., sunfish). The comparisons did not show consistent differences among trophic groups other than piscivores. Among zooplanktivores, mercury concentrations were low in golden shiners. However, where analyzed, concentrations in alewife, another zooplanktivore, were similar to those of sunfish from the same site. The lack of strong relationships may be due to coupling of sediment and water mercury by physical and chemical processes, and by trophic links between different food webs. For example, invertebrate feeders may feed on benthic organisms as well as invertebrates

Table 17. Number of sites with adjusted average mercury concentration of chain pickerel within different ranges, for different combinations of measured site water chemistry.

Chain Pickerel							
	Conductivity	**pH**	**Mercury Concentration Ranges (ppm)**				
	µmhos		**< 0.36**	**0.36 - 0.54**	**0.54 - 0.94**	**> 0.94**	**All**
	< 80	< 6	1	1	9	6	17
	< 80	> 6	1	-	-	1	2
	> 80	< 6	1	-	-	-	1
	> 80	> 6	10	3	2	1	16
	DOC	**SO_4**	**Mercury Concentration Ranges (ppm)**				
	mg / L	**mg / L**	**< 0.36**	**0.36 - 0.54**	**0.54 - 0.94**	**> 0.94**	**All**
	< 10	< 8.5	4	1	2	2	9
	< 10	> 8.5	9	3	1	-	13
	> 10	< 13	-	-	8	6	14
	> 10	> 13	-	-	-	-	0
	DOC	**Alkalinity**	**Mercury Concentration Ranges (ppm)**				
	mg / L	**mg / L**	**< 0.36**	**0.36 - 0.54**	**0.54 - 0.94**	**> 0.94**	**All**
	< 10	< 5	2	2	1	1	6
	< 10	> 5	11	2	2	1	16
	> 10	< 5	-	-	8	6	14
	> 10	> 5	-	-	-	-	0

Table 18. Number of sites with adjusted average mercury concentration of largemouth bass within different ranges, for different combinations of measured site water chemistry.

Largemouth Bass							
	Conductivity	pH	Mercury Concentration Ranges (ppm)				
	µmhos		< 0.36	0.36 - 0.54	0.54 - 0.94	> 0.94	All
	< 80	< 6	-	1	1	3	5
	< 80	> 6	-	1		1	2
	> 80	< 6	1	-	-	-	1
	> 80	> 6	29	11	5	2	47
	DOC	SO_4	Mercury Concentration Ranges (ppm)				
	mg / L	mg / L	< 0.36	0.36 - 0.54	0.54 - 0.94	> 0.94	All
	< 4	< 13	5	3	-	-	8
	< 4	> 13	8	2	1	3	14
	4 - 10	< 13	9	3	2	1	15
	4 - 10	> 13	7	4	2	3	16
	> 10	< 13	1	1	1	-	3
	> 10	> 13	1	-	1	-	2
	DOC	Alkalinity	Mercury Concentration Ranges (ppm)				
	mg / L	mg / L	< 0.36	0.36 - 0.54	0.54 - 0.94	> 0.94	All
	< 4	< 5	1	-	-	1	2
	< 4	> 5	12	5	1	2	20
	4 - 10	< 5	2	1	-	-	3
	4 - 10	> 5	14	6	4	4	28
	> 10	< 5	1	1	1	-	3
	> 10	> 5	1	-	1	-	2

epiphytic on submerged plants. These epiphytic organisms may be more linked to openwater food webs than benthic. Several species of fish, especially bluegill, blue-spotted sunfish (Graham 1989), black crappie, and yellow perch, may feed on zooplankton as well as benthic or epiphytic prey.

This study did document a fish size related effect which can affect bioaccumulation of mercury. "Dwarf" species of sunfish (genus *Enneacanthus*; blue-spotted and black-banded sunfish) were analyzed from several sites. These species live several years, but reach maximal sizes typical of large young-of-year of *Lepomis* sunfishes (e.g., bluegill, pumpkinseed and redbreast sunfish). The dwarf sunfish can be important parts of the diet of chain pickerel and other predatory fish. Both *Enneacanthus* and *Lepomis* were analyzed from Grover's Mill Pond. For similar-sized fish, concentrations were higher in the blue-spotted sunfish. Bioaccumulation by predatory fish may be increased by the presence of the dwarf sunfish, since these present relatively old (and higher mercury) prey to moderate-sized predatory fish. The dwarf sunfish are the dominant or only sunfish in Pine Barrens lakes, and their presence could be a factor in mercury bioaccumulation in these sites. Since the Pine Barrens lakes have other characteristics enhancing bioaccumulation (high DOC, much wetland area within their watersheds), the importance of this factor cannot be established. Mercury concentrations of largemouth bass in Grover's Mill Pond were not notably high.

RECOMMENDATIONS FOR FURTHER STUDY

This followup study generally corroborated the findings of the earlier screening study. Together, these studies provide extensive information on mercury in New Jersey freshwater fishes. Future work can focus more narrowly on unresolved issues and on trend analysis. Areas for future work include providing more precise information on regions or taxa which are variable or currently poorly known, sampling over time to determine temporal trends, and investigation of mechanisms of bioaccumulation.

Increasing Precision and Spatial Coverage

Several types of investigations will aid New Jersey in estimating potential risks from mercury bioaccumulation and defining consumption advisories. Sampling of previously unsampled sites or taxa is valuable to identify localities or species with potential high bioaccumulation. More information on correlates of mercury concentration would also improve predictive models, which will aid in identifying potential areas of risk.

1) Waterbodies in strata with variable mercury levels. The analyses of among-site variation show that while broad predictions can be made about mercury bioaccumulation from lake characteristics, there is much variability among sites. This variability probably derives from influences of historical mercury inputs and effects of factors not accounted for in the predictive models. The most critical areas for more work would be in the north part of the state, especially in the northeastern area, where industrial inputs were probably more prevalent. In addition, areas at the edge of the Pine Barrens are relatively variable in the amount of bioaccumulation. In contrast, there was relatively low variability among Pine Barrens sites (most sites having relatively high bioaccumulation), in Coastal Plain streams or lakes outside the Pine Barrens, and in coldwater streams and rivers (with relatively low bioaccumulation).

2) Sampling of poorly characterized strata. Some fish from Crater Lake, in Sussex County, had relatively high mercury concentrations considering their trophic level. Crater Lake was selected as a representative of lakes on the Shawangunk Formation, which are poorly buffered, possibly leading to high bioaccumulation. Further investigation of fish, especially piscivorous fish, from similar lakes is recommended.

3) Sampling of some additional taxa is recommended. Snapping turtles are high trophic level species which are consumed. Eels can be resident in freshwater for a number of years, have a potential for bioaccumulation, and support an important commercial fishery. Sampling of both species is being done as part of ongoing studies by ANSP. These studies can provide information on the need for more intensive sampling.

4) Correlations between mercury concentrations in fish and water quality parameters were established. While strongly significant, there was still substantial variation in mercury concentrations which was not explained by these models. Improvements in these models may

be obtained by more extensive measurements of water quality parameters and by inclusion of additional types of variables. The analysis was based largely on spot sampling of water chemistry which is unable to incorporate seasonal or spatial variation in water quality parameters. More extensive sampling in a few lakes would be valuable in establishing ranges of variability in water chemistry. Such sampling could be especially valuable in lakes at the edge of the Pine Barrens, where considerable seasonal variation is expected, and in northern lakes, especially the larger lakes, where spatial and seasonal variation is expected.

Information on watershed characteristics could be valuable in modeling mercury concentrations. Information such as proportion of wetlands, soil/geology, and land use could be derived from GIS data and would provide information on factors influencing mercury transport and methylation. These variables would supplement the water chemistry parameters.

Information on Temporal Trends in Mercury Concentrations

Analyses of temporal trends in mercury concentrations are important. The time scale of sampling to detect temporal trends depends on the expected rates of change in mercury concentrations. Different rates of change are expected for waterbodies with different sources of mercury, and these differences should be considered in planning subsequent sampling. Comparison of studies conducted in New Jersey during 1992-1997 with studies in the 1970s suggests decreases in mercury concentrations in areas which were affected by point-source contamination. These changes probably result from decreases in inputs, and burial or flushing of mercury from historical contamination. For most waterbodies, atmospheric inputs have been the dominant ultimate sources of mercury. Regulation of anthropogenic sources in recent years have decreased atmospheric emissions of mercury. However, it is currently unknown how fast aquatic systems will respond to such changes. Because of long distance transport and mixing of mercury in the atmosphere, and because of reservoirs of mercury in soils and sediments within watersheds and waterbodies, there may be an appreciable lag between decrease in emissions and decreases in bioaccumulations. However, there have been suggestions that relatively rapid changes may occur, e.g., in locations near industrial areas which have decreased emissions. Thus, trend sampling in the next few years would be important to determine rates of response of aquatic systems to environmental regulation.

5) Monitoring of a small group of lakes over time would be valuable in determining temporal trends in bioaccumulation, e.g., resulting from decreases in atmospheric emissions and deposition. An alternative approach would be to select sites randomly from the existing stratification and look for temporal trends in mean concentrations within strata.

6) Monitoring of atmospheric deposition. There are currently no mercury deposition monitoring sites in New Jersey in the National Atmospheric Deposition Program. Data on atmospheric deposition would important to demonstrate changes in mercury inputs, e.g., resulting from controls on anthropogenic emissions. Such sampling, combined with analyses of mercury in sediment and biota, would be important in understanding the importance of input rates and in-lake processes on mercury bioaccumulation.

7) Sampling of relatively new reservoirs which were previously sampled. High rates of bioaccumulation have been observed in newly impounded reservoirs. Mercury concentrations in fish tissue in such reservoirs tend to decrease over time, though the rate of decrease cannot be generally predicted. In the 1992-1993 study, relatively high concentrations were seen in fish from Manasquan Reservoir and Merrill Creek Reservoir, two young reservoirs. Repeat sampling by NJDEP in Manasquan Reservoir in 1994 did not find as high levels in largemouth bass. Repeat sampling, e.g., at 4- to 6-year intervals, is recommended to follow possible temporal trends in bioaccumulation.

8) Sampling of other sites with high mercury concentrations. Sampling is recommended where historic point sources are likely or known to have been present. Decreases in concentrations may be expected. Repeat sampling at intervals of about 6-10 years is recommended.

Information on Mechanisms Controlling Bioaccumulation

Several of the studies mentioned above will provide information on mechanisms. In particular, relationships between deposition rates and mercury concentrations in fish tissues will be useful in making the link between sources and bioaccumulation. Additional information on processes within waterbodies would also be important.

9) Mercury concentrations in sediments. Information on concentrations of methylmercury in sediments would be useful in establishing the relative importance of sediment methylation as the dominant control of mercury concentrations in higher trophic levels, e.g., relative to trophic relationships controlling bioaccumulation through the food chain. Together with information on deposition rates, this information would provide important information on external and internal processes affecting bioaccumulation.

10) The role of small, relatively long-lived prey (e.g., “dwarf” sunfishes) as forage fishes in Pine Barrens and other systems should be further investigated. Information on ages and age-specific concentrations of these forage fishes, their role in the diets of predators could be used to model the importance of this factor in bioaccumulation.

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APPENDIX A

Summary data from previous ANSP studies (ANSP 1994a, b, c) on mercury concentrations in freshwater fishes in New Jersey. These data complement data from the 1996 study, as presented in Tables 4 and 5.

APPENDIX B

Data on individual specimens analyzed as part of the 1992 ANSP screening level study, the 1993 Camden County study, the 1994 Hackensack Water Company study, and the 1995 mercury study.

APPENDIX C

Summary of mercury concentrations in fishes from other studies in New Jersey and nearby areas.

APPENDIX D

Results of followup study by the New Jersey Department of Environmental Protection and the New Jersey Department of Health on selected sites previous sampled in the 1992 ANSP screening study.