Fish Consumption and Human Health Risks

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Executive Summary

Methylmercury contamination of fish has become a problem of national significance. Methylmercury can cause a variety of health effects, including cardiovascular disease and neurological impairment in fetuses and neonates. The Virginia General Assembly recognized the seriousness of mercury contamination and directed the Department of Environmental Quality (VA DEQ) to collect additional information on the problem. VA DEQ investigated methylmercury contamination of fish in certain waters of eastern Virginia because monitoring data indicate that catfish, large mouth bass and several other predatory fish have the highest methylmercury levels. VA DEQ contracted with Virginia Commonwealth University (VCU), Center for Environmental Studies (CES) to conduct fish consumption surveys in the affected waters and estimate the associated health risks from resulting methylmercury exposures. CES developed a fish consumption survey, and worked with VA DEQ staff to identify the launching and fishing locations where anglers could be surveyed. The survey was designed to obtain information on fishing behaviors, fish consumption, and demographic data on the anglers and families. During the summer of 2007, a team from CES administered the survey to 158 anglers at boat launching and fishing sites. Surveys were completed for anglers who were fishing at 17 locations on 5 rivers: the James River below Richmond, the Chickahominy, Pamunkey, Mattaponi, and upper Piankatank Rivers. These rivers are affected by methylmercury contamination, have been surveyed in previous similar investigations and are used by anglers for recreational fishing.

The surveys were administered to anglers from all 17 locations on all 5 rivers, predominantly on Friday, Saturday or Sunday. Approximately 44% of all respondents and their families consume the fish that they catch from these waters. Half (50%) of the anglers only, not family members consume some fish that they catch, and more men (54%) than women (43%) were reported to consume the fish with elevated MeHg levels. The most commonly consumed fish were catfish, spot or croaker, sunfish and largemouth bass; catfish and largemouth bass are

two of the species on the fish consumption advisory. Catfish also represented the largest number of meals and total amount of self-caught fish consumed per year. The data on fish consumption were analyzed with VA DEQ data on methylmercury concentrations in fish that had been collected in previous years to estimate the amount of methylmercury consumed in fish yearly. In order to estimate total methylmercury from all fish consumption, canned tuna and purchased fish consumption were added to mercury exposures from self-caught fish. Mercury levels in tuna and purchased fish were taken from national data.

The methylmercury exposures determined from survey data and VA DEQ fish tissue levels were compared to the dose of mercury exposure that the Environmental Protection Agency has set (and Virginia Department of Health uses) as the dose without appreciable health risks, based on the reference dose or RfD.

The analysis of the fish consumption and fish tissue concentrations was performed using a probabilistic computer program that is used for risk assessments. This program randomly selects certain values, as defined, to use in the equations for determining total mercury from all fish consumed. The analysis indicates that a significant number of anglers who regularly catch and consume significant amounts of catfish and large mouth bass from the affected waters are exposed to methylmercury at levels above the U.S. EPA reference dose of 0.1 ug/kg-day.

The present investigation highlighted several areas that are unknown or have very little data and additional data gathering would close significant gaps in our current understanding of the situation in Virginia. These areas include:

- This survey only obtained data from a few women and no family members and further surveys would be needed to obtain direct fish consumption information on women and children in angler's families.
- Fish consumption patterns of Spanish speaking anglers especially in the Richmond area
- the Native American tribes in the area could be contacted to request their participation

- Other waterbodies could not be surveyed in this investigation and additional survey efforts are needed to provide site specific data outside the rivers surveyed
- The risks of combined exposures to multiple contaminants in fish are unknown
- The population of anglers who consume fish from the affected waters experience cumulative risks that could be examined.

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INTRODUCTION AND BACKGROUND

Mercury (Hg) can be found in the environment in elemental, inorganic, and organic forms. Methylmercury (MeHg), one of the organic forms of mercury, is of concern because it bioaccumulates in the aquatic food chain and humans can be exposed via consumption of contaminated fish (NRC 2000). While Hg comes from both natural and anthropogenic sources, the largest identified source of Hg emissions are coal fired power plants (U.S. EPA 1997a). Particles of inorganic Hg are emitted into the air and can deposit onto the land or into waterbodies where microorganisms can convert the inorganic Hg into MeHg. The methylated form of mercury is easily absorbed by living organisms and accumulates in the food chain (ATSDR 1999).

MeHg is known to be highly toxic, as noted from the mercury poisonings in Minnamata, Japan and in Iraq. Health effects of these poisoning episodes included sensory and motor impairment in adults and mental retardation, cerebral palsy, deafness, blindness, and slurred speech (dysarthria) in children exposed in-utero (NRC 2000).

The potential for a toxic substance like methylmercury to cause adverse health effects is assessed by comparing the level of exposure an individual experiences to a risk assessment benchmark value known as a reference dose (RfD). The RfD is a numerical estimate of an allowable daily oral exposure to the human population that is not likely to cause harmful effects during a lifetime. If the exposure remains below the RfD, there is little likelihood of adverse effects. The possibility of toxic effects increases as the exposure level increases above the RfD (see NRC 2000). In 1995, the U.S. EPA set the reference dose (RfD) of 0.1 µg/kg-day based upon a poisoning episode in Iraq from grain contaminated with a MeHg fungicide (see U.S. EPA 2005). However, most of the U.S. population is more likely to be exposed to chronic-low dose MeHg exposure through the consumption of MeHg contaminated fish, U.S. EPA wanted the RfD based on a braoder array of investigations. U.S. EPA contracted with the National Research Council to re-evaluate the RfD based on larger epidemiological studies from the Seychelles,

Faroe Islands, and New Zealand. The NRC recommended consideration of the 95% lower confidence limit for the benchmark doses for a number of neurological endpoints based upon the performance on neuropsychological tests. As a result of the NRC analysis, U.S. EPA reviewed the RfD in 2001, basing the RfD on the results of the Faroe Islands study. On these grounds, U.S. EPA kept the current RfD the same at 0.1 µg/kg-day (U.S. EPA 2005).

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1.1 SITUATION IN VIRGINIA

In 1999, the fish tissue monitoring program of the VA Department of Environmental Quality found fish with high levels of mercury in the Dragon Run Swamp. The fish tissue monitoring program had been monitoring mercury and organic chemicals in fish tissues from a number of waterways owing to past contamination from specific sites. The results in Dragon Run Swamp, however, were unexpected, because this region has very little human activity, is free of industry and intensive farming, and is considered “pristine.” There were no obvious point-sources of mercury in the swamp, so it was hypothesized that the mercury was coming from air deposition, as described in national investigations conducted by U.S. EPA. As a result of the results in Dragon Run Swamp, VA DEQ extended the mercury sampling effort to a larger group of rivers.

When fish were sampled from other waterbodies in the Coastal Plain with similar characteristics to the Dragon Run (slow-moving, acidic water), similarly elevated concentrations of Hg were found in the fish. The program has now reported elevated mercury levels in fish from a number of rivers and lakes (Table 1). The rivers with elevated MeHg in fish tissues are shown in Figures 2.1 and 2.2.

Table 1.1 Waterbodies with mercury fish consumption advisories:
From: http://www.vdh.state.va.us/epidemiology/DEE/PublicHealthToxicology/Advisories/index.htm

Watershed	Waterbody	Location	Species Associated with Hg Advisory
Chesapeake Bay and Small Coastal Basin	Lake Trashmore	Virginia Beach City	Large Mouth Bass
	Lake Whitehurst	Norfolk City	Carp
	Blackwater River	Surry County, Southampton County, Isle of Wight County, Franklin City, and Suffolk City, Sussex County, Prince George County, and Petersburg City	Largemouth Bass Chain Pickerel Bowfin Redear Sunfish White Catfish Redhorse Sucker Longnose Gar
Watershed (cont.)	**Waterbody (cont.)**	**Location (cont.)**	**Species Associated with Hg Advisory (cont.)**
Chowan and Dismal Swamp Basin	Great Dismal Swamp Canal	Chesapeake City and Suffolk City	Bowfin Chain Pickerel
	Nottoway River	Greensville County, Sussex County and Southampton County	Largemouth Bass Smallmouth Bass Bowfin Chain Pickerel Redhorse Sucker Spp. Longnose Gar Channel Catfish Sunfish Spp.
	Dragon Run Swamp/ Piankatank River	Essex County, Middlesex County, King and Queen County, and Gloucester County	Large Mouth Bass
James River Basin	Harrison Lake	Charles City County	Redear Sunfish Largemouth Bass Chain Pickerel Bowfin
	Chickahominy River	Charles City County New Kent County	Largemouth Bass Chain Pickerel Bowfin
York River Basin	Lake Gordonsville	Louisa County	Large Mouth Bass
	Pamunkey River	Hanover County, King William County, and New Kent County	Blue Catfish
	Mattaponi River	King William County and King and Queen County	Large Mouth Bass
	Herring Creek	King William County	Bluegill Sunfish Yellow Bullhead Catfish

The fish tissue monitoring results raised concern for several reasons. First, there are no known point sources of mercury in most of the waterbodies that are affected. The only explanation seemed to be the atmospheric deposition of mercury, with subsequent transformation into methylmercury, uptake and accumulation in fish. The sources of mercury emission into the atmosphere were not known precisely and may well include long-range transport. Second, mercury, specifically methylmercury, is highly toxic, especially to the developing nervous system, causing I.Q deficits in children. Third, the developing fetus seems to be the most sensitive to the effects of methylmercury. Fourth, the affected waters are used for both recreational fishers and fishers who rely on their catch for food, although the exact extent of the use was not well known. Fifth, methylmercury was found in several types of fish, both catfish and top predators such as bass. Finally, methylmercury contamination of the coastal plain rivers could be a long term condition that would require a more complex solution than if the source were a direct discharge into the waters.

The impacts on Virginia from mercury contaminated fish could include health consequences for the people who consumed fish from these waters, in spite of warnings to limit or eliminate such consumption. The health effects of MeHg poisoning are primarily neurological damage that is likely to be permanent for children, the most sensitive members of the population. Adults may also suffer from neurological damage at high MeHg doses and an increased risk of cardiovascular disease. Fish advisories on the rivers and lakes may also cause a reduction in recreational uses, with the possibility of some, as yet undescribed economic consequences. The total economic impact of methylmercury contamination is unknown.

1.2 SOURCES OF MERCURY

Mercury is generally found in three forms: elemental (metallic) mercury, inorganic mercury, and organic mercury. Mercury can enter a waterbody either through atmospheric

deposition or through point source discharges. Although metallic mercury (used in thermometer, switches, etc.) can volatize into the air, most of the air born mercury comes from burning hazardous waste and burning coal. According to the U.S. EPA, “coal-burning power plants are the largest human-caused source of mercury emissions to the air in the United States, accounting for over 40 percent of all domestic human-caused mercury emissions” (U.S. EPA 1997a).

1.3 FATE AND TRANSPORT OF MERCURY

The atmospheric particles of elemental or inorganic mercury eventually settle into a water body or onto land where the particles wash into the water. Mercury particles can then be transformed by microorganisms into methymercury, which is easily absorbed by plants and animals, and is a more toxic form of mercury. The methylation process is enhanced under anaerobic conditions (such as a swamp) where the types of bacteria capable of producing methylmercury are likely to flourish (ATSDR 1999).

1.4 BIOACCUMULATION OF MERCURY

Because methylmercury can bioconcentrate, bioaccumulate, and biomagnify, even small environmental concentrations of mercury in water can readily accumulate to potentially harmful concentrations in fish (U.S. EPA 1997b). The ratio of concentration of methylmercury in fish tissue to that in water is usually between 10,000 and 100,000 (U.S. EPA 1978). MeHg in fish tissue is dependent on the chemistry of water body and the trophic level of the fish, with the higher trophic level fishes generally having higher mercury concentrations in their tissues. Mercury binds to protein, and in fish mercury bioaccumulates in the muscle tissue, meaning that the larger and older fish generally have higher mercury concentrations than younger, smaller fish.

1.5 HUMAN EXPOSURE TO MERCURY

Toxicokinetics of MeHg

Absorption

Unlike dimethylmercury, methylmercury is not easily absorbed through the skin. Methylmercury vapors in the air at room temperature are easily absorbed through the lungs (ATSDR 1999); however, route of human exposure to methylmercury is primarily oral. Methylmercury is the form of mercury that is most easily absorbed through the digestive tract, and it is estimated that 90% to 95% of the methylmercury ingested will be absorbed into the bloodstream (NRC 2000, ATSDR 1999). Additionally, animal studies indicate that gastrointestinal absorption is in excess of 90% of the oral dose, and that age (including neonatal stage) has no effect on the absorption rate (Walsh, 1982).

Distribution

Once in the blood, methylmercury is easily transported to other organs including the brain, and in the case of pregnant women, methylmercury enters the fetus's blood, organs, and developing brain (ATSDR 1999). Both inorganic mercury and methylmercury can be passed into a nursing woman's breast milk. Distribution of methylmercury to all tissues is complete within about 4 days in humans, and at this time the brain contains approximately 6% of the dose (Kershaw et al., 1980).

Biotransformation/ Excretion (MeHg half-life)

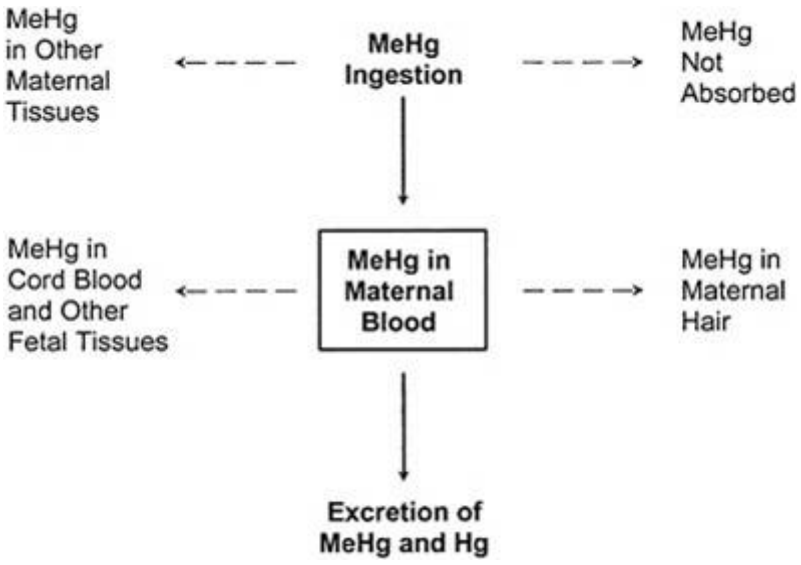
Over time, most of the methylmercury is transformed in the body to inorganic mercury and is then excreted in the urine and feces. Small amounts of the inorganic mercury can further be transformed in the body to metallic mercury and exhaled through the lungs as mercury vapor

(ATSDR 1999). The excretion rate is approximately 1% of the total body burden per day, with the half-life in blood of 48-53 days and the whole body half-life of 70-80 days (Kershaw et al. 1980, U.S. EPA 1997b, NRC 2000). However, the methlymercury converted to inorganic mercury in the brain has a much longer half-life, in the range of years.

Biomarkers and Pharmacokinetic models

In the determination of the dose-response relationship, biomarkers of methylmercury exposure can be used as surrogates when the ingested dose is unknown. The commonly used biomarkers are total mercury blood concentration, fetal-cord-blood concentration, and hair concentration. Using the mercury concentrations in these biomarkers, the ingested dose can be estimated using either a physiologically based pharmacokinetic (PBPK) model or by a simplified one-compartment model (Fig. 1.1 from NRC, 2000).

Figure 1.1 One-Compartment Model



source: NRC 2000

The one-compartment model used by International Programme on Chemical Safety (1990) and the US Environmental Protection Agency (1997)) collapse the distribution and redistribution of methylmercury among several body compartments into one compartment that assumes the blood concentration to be at a steady state. Under this assumption, the steady state dose can be calculated by the following equation:

$$D = \frac{C \times b \times V}{W \times A \times F}$$

Where D = steady state dose
C = concentration of MeHg in the blood (µg/L)
b = elimination rate constant (fraction of the concentration eliminated per day (day^{-1})
V = blood volume (L)
W = body weight (kg)
A = fraction of ingested MeHg that is absorbed
F = fraction of absorbed MeHg that is distributed in the blood

When the biomarker of exposure is hair concentration or fetal-cord-blood concentration, these factors can be substituted for C in the above equation as C = (1/R) x Z, where R is either the hair-to-blood concentration ratio (µg/g)/(µg/L) or the cord-blood to maternal-blood ratio and Z is the hair concentration or fetal-cord-blood concentration. These equations can be used either to calculate the ingested dose from a given blood concentration, hair concentration, or fetal-cord-concentration, or conversely to calculate these biomarker levels from a given ingested dose.

Inter-individual Toxicokinetic Variability

The relationship between ingested dose and the concentration of MeHg in hair or cord blood depends on physiological factors that vary among individuals in the population. Therefore, there is no single conversion factor to translate an ingested dose into a biomarker concentration (or vice-versa, from a biomarker concentration to an ingested dose.) Based upon recommendations from the NRC report (2000), the U.S. EPA used the central tendency for each physiological parameter when reconstructing the ingested dose from the biomarker when deriving the revised RfD. An alternative to using the central tendency estimate is to use the

distribution of each parameter in a Monte Carlo simulation as Stern did in 1997 and 2005. In 1997, Stern used distributions for each parameter from the literature that were relevant to women of childbearing age (18 – 45). In 2005 Stern revised his analysis to use empirical or parametric distributions appropriate for third-trimester pregnancy specific values. A comparison of the values used in these three analyses can be seen in Table 1.2 below:

Table 1.2 Comparison of Physiological Parameters. Ingestion, absorption, transfer factors and relevant ratios for calculating methylmercury in humans

Parameter	U.S. EPA (1995)	Stern (1999)	Stern (2005)
$\mathbf{R_h}$ (hair to blood ratio)	0.25	Cumulative probability distribution[1]: min: 0.073 10%: 0.224 25%: 0.265 50%: 0.292 75%: 0.307 90%: 0.41 max: 0.535	(not used in analysis)
$\mathbf{R_c}$ (cord blood to maternal blood ratio)	1	(not used in analysis)	lognormal (μ: 1.7, σ: 0.9)[10]
b (elimination rate)	0.014/day	lognormal (μ: 0.011, σ: 0.0037)[2] ---------- lognormal l(μ: 0.014, σ: 0.0026)[3]	empirical probability distribution[11]: min: 0.009/day max: 0.046/day
V (blood volume)	5 L	lognormal (μ: 3.57, σ: 0.443), rank order correlation with **W**, r=0.63 [4] ---------- = 0.037 L/kg x **W** + 1.43 [5]	cumulative probability distribution[12]: min: 3.707 L max: 7.902 L correlated with W, r=0.49
A (fraction of ingested MeHg that is absorbed)	0.95	normal (μ: 0.94, σ: 0.016)[6]	cumulative probability distribution[13]: min: 0.940 max: 0.999
F (fraction of absorbed MeHg that is distributed in the blood)	0.05	lognormal (μ: 0.077, σ: 0.008)[7] ---------- lognormal l(μ: 0.067, σ: 0.019)[8]	normal (μ: 0.052, σ: 0.0095)[14]
W (body weight)	60 kg	Cumulative probability distribution[9]: min: 34.75 kg max: 153.3 kg	lognormal (μ: 80.9 kg, σ: 16.3 kg)[15]

[1] combined data set from Kershaw et al. (1980) and Birke et al. (1972)
[2] from Al-Sharistani (1974)
[3] average of Kershaw et al. (1980), Smith et al. (1994), Sherlock et al. (1984), Al-Sharistani et al. (1974), and Miettinen et al. (1971)
[4] combined data set from Brown et al. (1962), Retzlaff et al. (1969), Huff and Feller (1956)
[5] combined data set from Brown et al. (1962), Retzlaff et al. (1969), Huff and Feller (1956)
[6] from Miettinen et al. (1971)
[7] from Smith et al. (1994)

[8] average of Smith et al. (1994) and Kershaw et al. (1980)
[9] from NHANES III (1996)
[10] from Stern and Smith (2003)
[11] from Cox et al. (1989)
[12] from Thomson et al. (1938) and Caton et al. (1951)
[13] from Miettinen et al. (1971)
[14] from Sherlock et al. (1984) and Kershaw et al. (1980)
[15] from CDC (2004)

The principal target organ of oral exposure to methylmercury is the central nervous system. Methylmercury is rapidly transported across the blood-brain barrier and accumulates in the brain where it slowly demethylates to inorganic (mercuric) mercury. Both the adult and fetal brains are damaged by methylmercury (and the oxidized inorganic mercury), but the fetal brain is more sensitive.

1.6 HEALTH EFFECTS OF MERCURY

Health Effects:

The danger posed by methylmercury was first elucidated by several tragic poisoning episodes. In the 1950s, outbreaks of a severe neurological disease were first noted in Minamata City, Japan. The cause of the epidemic was eventually traced to the consumption of fish and shellfish from Minamata Bay that were contaminated with methylmercury that came from the wastewater discharge from the local chemical plant. Both adults and children exhibited adverse health effects; however, children exposed in-utero were more sensitive, suffering from mental retardation, cerebral palsy, and other central nervous system defects (NRC 2000). Similar epidemics of neurological disorders occurred in Iraq in 1960, 1965, and 1971-72; however, in Iraq the poisoning was a result of the handling and consumption of grain treated with ethyl or methylmercury fungicides (ATSDR 1999). The results from these high-dose poisoning episodes were similar: adults suffered from loss of sensation in the hands, feet, and around the mouth (paresthesia), uncoordinated walking (ataxia), slurred speech (dysarthria), diminution or loss of sight, loss of hearing, and death. Infants exposed to the highest doses either in utero or through their mother's milk suffered severe brain damage (Bakir et al. 1973). The high dose exposures

have served to inform the health and medical communities on the health effects from MeHg poisoning, the mechanism of action and the most sensitive populations.

Because both the poisoning episodes in Japan and Iraq were studied retrospectively, exposure doses had to be estimated in adults through blood concentrations and in infants exposed *in utero* through maternal hair concentrations. Using hair as a biomarker of exposure has the advantage of being able to reconstruct a timeline of exposure in both duration and magnitude. Using pharmokinetic models, maternal hair mercury concentration can be used as a surrogate for the dose of mercury received by the fetal brain and hair mercury concentration can also be used to estimate the ingested dose (NRC 2000).

While dose response functions can be estimated from the data from the poisoning episodes in Japan and Iraq, these exposure scenarios are not comparable to chronic low-dose exposure from the consumption of fish or other seafood. To better understand the effects of chronic low-dose exposure, several prospective epidemiological studies have been carried out on populations around the world. The developing central nervous system is assumed to be the most sensitive to chronic low-dose exposure, therefore status on neurological examination, age at reaching developmental milestones, and performance on neurobehavioral tests, and other endpoints in children were examined in these studies (NRC 2000).

Finally, animal studies have shown that high level, long term exposure to methylmercury produces adverse effects including: damage to the nervous system; damage to the kidneys and the digestive tract (stomach and large intestine); changes in blood pressure and heart rate; damage to the developing fetus; adverse effects on the male reproductive organs and sperm; increases in spontaneous abortions and still births. Of all the adverse effects, damage to the nervous system occurred at the lowest doses (ATSDR 1999).

The following is a summary of effects of methylmercury on the different organ systems. The concern of this study is exposure to methylmercury through the consumption of

contaminated fish; therefore, the health effects discussed are associated with the oral route of exposure as opposed to inhalation or dermal exposure.

Gastrointestinal effects:

Gastrointestinal effects were noted in an ethylmercury poisoning episode in Iraq in the form of abdominal pain, vomiting, diarrhea or constipation (Jalili and Abbasi 1961). Long-term exposure of rats to 4.2 mg Hg/kg/day resulted in necrosis and ulceration of the cecum, and long-term exposure of mice to 0.1 mg Hg/kg/day resulted in ulceration of the glandular stomach (ATSDR 1999).

Hepatic effects:

In the Iraqi poisoning episode, autopsies of four adults and four infants who died as a result of methylmercury poisoning showed fatty changes in the liver in most cases. (Al-Saleem & the Clinical Committee on Mercury Poisoning 1976).

Renal effects:

The kidney is the critical organ of toxicity from the ingestion of inorganic mercury (mercuric salts) (ATSDR 1999), and several case studies and animal studies have demonstrated renal toxicity from the ingestion of organic mercury as well. In an ethylmercury induced poisoning episode in Iraq, affect individuals exhibited excessive urination (polyuria), excessive thirst (polydipsia), and protein in the urine (albuminuria) (Jalili and Abbasi 1961). In the case of the family poisoned from consuming ethylmercury contaminated pork, the two boys that died also exhibited albuminaria, increased blood urea, and urinary sediment (Cinca et al. 1979). A study of residents of an area of Minamata Japan that had the highest incidence of Minamata disease (caused by the consumption of methylmercury contaminated fish) revealed a

higher than expected death rate attributed to nephritic disease among women but not among men (Tamashiro et al. 1986). NRC's Toxicological Effects of Methylmercury (2000) cites eight studies of rodents that described methylmercury induced renal toxicity.

Hematological effects:

ATSDR noted that no human studies of hematological effects from the oral ingestion of organic mercury were located in their 1999 Toxicological Profile of Mercury (ATSDR 1999); however, they noted that long them exposure of rats to 4.2 mg Hg/kg/day resulted in anemia, but that may have been a secondary effect of gastrointestinal bleeding.

Respiratory effects:

In autopsies of four adults and four infants who died as a result of methylmercury poisoning in Iraq, in all four adults and one of the infants bronchopneumonia was considered the immediate cause of death (Al-Saleem & the Clinical Committee on Mercury Poisoning 1976). According to ATSDR, however, it is unclear if this was a direct effect on the respiratory system or a secondary effect of the poisoning (ATSDR 1999). One animal study reviewed by the ATSDR showed no "treatment related histopathological lesions" in rats from long term exposure to 0.1 mg Hg/kg/day. (ATSDR 1999)

Cardiovascular effects:

The cardiovascular effects such as changes in blood pressure and cardiac function were first noted in both inorganic and organic poisoning episodes; however, recent epidemiological studies have also found associations between low level exposure to methylmercury and increased risk of myocardial infarction, hypertension, and changes in heart rate variability.

Heart-rhythm abnormalities were observed in at least two of the organic mercury poisoning incidents: in the 1956 Iraqi ethylmercury poisoning episode (Jalili and Abbasi 1961) and from a family that consumed a hog that had eaten ethylmercuric contaminated seed (Cinca et al. 1979).

In a prospective epidemiological study, Salonen et al. studied the relationship between the dietary intake of fish, the estimated dose of mercury, the measured mercury hair content, and the amount of mercury excreted in the urine, to the risk of acute myocardial infarction and death from coronary heart disease or cardiovascular disease. The study group was made up of 1833 Finnish men aged 42 to 60 years with no prior history of heart disease, heart attacks, or strokes. The cohort was initially followed for an average of 5 years for acute myocardial infarction and an average of 6 years for death. Salonen et al. (1995) found that dietary intake of fish and hair mercury concentrations were associated with significant increases in the risk of acute myocardial infarction and death from coronary heart disease, cardiovascular disease, or any cause. Men in the highest tertile (2.0 μg/g) of hair mercury concentration had a 2.0-fold (95% confidence interval, 1.2 to 3.1; P=.005) higher risk of acute myocardial infarction and a 2.9-fold (95% CI, 1.2 to 6.6; P=.014) adjusted risk of cardiovascular death compared with those with hair mercury content < 2.0 μg/g. The authors suggested that the mercury could be causing lipid peroxidation, thereby antagonizing the beneficial effects of the n-3 fatty acids found in fish. In a follow up study, Rissanen et al. (2000) extended the study time for the same cohort of Finnish men to 10 years and also measured the blood levels of docosapentaenoic acid (DPA), docosahexaenoic acid (DHA), and eicosapentanoic acid (U.S. EPA) (all end product n-3 fatty acids from fish). This study confirmed the hypothesis that fish oil derived fatty acids reduce the risk of acute coronary events in the study population (middle age men from Eastern Finland), but high levels of mercury (as measured in hair content) reduced the beneficial effects of the fatty acids. Virtanen et al. did a similar analysis from the same study (Kuopio Ischaemic Heart Disease Risk Factor Study) and found that men with greater than 2.03 ug/g hair mercury

concentration had an adjusted 1.6 fold increase in risk of an acute coronary event, 1.68 fold risk of cardiovascular death, 1.56 fold increase risk of coronary heart disease, and 1.38 fold risk of any death (Virtanen et al. 2005)

Prenatal exposure to low levels of methylmercury has also been associated with changes in cardiovascular function. In a prospective study a cohort of 1000 children from the Faroe Islands, Sorenson et al. (1999) found an association between prenatal exposure to methylmercury and cardiovascular function at age 7. In this study, Sorenson et al. (1999) found that blood pressures and the cord blood mercury concentration showed a linear relationship, with diastolic blood pressure increasing by 13.9 mmHg (95% CL – 7.4, 20.4) and systolic pressure increasing by 14.6 mmHg (95% CL = 8.3, 20.8) as cord blood Hg levels increased from 1 to 10 µg/liter. Above 10 µg/liter no relationship was seen between cord blood level and blood pressure.

Central Nervous System Effects:

Developing nervous system

High-dose in utero exposure to methylmercury can result in congenital Minamata disease (CND – caused by the maternal consumption of heavily contaminated fish and shellfish in Japan) characterized by mental retardation, primitive reflexes, cerebellar ataxia (loss of muscle coordination), disturbances in physical growth, dysarthria (slurred speech), and limb deformities (NRC 2000). The most severely affected children exposed in utero in Iraq had similar symptoms: blindness, deafness, paralysis, hyperactive reflexes, cerebral palsy, and mental retardation (NRC 2000).

Low-dose but chronic exposure to methylmercury was examined in epidemiological studies in the Faroe Islands, the Seychelles Islands, New Zealand, and others for more subtle neurological effects. The Faroe Island study used the mercury content in maternal hair, cord

blood, and cord tissue as biomarkers for exposure and examined a cohort of 1010 children at age 7 (917 children examined) and age 14 (878 children examined). The children were given a battery of neuropsychological tests; significant associations between higher prenatal methylmercury exposure and lower finger tapping speed, increased reaction time on a continued performance task, and lower cued naming scores were found at age seven and again at age 14 (Debes et al., 2006).

The New Zealand study matched children of mothers who had hair-mercury levels above 6 ppm during pregnancy with 3 control children of mothers who had lower hair mercury levels. One group of control children came from mothers who had hair mercury concentrations between 3 and 6 ppm, and the other 2 control children had mothers who's mercury hair concentrations during pregnancy was 0-3 ppm; one mother being a high fish consumer, the other being a low fish consumer. When the children were 6 to 7 years old they were assessed on 26 psychological and scholastic tests. Kjellstrom et al (1989) found a significant relationship between higher prenatal methylmercury exposure and decreased performance on five of the tests based upon the category of mercury exposure. Crump et al. 1989 reanalyzed the data by performing a regression analysis of the actual maternal hair mercury levels. When one highly influential point was omitted, Crump et al. found a significant relationship (α=0.1) between maternal hair mercury levels and scores on six of the psychological and scholastic tests (Crump et al. 1998). The regression coefficients for the significant tests (especially the Wechsler Intelligence Scale for Children-Revised (WISC-R)) can be used as a dose response function.

The Seychelles study followed 779 mother-infant pairs from a primarily fish-eating population. The children in this study were assessed at various ages between birth and 5.5 years on a number of standardized neuropsychological endpoints. No significant associations were found between cord-blood mercury or maternal hair mercury and the children's performance on the neuropsychological tests. (Davidson et al. 1998, Davidson et al. 2006)

Dose-response functions:

Reference Dose

The reference dose "is is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime" (U.S. EPA 2001). U.S. EPA chose a benchmark dose analysis (and the quantitative analysis done by the NRC (2000)) to derive a dose-response relationship from the three studies mentioned above. U.S. EPA considered any score at or below the 5th percentile of the populations' distribution of scores as an abnormal response. Thus for the methylmercury RfD analysis U.S. EPA set the benchmark response to 0.05, which in this case would double the number of children who scored at the the population's 5th percentile. The benchmark dose lower limit (the lower 95% confidence limit of the BMD_{05}) was then calculated from the significant test results in all three studies: the Faroe Islands, Seychelles, and New Zealand studies. For the RfD U.S. EPA used the $BMDL_{05}$s (quantified in mercury cord blood) from several scores for the Faroe Islands study and converted those doses into maternal ingested doses using the one-compartment model. The RfDs were then derived by dividing the ingested doses by an uncertainty factor of 10; the values of the RfDs for a number of endpoints in all three studies converged around 0.1 ug.kg.day (NRC, 2000; U.S. EPA 2001).

Table 1.3 Reference Dose and Virginia Consumption Advisories

Threshold	**directed at/ protective of**	**compare consumption to:**
RfD	sensitive subgroups	oral dose of 0.1 ug/kg/day
VA consumption advisory	Women of childbearing age and children	No meals of certain species of fish
VA consumption advisory	all anglers	No more than 2 meals/month of certain species of fish

Table 1.4 Cardiovascular Health Effects Dose/Response Functions

Group	**outcome**	**relative risk**	**source**
adult males with hair conc. over 2 ppm	relative risk for non-fatal and fatal myocardial infarctions	1.69 compared to lower hair concentrations	Salonen et al. (1995)

adult males	relative risk for non-fatal and fatal myocardial infarctions	1.068 per 1 ppm hair Hg concentration over 2 ppm	Salonen et al. (1995)
adult males with hair conc. over 2 ppm	Relative risk for all-cause mortality	1.93 compared to lower hair concentrations	Salonen et al. (1995)
adult males	relative risk for all-cause mortality	1.09 per 1 ppm hair Hg concentration over 2ppm	Salonen et al. (1995)

Table 1.5 Neurological Health Effects Dose/ Response Functions

based on:	outcome	Dose/Response	source
Seychelles, Faroe Islands, NZ cohorts	change in IQ points per 1 ppm increase in maternal hair Hg concentration	-0.7 (plausible values ranging from 0 to 1.5)	Cohen et al. (2005)
Cohen et al. and Crump et al. (1998)	change in IQ points per 1 ppm increase in maternal hair Hg concentration	-0.6	Rice and Hammitt (2005)
Seychelles, Faroe Islands, NZ cohorts	change in IQ points per 1 ppm increase in maternal hair Hg concentration	-0.18 (95% CI: -0.378,-0.009)	Axelrad et al. (2007)

1.7 PURPOSE OF THE VIRGINIA STUDY

The purpose of this study was to obtain Virginia-specific fish consumption information and combine that with information from VA DEQ's fish tissue database to assess the range of exposures for the population of Virginia anglers (and their household members) that eat fish from Virginia's freshwater-tidal rivers. This distribution of exposures was then used to construct a distribution of adverse health effects based upon the dose response functions described in the literature. A second objective of this survey was to obtain demographic information from the target population to characterize the sub-populations at greatest risk.

The concentration of methylmercury in fish tissue obtained from VA DEQ's fish tissue database was combined with information derived from the consumption survey to produce baseline estimates of ingested doses. Dose-response functions from the literature were then

applied to these doses to estimate the probability of health impacts to the anglers and the household members who consume contaminated fish from the study area. In addition to estimating risks under present exposure conditions, risks were estimated for lower mercury contamination conditions. VA DEQ estimated mercury air-deposition across Virginia after 2010 and 2018 in response to planned regulatory controls. These estimates were used to estimate the potential changes in fish contamination levels and the resulting possible changes in health risks. These estimates of risks to human health will be analyzed by VA DEQ to predict economic benefits and costs due to current levels of mercury versus potential future reductions.

2 METHODS

2.1 FISH CONSUMPTION SURVEY OF POPULATION OF INTEREST

To acquire the Virginia-specific fish consumption information, a survey was designed to obtain recreationally-caught freshwater fish and total fish consumption information from the population of freshwater anglers that fish in Virginia's coastal plain. Personal interviews of anglers were conducted from June 2007 until September 2007, at 17 fishing access points in the region of interest. The survey locations were chosen by VCU and DEQ staff as the most likely places to find both anglers fishing by boat or by shore within the range of the areas under a fish consumption advisory for mercury. The original proposal also included a plan to interview the Native American tribes that live in Virginia's coastal plain; however, they declined to participate.

2.1.1 SURVEY INSTRUMENT DESIGN

The sampling method for the recreational freshwater anglers was a creel survey at 17 selected fishing access points. The survey instrument was based upon previously used survey instruments (Jones 2002), and was designed to minimize the time burden (estimated at 10 minutes) upon the participating subjects.

Target populations and sampling strategy

The target populations for this survey were recreational freshwater anglers and their household members who fish in Virginia's coastal plain and Native Americans who live in Virginia's coastal plain. To sample the population of recreational freshwater anglers, 17 fishing access points in the region of interest were visited multiple times on different days of the week and at different times of day over a four month period (June – September). All adult anglers present (either boat fishing or shore fishing) at the survey times were approached and asked to participate in the survey. Subjects were asked if they have been interviewed before, and those who had previously completed the survey were not re-interviewed. With this method we assumed that the population of anglers who fish at least once from June – September have an equal probability of being interviewed and as such we did not assign a sampling weight based upon the subject's fishing frequency.[1]

Specific data obtained from the survey:

- fishing behavior information: frequency of recreational freshwater fishing, average distance traveled to fishing locations, range of fishing locations;
- motivation for fishing: recreation, food, both;
- the species of recreational freshwater fish most frequently consumed;
- the average meal size and frequency of self-caught fish meals consumed by anglers;
- the average meal size and frequency of purchased fresh or frozen fish or shellfish meals consumed by anglers;
- the average meal size, frequency and type of canned tuna fish consumed by anglers;
- household make-up: number of children under five, the number of children six to 15 years old, the number of women 16 to 49 years old, the number of men 16 to 49 years

[1] I n the Exposure Factors Handbook (U.S. EPA, 1997), the U.S. EPA noted that a weakness of the creel survey was the possibility of overestimating the target population distribution if the sampling time was limited in duration.

old, the number of people over the age of 50, and the number of people in each age group that eat fish that the angler catches;

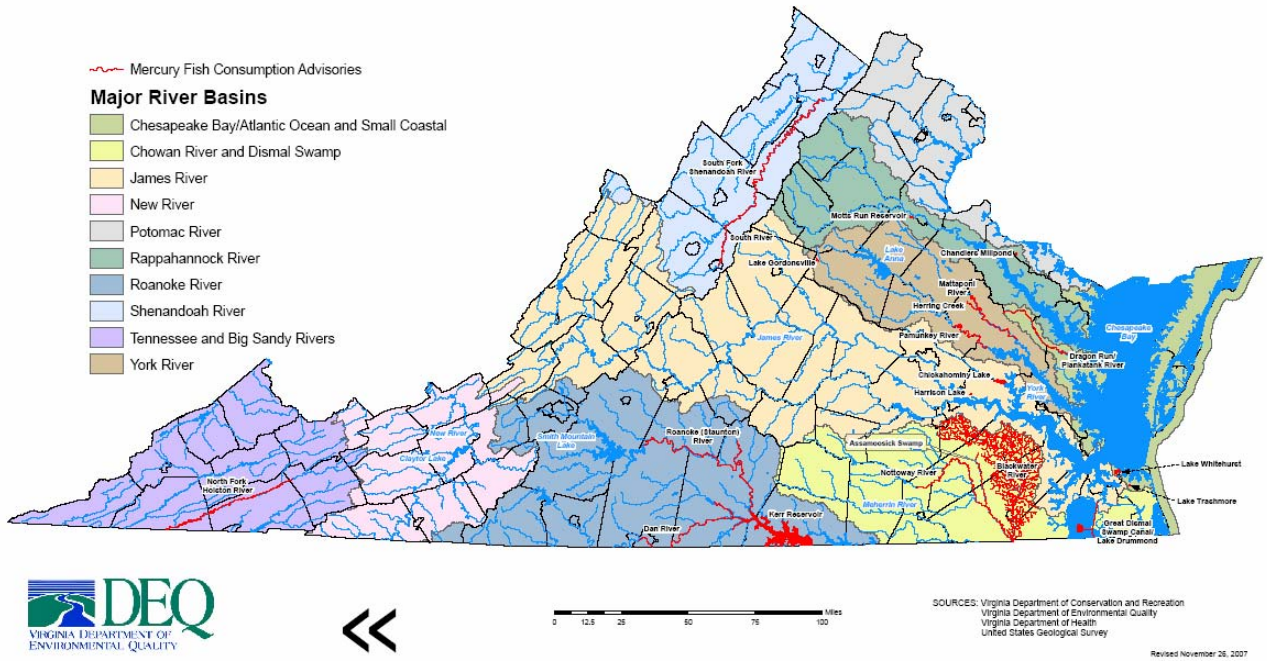
- demographic information: race, age, education level, income level, zip code

2.1.2 SURVEY LOCATIONS

The survey locations were chosen in consultation with VA DEQ to provide a good sample from the area of interest (Eastern rivers under fish consumption advisories for mercury). Survey locations were chosen where we believed we would find the most anglers, so that we could maximize the sample number with the surveying effort. Thirteen survey sites were initially identified; however, five additional sites (2 on the Pamunkey, 2 on the Chickahominy, and one on the Piankatank) were added. These new survey locations were all mentioned by several anglers during interviews as “good places to find anglers.” The addition of these new sites was necessary because of problems encountered with the some of the survey sites initially identified for the Piankatank and Chickahominy rivers.

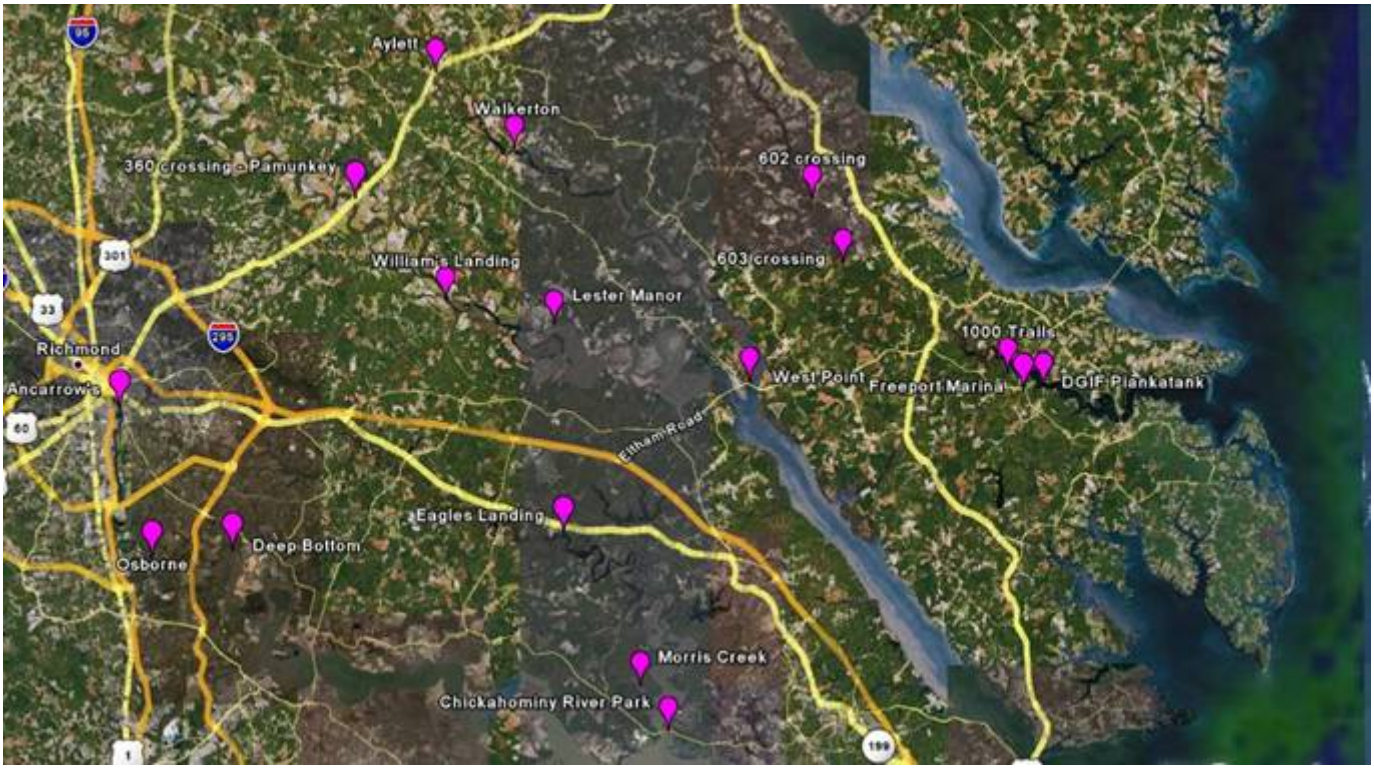
Two of the sites originally identified: 1000 Trails and Rockahock campgrounds have been problematic. Rockahock campground was chosen for its proximity to Walkers Dam, but because of the concerts held at that location in the early summer, surveys were not able to be completed on the dates that the survey team visited. Chickahominy Lake in general has been difficult to survey in part because of the lack of public access, but also because Walkers Dam was partially breached in the late spring, causing the lake level to drop. We were advised by anglers interviewed on other rivers who said they fished Chickahominy Lake that Ed Allens Campground and Eagles Landing were more heavily used by anglers. The survey team was invited by Jill O’Brien-Jones, the owner of Eagles Landing, to interview anglers at that location; however, she advised the team that because of the low lake level, boat access (and the likelihood of meeting anglers) was best at high tide. 1000 Trails Campground was chosen as

Figure 2.1 Waters Under VDH Fish Consumption Advisories For Mercury



one of the few boat ramps on the Upper Piankatank River. Two survey visits were completed before the boat ramp closed in late June. At that time the survey team was advised to try Freeport Marina a few miles down river.

Figure 2.2 Map of Survey Locations



map from Google Earth

2.2 FISH TISSUE MERCURY CONCENTRATIONS

As part of the VA DEQ Fish Tissue and Sediment Monitoring Program, fish are collected by the VA DEQ each summer. Fish are weighed, measured, and a 1 g sample of muscle tissue is analyzed for total Hg (among other contaminants). Since previous studies indicated that 90% of the Hg found in fish tissue was MeHg, the VA DEQ assumes that all mercury is MeHg. (Barron 2007). By assuming 100% of the mercury is MeHg, VA DEQ is protective of those cases in which all the mercury is MeHg and accounts for variation around the 90% value. The assumption of 100% v 90% has a small effect on the results of this prediction and on setting health advisories. Over 3,000 fish tissue samples with mercury concentrations are listed in VA DEQ's fish tissue database for the years 1999-2006. For the risk assessment, we only used the samples that corresponded to our survey areas. The sample was further reduced by only

including the fish that the anglers reported eating. Fish such as carp, longnose gar, bowfin, and gizzard shad were excluded because these species were never or rarely reported consumed. The values of each species/class of fish were then grouped from the 5 rivers to create distributions of mercury concentrations for each species. The distribution was constructed so that the frequency of each observation was equal to 1/n.

Distributions for fish tissue concentrations projected in 2010 and 2018 were constructed by multiplying each observation by the corresponding reduction factor for the river. Reduction factors were determined by VA DEQ based upon projected reductions in air deposition provided by an air- modeling study that estimated reductions in air-deposition rates of total mercury across Virginia in future years 2010 and 2018. The modeled reductions in total mercury deposited into the individual river watersheds were used to estimate future mercury deposition in comparison with the base line mercury deposition rates estimated for the year 2002. The modeled deposition rates for the base year of 2002 is considered representative of the conditions that were responsible for the fish-mercury concentrations that were detected during the VA DEQ fish monitoring between 1998-2006. This information was used to calculate a "reduction factor" for future years, representing the remaining air–deposited mercury compared to the rates of 2002. For example; the air model predicted the rate for 2010 of air-deposition of total mercury onto the watershed of the Dragon Run swamp to be 82.01% of the mercury deposition rate in 2002. This amount represents an estimated 17.9% reduction in the air deposition rate for total mercury in 2010 compared to the deposition rate of 2002. This procedure yields a "reduction factor" of 0.8201 modeled for this watershed based on projected 2010 deposition levels. The reduction factor for the river basin can be used to estimate future fish –mercury concentrations levels in response to reduced mercury deposition.

It was assumed by VA DEQ that the fish-mercury-concentrations in an ecosystem are in dynamic equilibrium with mercury inputs to that watershed and that a reduction in mercury deposition will result in a proportional reduction in fish-mercury concentrations after the

ecosystem re-equilibrates to the lowered inputs of mercury. Under this scenario, the reduction factor for the watershed can be multiplied times the fish-mercury concentrations seen in previous monitoring (which are assumed to be a result of deposition rates reprsented by the 2002 base year) to estimate future mercury-fish concentrations after the projected reductions in mercury deposition rates have occurred. For example; if previous samples of largemouth bass from the Dragon Run contained an average concentration of mercury of 1.0 part per million, then after the projected 2010 reductions in air deposition rates take effect we can estimate that future concentrations in this species may average 1.0 ppm x 0.8201 (the river-specific reduction factor) = 0.8201 parts per million mercury.

The reduction factors calculated for 2010 and 2018 are shown in table 2.1 for the specific river basins important to this fish consumption and risk assessment study.

Table 2.1 Modeled Reduction Ratios in Hg-Air Deposition

Ratio (unitless) of projected mercury deposition in future years, following emission reductions, compared to base year 2002

Modeled Year:	2010	2018
Dragon Run / Swamp:	0.8201	0.7972
Mattaponi River:	0.8120	0.7853
Pamunkey River:	0.8063	0.7830
Chickahominy River:	0.8096	0.7885
James River (Richmond-Hopewell):	0.7186	0.6850

The values used to estimate the current (2008), 2010, and 2018 fish tissue mercury concentrations of fish caught in the survey area are presented in the appendix.

Purchased fish tissue mercury concentrations were taken from Carrington et al. (2004). Using data from the U.S Food and Drug Administration and the National Marine Fisheries Service, Carrington et al. (2004) determined the market share and mean mercury concentration

for the 42 most consumed species. These data accounted for 99% of all seafood eaten and were used to simulate the types and mercury concentrations of purchased fresh or frozen fish or shellfish in the model. The data were modified to remove canned tuna as we asked about this type of purchased meal separately. Once the canned tuna had been removed, the market shares were converted into a cumulative probability distribution. Albacore and light canned tuna had their own empirical distributions where the frequency of each observation =1/n. No adjustments were made in purchased fish tissue concentrations for 2010 and 2018. The values used to model the current fish tissue mercury concentrations of purchased fresh or frozen fish or shellfish and canned tuna are presented in the appendix.

2.3 STATISTICAL ANALYSIS

Data were entered into a MS Access database and then exported to MS excel and SAS version 9.1 for analysis. Data were assessed for normality, and because the quantitative variables were not normally distributed, non-parametric tests were used. Comparisons of fish consumption patterns (frequency, amount consumed) grouped by subject characteristics were made by using one-way nonparametric analysis (SAS procedure NPAR1WAY WILCOXON). The p-values reported are from the Kruskal-Wallis test (one-way ANOVA statistic). Spearman correlation coefficients were used to analyze the relationship between continuous variables, and the relationship between categorical variables was assessed with Pearson chi-square analysis. Multiple linear regression analysis was used to evaluate the contribution of the independent variables (age, race, education level, income level, zip code) and the dependent fish consumption variables (frequency, amount consumed). For all test statistics the level of significance was $\alpha = 0.05$.

2.4 RISK ASSESSMENT MODEL

The risk assessment models were designed to evaluate three outcomes: exceeding the reference dose, the loss of IQ points from prenatal exposure to MeHg through the maternal diet, and the change in the relative risk of myocardial infarction in adults over 50. The models simulated the baseline outcomes using the most recent (1999 – 2006) fish tissue Hg concentrations from VA DEQ, and future outcomes using the projected decreases in fish tissue Hg concentration in 2010 and 2018 as predicted by the deposition models.

The sample of 75 anglers who eat self-caught fish was expanded to 222 by including all the household members who were reported to eat the fish caught by the anglers. The gender and age group of all household members was recorded, but the meal frequency and meal size of household members was not asked, so assumptions had to be made for those parameters. It was assumed that household members would eat equally as frequently as the angler, and that adult household members would have the same meal size. Both assumptions increase the uncertainty of estimating MeHg exposure for the household members. These assumptions overestimate exposures for those who consume smaller fish portions and/or less often, and underestimate exposures for those who consume larger meal sizes more often. The meal size and meal frequency of the household members is a source of uncertainty in the analysis that could be improved with a more detailed survey (and possibly different type) for the population of interest.

To model the loss of IQ points from prenatal exposure to MeHg through the maternal diet, the population of interest is women of childbearing age. To approximate this group, the survey results were divided by gender and age group and the subsample from women 16 to 49 years old (n=52) was used for the simulation. Two of the survey results used were from female anglers who had been interviewed; the remaining 50 survey results used were from anglers who reported women 16 to 49 living in their households who ate fish that the angler caught from the river where interviewed. Again, because we did not have the fish meal frequency and meal size for family members, it was assumed that these 50 women had the same meal frequency and

size as their angler. Using the survey results and fish mercury concentrations from VA DEQ's fish tissue database a probability distribution of ingested doses was created through a Monte Carlo simulation.

Instead of using single point estimates of each parameter in a model, Monte Carlo simulations use probability distributions for each parameter. Thousands of trials are run and each time a random value for each parameter is sampled from its probability distribution. Thus, instead of the model resulting in a single value, the simulation produces thousands of possible values. These resulting values can then in turn be described by a probability distribution.

The simulation was done in two loops. The outer variability loop accounted for differences between individuals in terms of eating habits and body weights. The outer loop began by choosing an individual from the subsample (for models 1 and 2 this was women 16 to 49) at random and looking up her reported meals per year of self-caught, purchased, and canned tuna fish, and her corresponding meal sizes reported for each type of fish meal. The number of meals of each type of fish eaten became the number of iterations through the inner loops. For each meal, a mercury concentration was sampled from the fish tissue concentration distribution for the corresponding type of fish, and then multiplied by the individual's reported meal size to get the dose of mercury (in ug) for that meal. The doses for all fish meals were summed to obtain the annual dose (ug/year), and this value was then divided by a bodyweight (kg) chosen from a probability distribution, and averaging time (365 days) to arrive at the average daily intake (ADI). (see equation 1). This average daily intake can then be compared to U.S. EPA's reference dose (0.1 ug/kg/year) which "is an estimate of the amount of a chemical that a person can be exposed to on a daily basis that is not anticipated to cause adverse health effects over a person's lifetime" (U.S. EPA, 2001). The value for the ADI was stored and the outer loop began again with the next individual.

Equation 1: Average Daily Intake ($\mu g/kg\ day^{-1}$):

$$D = \frac{\sum_{i}^{n} (c_i \times s_i \times f_i)}{W \times a}$$

Where n = number of types (species) of fish eaten
c_i = MeHg concentration for the i^{th} species (ug/g)
s_i = meal size for the i^{th} species (g/meal)
f_i = meal frequency for the i^{th} species (meals/year)
W = body weight (kg)
a = averaging time (365 days)

The next step in the model was to convert ADI into blood concentration levels using the one-compartment model (NRC 2000, U.S. EPA 2001). The parameters of the one-compartment model (see equation 2) became assumptions in the Monte Carlo simulation. The simulation was run with two sets of assumptions: point estimates from U.S. EPA's Integrated Risk Information System (model 1), and distributions from Stern 1998 and Stern 2005 (model 2). The assumptions for the two models are shown in table 2.2. Whereas the U.S. EPA point estimates of these parameters are not necessarily gender or pregnancy specific, the distributions used by Stern were chosen to better approximate the values of the parameters for women of childbearing age in the third semester of pregnancy.

Table 2.2 Model Assumptions for Physiological Parameters

Parameter	Model 1 Assumptions: Point Estimates (U.S. EPA 2001)	Model 2 Assumptions: Distributions (Stern 1998, Stern 2005)
$\mathbf{R_h}$ (hair to blood ratio)	0.25	cumulative probability distribution: min: 0.073 max: 0.535
$\mathbf{R_c}$ (cord blood to maternal blood ratio)	1	lognormal (μ: 1.7, σ: 0.9)
b (elimination rate)	0.014 days $^{-1}$	empirical probability distribution: min: 0.009 days $^{-1}$ max: 0.046 days $^{-1}$
V (blood volume)	5 L	cumulative probability distribution: min: 3.707 L max: 7.902 L correlated with W, r=0.49
A (fraction of ingested MeHg that is absorbed)	.95 (unitless)	cumulative probability distribution: min: 0.940 max: 0.999

F (fraction of absorbed MeHg that is distributed in the blood)	0.059 (unitless)	normal (μ: 0.052, σ: 0.0095)
W (body weight)	67 kg	lognormal (μ: 80.9 kg, σ: 16.3 kg)

Equation 2: Blood concentration (μg/L):

$$C = \frac{D \times W \times A \times F}{b \times v}$$

Where D = average daily intake (μg/kg day $^{-1}$)
W = body weight (kg)
A = fraction of ingested MeHg that is absorbed (unitless)
F = fraction of absorbed MeHg that is distributed in the blood (unitless)
b = elimination rate constant (fraction of the concentration eliminated per day (day $^{-1}$)
v = blood volume (L)

The distribution of maternal blood concentrations was then converted into hair concentrations using Equation 3. For model 1 (point estimate model), the value of R was set to 0.25 (or 250:1 hair to blood ratio) as used in U.S. EPA 2001. For model 2, the assumption for R was a cumulative probability distribution; min: 0.073, max: 0.535 (Stern 1998).

Equation 3: Hair Concentration (μg/g):

$$H = C \times R$$

Where C = blood concentration
R = conversion ratio ((μg/g)/(μg/L))

The dose response functions found in the literature result from the analysis of the Faroe Islands study, the Seychelles study, the New Zealand study, or a combination of all three. Results of these analyses are reported as decrease in IQ points per ppm increase in maternal hair mercury.

The distribution of fish tissue concentrations was created from VA DEQ's fish tissue database. Only fish tissue samples that came from the portions of the rivers that roughly corresponded to the area covered by the survey were included; the samples were further filtered

to only include the types of fish reported as being consumed in the survey. It was assumed that the fish caught by VA DEQ were similar to the fish caught by the anglers.

2.5 OUTCOMES TO BE EVALUATED

The present investigation was intended to provide estimates of the fishing behaviors of anglers from Virginia and estimate fish consumption patterns for the purpose of estimating risks from methyl mercury. The fish consumption data were then used with VA DEQ data on fish tissue mercury data to estimate the probability that anglers and family members would be exposed to mercury levels exceeding the U.S. EPA's RfD or VDH recommended safe level. The health outcomes were based on neurological deficit measures as a function of the amount of mercury in hair or in blood, as reported in the literature. The target population was all the people who consumed fish caught recreationally from the eastern rivers targetted because of excess methyl mercury in fish.

3 RESULTS

3.1 SURVEY RESULTS

Quantitative variables of interest (fishing frequency, years fishing, travel distance, number of purchased fresh or frozen meals eaten per year, meal size of purchased fresh or frozen fish, number of canned tuna meals eaten per year, meal size of canned tuna meals, number of meals of self-caught fish eaten per year, and meal size of self-caught meals) were tested for normality. The only quantitative variable that was normally distributed was age – the rest of the variables did not follow a normal distribution, so non-parametric tests were used to test correlations and to test for differences between means.

The overall response rate was 86% completion. Counting against the response rate are 19 anglers who declined to do the survey and 3 anglers who could not complete the survey because of a language barrier (Spanish). Not counted towards response rates:

- 10 people who said it was their first time fishing (ever or on that river)
- people who had already been interviewed
- people who were not fishing on the target river (such as those anglers encountered at West Point who only saltwater fish in the York River)

Fishing frequency:

Fishing frequency was significantly negatively correlated with travel distance ($r = -0.31$, $p<0.0001$) and marginally and negatively correlated with income ($r = -0.16$, $p=0.05$). The mean number of days fishing per year (on the river where interviewed) was 44.13 (n=158, standard deviation = 61.42), ranging from 1 to 364 days per year. There was no difference in fishing effort by race, gender, income level, or whether or not the angler ate his/her catch. There was a significant difference in fishing effort between the rivers ($p=0.005$) and by knowledge of consumption advisories ($p=0.02$). Anglers with knowledge of a consumption advisory (n=83) reported fishing an average of 57.36 days per year, whereas those without knowledge of advisories (n=73) reported fishing an average of 29.06 days per year. The average number of days anglers reported fishing on the river where interviewed can be seen in table 3.1 below:

Table 3.1 Mean Number of Days Fishing per Year

River	N	Mean
Chickahominy	19	42
James	60	66
Mattaponi	39	22
Pamunkey	19	48
Piankatank	21	22

Years fishing:

The number of years the angler reported fishing on the river where interviewed was significantly and positively correlated with his or her age ($r = 0.27$, $p=0.0008$), significantly and negatively correlated with travel distance ($r = -0.25$, $p = 0.001$), and marginally and negatively correlated with his or her education level ($r = -0.16$, $p=0.05$). The overall mean number of years fishing on the river where interviewed was 16 years (n=156, standard deviation = 14.94) with a

range of 0.83 (I month) to 70 years. There was no difference in years fishing by race, gender, income level, river, or whether or not the angler ate his/her catch. There was a significant difference (p=0.02) in years fishing by knowledge of advisory, with those with knowledge of advisories (n=83) fishing having fished an average of 18.26 years on the river, and those without knowledge of the advisory (n=73) having fished an average of 12.49 years on the river.

Travel Distance:

The distance the angler reported having traveled to reach the location where interviewed was significantly and negatively correlated with years fishing (r = -0.25, p = 0.001), but only marginally (p=0.06) and positively correlated with both income level and education level (r = 0.18 and r = 0.15 respectively). The overall mean distance traveled was 18.9 miles (n= 158, standard deviation = 19.39) and ranged from <1 mile to 90 miles. There was no difference in travel distance by race, gender, income level, knowledge of advisory, or whether or not the angler ate his/her catch. There was a significant difference (p=0.04) in travel distance between the rivers, with those anglers fishing on the James having traveled significantly fewer miles. The average travel distances for the five rivers can be seen in table 3.2 below. By looking at the frequency of anglers by their zip code (figure 3.1) is clear that most of the anglers came from the eastern part of Metro Richmond and Gloucester County

Table 3.2 Mean Travel Distance

River	N	Mean travel distance (miles)
Chickahominy	19	27.5
James	60	10.8
Mattaponi	39	20.7
Pamunkey	19	23.9
Piankatank	21	26.6

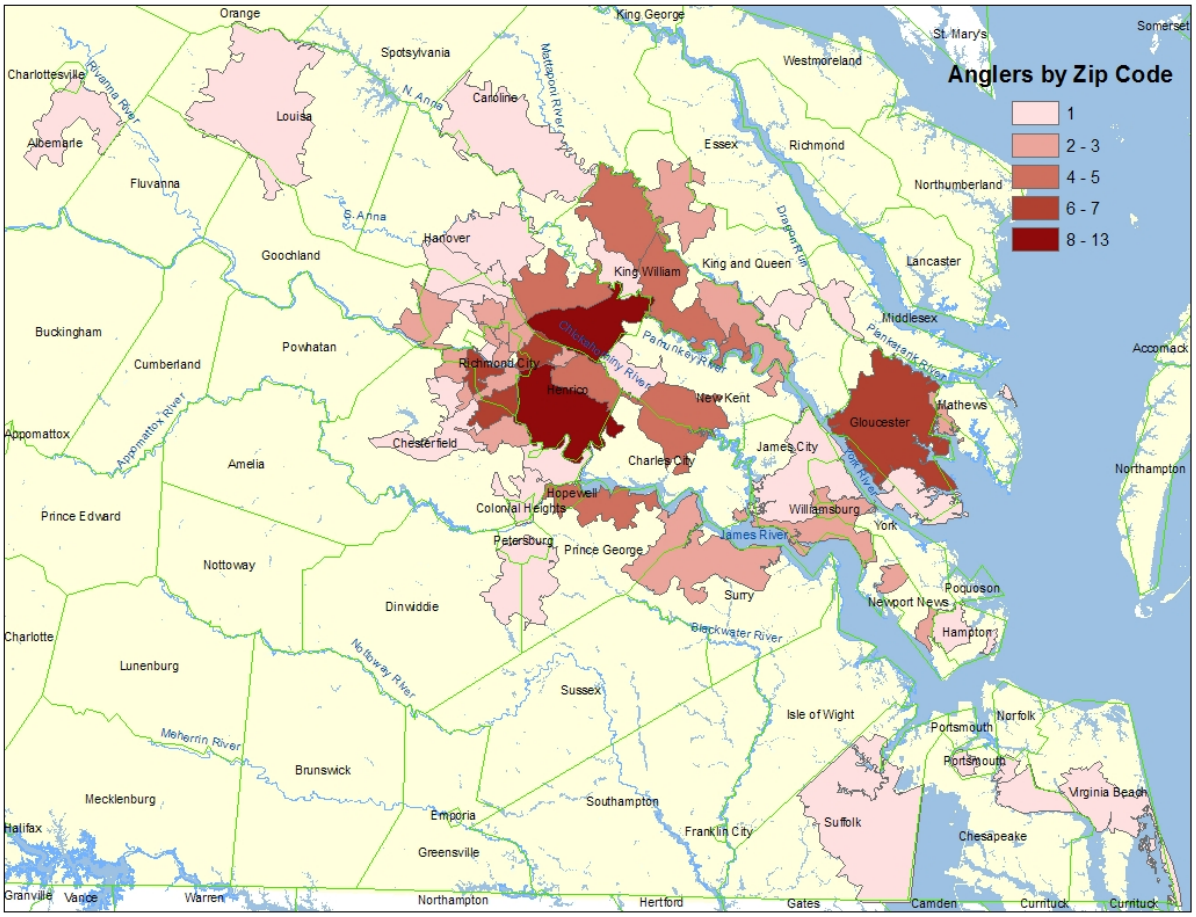


Figure 3. 1. Distribution of anglers by zip code- given as number of anglers in the response group

Consumption of purchased fresh or frozen fish:

The number of meals consumed of purchased fresh or frozen fish significantly and positively correlated with education level when non-consumers were included ($r = 0.20$, $p = 0.01$), but not significantly correlated ($p=0.17$) when the non-consumers were excluded from the analysis. The overall mean number of purchase fresh or frozen meals consumed per year (including non-consumers) was 35 ($n = 155$, standard deviation = 49.04). However, 18 of the 155 respondents to this question (11.6%) reported never eating purchased fresh or frozen fish; when the non-consumers are excluded, the average meals per year of fresh or frozen fish

consumed is 39.85 meals per year (n=137, standard deviation = 50.37). There was no difference in number of purchased meals consumed by race, gender, income level, education level, knowledge of advisory, or whether or not the angler ate his/her catch. There was a significant difference (p=0.04) between the rivers; the number of meals of fresh or frozen fish eaten per year by anglers on the different rivers is shown in table 3.3 below:

Table 3.3 Mean Number of Meals of Purchased Fresh or Frozen Fish or Shellfish per Year

River	N (including non-consumers)	Mean number of meals	N (consumers only)	Mean number of meals
Chickahominy	19	32	16	38
James	58	43	51	49
Mattaponi	38	44	35	48
Pamunkey	19	23	16	27
Piankatank	21	12	19	14

The average meal sizes reported for purchased fresh or frozen fish was 241.8 g per meal (n=138, standard deviation = 161.14). There was no difference in purchased meal size by race, income level, education level, knowledge of advisory, river, or whether or not the angler ate his/her catch. There was a significant (p=0.004) difference in the meal sizes of men (249.08 g, n=126) and women (165.38 g, n=12); however, the small sample size of the women might make this result questionable.

Consumption of canned tuna:

The meals of canned tuna consumed per year was significantly and positively correlated with education level (r = 0.20, p = 0.02) when non-consumers of canned tuna were included, but not significant when the non-consumers of canned tuna were excluded (r = 0.17, p = 0.06). The overall mean number of canned tuna meals eaten per year (including non-consumers of canned tuna) was 29.15 (n = 156, standard deviation = 53.10). Thirty-five anglers (22.4%) reported that they never ate canned tuna fish; when the non-consumers were excluded, the mean number of meals per year was 37.54 (n=121, standard deviation = 57.54) When non-consumers of tuna were included in the analysis, there was a marginally significant (p=0.05) difference tuna consumption between those anglers who ate the fish they caught and those who did not; 24.31

meals per year and 33.92 meals per year respectively; however, this difference was not significant when non-consumers were excluded. There was no difference in tuna consumption by race, income level, gender, knowledge of advisory, or river. The mean canned tuna meal size was reported to be 163.19 g (n=122, standard deviation = 105.59). There was no difference in canned tuna meal size by race or river. Women reported significantly (p=0.02) smaller meal sizes for canned tuna fish (117.45 g, n=14) than men (169.04 g), but again because of the small sample size for women, there is uncertainty with this result. Those anglers who reported knowledge of fish consumption advisories had significantly larger meal sizes of canned tuna: 165.15 g (n=63) versus those who did not know of fish consumption advisories: 160.79 g (n=58).

Consumption of fish caught on the river where interviewed:

While 79 (50%) anglers responded that they "eat fish caught in this river," four of the anglers reported that they had not caught any fish this year; however, they intended to eat the fish when they caught them. Because meal frequency and meal size were not available for these four anglers, the actual number of anglers who eat self-caught fish used in the analysis was 75. Of the anglers who reported eating at least one meal of self-caught fish (n=75), 69 were male (92%) and 6 were female (8%). Of the six females, four reported being over the age of 50, and two were in the 16 – 49 age group.

Percentages of anglers that eat the fish they catch by gender, race, household income, education level, river, fishing mode, and knowledge of advisory

There was no significant difference in the percentage of male and female anglers who reported eating self-caught fish. However, there was a significant difference (p=0.003) based upon the self-reported race of the angler, with 44.41% of white anglers, 66.67% of black anglers, and 78.57% of "other" anglers (Hispanic, Asian, and Native American – grouped for analysis because of their small sample size) eating the fish they caught on the river where

interviewed. For the validity of the chi-square test some of the categories for household income and education level had to be combined. With fewer categories, there was a significant difference in the percent of anglers who ate their catch based upon income (p=0.04) and education level (p=0.02), given in Tables 3.4 and 3.5. Anglers with lower income and lower education levels were more likely to consume fish from the affected waters.

Table 3.4 Percent of Anglers Who Eat Their Catch by Household Income

	Household Income			
Eat fish caught in the river?	**Less than $24,999**	**$25,000 to $49,000**	**$50,000 to $75,000**	**more than $75,000**
No	40%	33.33%	50%	63.46%
Yes	60%	66.67%	50%	36.54%

Table 3.5 Percent of Anglers Who Eat Their Catch by Education Level

	Education Level			
Eat fish caught in the river?	**Less than high school**	**graduated high school**	**some college**	**Bachelors or Masters degree**
No	27%	48%	61%	65%
Yes	73%	52%	39%	35%

There was a marginally significant (p=0.05) difference in whether or not the angler ate his/her catch by fishing mode, with 41.89% of anglers fishing by boat, 48.84% of anglers fishing from a pier, and 65.85% of anglers fishing from the shore reporting that they ate the fish caught from the river where interviewed. There was also a significant difference (p=0.04) in the percent of anglers who ate their catch based upon their awareness of fish consumption advisories, with the anglers who are <u>not</u> aware of the advisories being 1.4 times more likely to eat the fish they catch from the river where interviewed than the anglers who are aware of advisories. There was no difference in whether or not the angler ate his/her catch based upon the river where interviewed.

Table 3.6 Percent of Angers Who Eat Their Catch by Awareness of Advisory

	Aware of advisory	
Eat fish?	**No**	**Yes**
No	41%	58%
Yes	59%	42%

Among the anglers who eat the fish they catch, the mean number of meals per year (of fish caught from the river where the angler was interviewed) was 20.37 (n=75, standard deviation=30.68). There was no difference in self-caught meal frequency size by gender, race, education level, knowledge of advisory, or river, There was a significant (p=0.03) difference in the number of meals of self caught fish eaten per year by household income as seen in table 3.7 below:

Table 3.7 Self-Caught Meals per Year by Household Income

Income range	N	mean	standard deviation	range
less than $14,999	5	20.31	20.16	1 – 49
$15,000 to $24,999	7	33.42	33.56	1 – 84
$25,000 to $49,000	21	32.31	45.55	1 – 200.1
$50,000 to $74,999	22	7.52	8.94	1 – 36
above $75,000	18	18.15	24.28	2 – 96

The mean reported meal size for self-caught fish was 276.59 grams (n=75, standard deviation = 188.01), and this was significantly correlated with meal size of purchase fresh or frozen fish or shellfish ($r = 0.5$, $p < 0.0001$). There was no significant difference in self-caught meal size by gender, race, income level, education level, river, or knowledge of advisory.

Species of recreational freshwater fish most frequently consumed:

Table 3.8 Count of Species Named		
Species Name	**Total**	**Percent**
catfish	44	33.33%
spot or croaker	26	19.70%
sunfish	23	17.42%
largemouth bass	16	12.12%
striped bass	9	6.82%
white perch	7	5.30%
perch (yellow)	6	4.55%
sucker	1	0.76%
Total	132	100.00%

The type of fishes consumed by the anglers was recorded on the survey sheets, but for analysis these fishes has to be condensed into groups. The fish species that make up each group can be found in the appendix. Table 3.8 shows the frequency of fish species as named as a type of fish the angler eats. However, when the number of reported meals of each species or the reported total grams eaten of each species (number of meals x meal size) are considered, the percentages change. For example, “spot or croaker” were ranked as the second

most named type of fish eaten, but when the mass of fish consumed is factored, yellow perch are the second most consumed fish in terms of mass.

Table 3.9 Sum of meals per year		
Species Name	**Total no.**	**Percent**
catfish	704	46%
perch (yellow)	261	17%
spot or croaker	200	13%
sunfish	134	9%
largemouth bass	111	7%
striped bass	84	6%
white perch	25	2%
sucker	9	<1%
Total	1528	100.00%

Table 3.10 Sum of grams per year		
Species Name	**Total grams**	**Percent**
catfish	239425	54%
perch (yellow)	65863	15%
spot or croaker	49727	11%
sunfish	34358	8%
striped bass	24826	6%
largemouth bass	23319	5%
white perch	6394	1%
sucker	3062	<1%
Total	446974	100.00%

Household make-up:

From 158 surveys, the reported number of people in each age group living in the household and the number who eat "fish caught from this river" (the river where the survey took place) are reported below. The ages of pregnant women were not asked, but it is assumed that they are a sub-set of the 16 to 49 age group.

Table 3.11 Percent of Household Members Who Eat Fish Caught from the Survey Rivers

Age group	Total reported living in all households	number of age group who eat caught fish	percent of age group who eat caught fish
5 or younger	46	18	39.13%
6 to 15	88	34	38.64%
50 or older	100	37	37.00%
women 16 to 49	127	54	42.52%
(pregnant women)	*11*	*3*	*27.27%*
men 16 to 49	164	88	53.66%
Total	525	231	44.00%

Table 3.12 Consumers of Caught Fish	
Age Group	**% of Consumers**
5 or younger	8%
6 to 15	15%
50 or older	16%

women 16 to 49	23%
pregnant	1%
men 16 to 49	38%
Total	100%

Demographic Information:

47% of the anglers interviewed were fishing from a boat, 28% from a pier or dock, and 26% from the shore. 90.38% of the anglers were men; 9.62% of the anglers were women. Anglers were asked to self-identify their race, and 6 anglers chose two categories to describe themselves (Table 3.13). In table 3.13 these anglers were counted in both categories. Tables 3.14 and 3.15 show the percentages when these 6 anglers are classified as "other."

Table 3.13 Anglers by Race/Ethnicity

Race/Ethnicity	Survey Results	Statewide 2006 Estimates from Census Bureau
White:	73.08 %	73.34%
Black:	23.08%	19.89%
Hispanic:	3.85%	6.37%
Asian:	0.64%	4.75%
Native American:	3.21%	0.07%

"Other"	Number	Percent
White & Black	3	1.92%
White & Native American	2	1.28%
Black & Native American	1	0.64%
Total		**3.85%**

Table 3.14

Race/Ethnicity	Number	Percent
White	109	69.87%
Black	32	20.51%
Asian	1	0.64%
Native American	2	1.28%
Hispanic	6	3.85%
"Other"	6	3.85%
Total	**156**	**100**

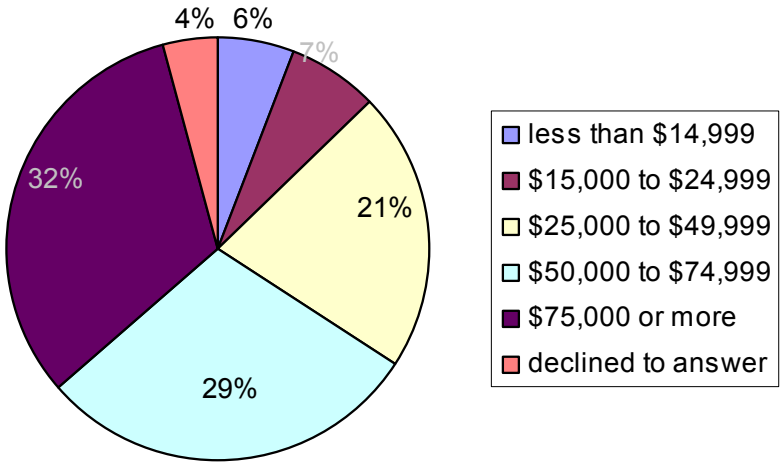
Table 3.15

Because of the low numbers of Hispanic, Asian, and Native American anglers, valid chi-square analysis could not be performed to determine if there is a relationship between race and household income, education level, river, fishing mode, whether or not the angler was fishing for

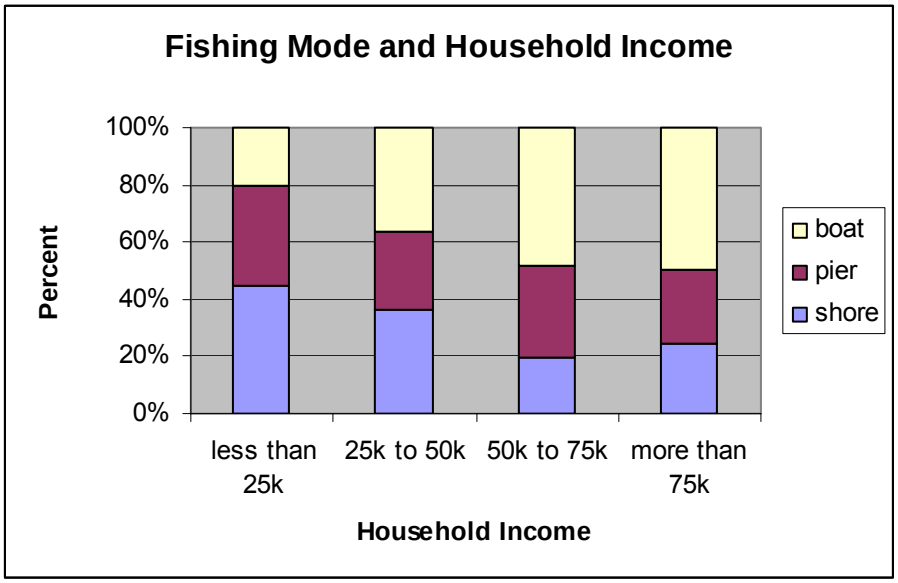
food, or the total number of people living in the household. There was no significant association between race and awareness of consumption advisories, but there was a significant (p=0.003) difference in the races in whether or not the angler gave away any of his/her catch, with 41.28% of white anglers giving away the fish they catch, 53.33% of “other” anglers giving away their catch, and 75% of black anglers giving away their catch.

Household Income: The majority of anglers (61%) self-reported their household income greater than $50,000 (Fig. 3.2). The distribution of household incomes is shown in Fig. 3.2.

Figure 3.2 Household Income



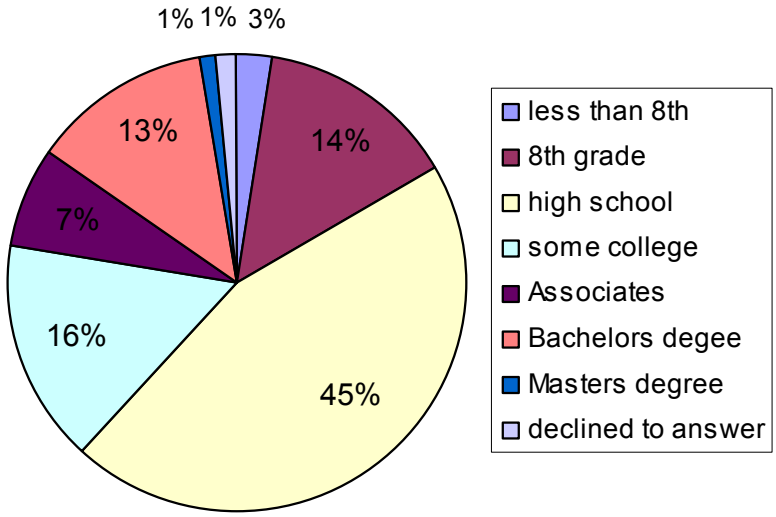
There was a significant difference (p=0.02) in fishing mode by household income, shown in Figure 3.3. The general trend showed that as income increased fishing from the shore decreased and fishing from a boat increased.



There was no significant difference in awareness of advisories or the likelihood of an angler giving fish away by household income.

Education Level: The breakdown in education level can be seen in figure 3.4 below:

Figure 3.4 Education Level



3.2 RESULTS OF RISK ASSESSMENT SIMULATIONS

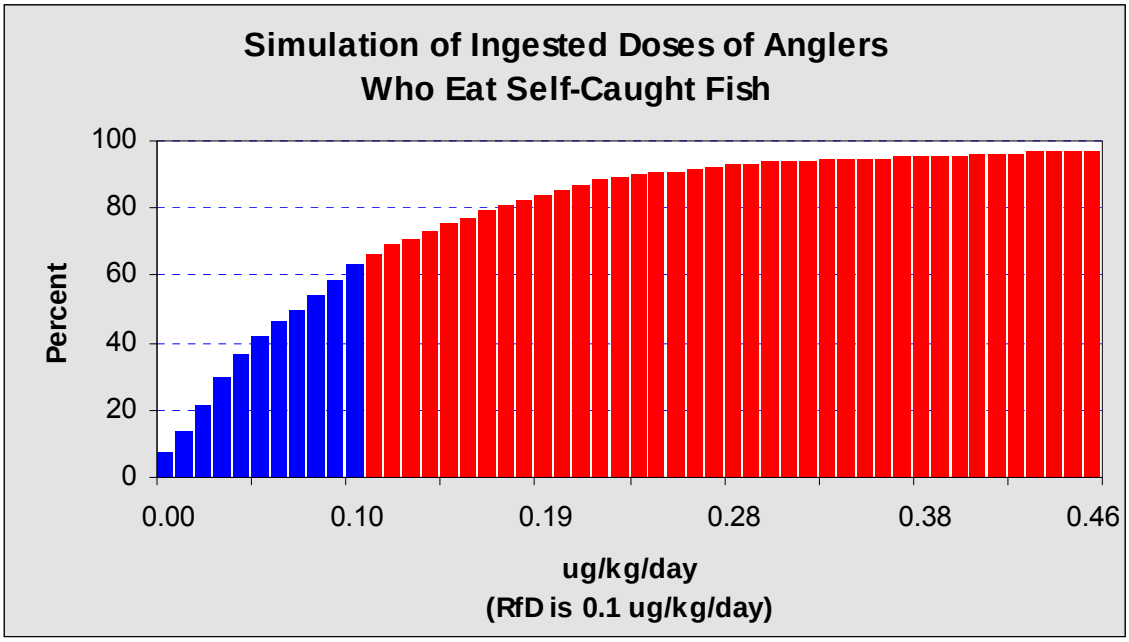
3.2.1 Percent of people exceeding RfD

The total ingested dose (sum of dose from caught fish, purchased fish, and canned tuna fish) can be compared to the reference dose (RfD) of 0.1 ug/kg/day set by the U.S. EPA. The mean values of ingested doses under the baseline scenario and the percent exceeding the RfD in the baseline, 2010, and 2018 scenarios can be seen in table 3.16 below. The distribution of the total ingested doses for all anglers is shown in figure 3.5 (doses above 0.1 ug/kg/day are in red):

Table 3.16 Mean Doses and % Exceeding RfD

Group	Mean Dose (current Hg levels)	% exceeding RfD (current Hg levels)	% exceeding RfD (2010 Hg levels)	% exceeding RfD (2018 Hg levels)
All anglers	0.11	38%	36%	36%
Men 16 to 49	0.10	37%	34%	34%
Women 16 to 49 (model 1)	0.15	49%	45%	44%
Women 16 to 49 (model 2)	0.12	39%	37%	36%
Adults over 50	0.11	39%	37%	36%

Figure 3.5 Distribution of Average Daily Intake of All Anglers



3.2.2 Loss of I.Q. Points

Two models were constructed for the loss of I.Q. points due to in-utero exposure to MeHg from the maternal diet. Model 1 used point estimates for values of the model parameters for body weight, blood volume, fraction of MeHg absorbed, fraction of Hg in blood, elimination rate constant, and blood to hair ratio, and Model 2 used probability distributions for these values. The point estimates are the assumed mean values of these physiological parameters as used by U.S. EPA in the RfD determination (U.S. EPA 2001, NRC 2000). The parameter distributions came from analysis by Alan H. Stern (Stern 1997, 2005). Both models simulated women (16 – 49) who consume fish caught in Virginia's freshwater tidal rivers using the current levels of mercury fish tissue concentrations (baseline scenario), fish tissue levels predicted from mercury deposition in 2010 (scenario 1), and fish tissue levels predicted from mercury deposition in 2018. 10,000 trials were run with forecast set for ingested dose (ug/kg/day), blood concentration (ug/L), hair concentration (ug/g), IQ points lost, and change in IQ points lost.

Blood concentrations were derived from the application of the one-compartment model to the Average Daily Intake Doses derived for comparison with the RfD. For Model 1 (mean values of physiological parameters) in the baseline scenario blood concentrations ranged from 0 to 33 ppm, with the mean concentration being 6 ppm and the median being 4 ppm. Under scenario 1 (2010 fish tissue mercury levels), the mean blood concentration was 5.3 ppm and the median concentration was 3.5 ppm. Under scenario 2 (2018 fish tissue mercury levels), blood concentrations dropped further to a mean of 5.25 ppm and a median of 3.4 ppm.

For Model 2 (probability distributions for values of physiological parameters), in the baseline scenario they ranged from 0 to 47 ppm, with the mean concentration being 5.4 ppm and the median being 3.4 ppm. Under scenario 1 (2010), the mean blood concentration was 4.9 ppm and the median concentration was 3.0 ppm. Under scenario 2 (2018), blood concentrations dropped further to a mean of 4.8 ppm and a median of 2.9 ppm.

Hair concentrations showed a similar decrease in the three scenarios as seen in tables 3.17 and 3.18 below:

Table 3.17 Hair Concentrations from Model 1 (Point Estimates of Parameters)

Hair Concentration (ug/g) from Model 1				
Scenario	**Range**	**Mean**	**Median**	**StDev**
baseline	0 – 8.3	1.49	1.00	1.15
scenario 1	0 – 8.3	1.33	0.87	1.35
scenario 2	0 – 8.3	1.31	0.85	1.33

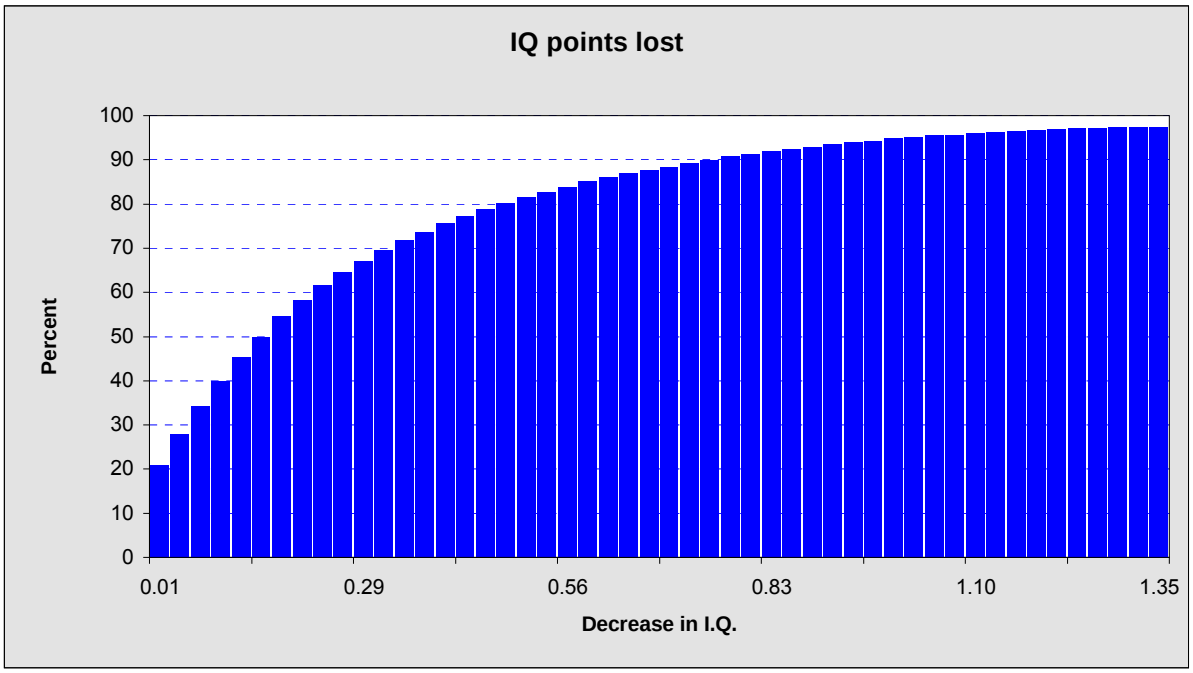
Table 3.18 Hair Concentrations from Model 2 (Distributions of Parameters)

Hair Concentration (ug/g) from Model 2				
Scenario	**Range**	**Mean**	**Median**	**StDev**
baseline	0 – 25	1.77	1.06	2.07
scenario 1	0 – 25	1.59	0.94	1.87
scenario 2	0 – 25	1.56	0.91	1.85

Hair concentrations were then converted into IQ points lost using the dose response function of -0.18 IQ points for each ppm increase in maternal hair mercury (Axelrad et al., 2007). The predicted IQ points lost in model 1 for the baseline scenario ranged from 0 to 1.49, with the

mean IQ points lost predicted to be 0.27 points and the median predicted to be 0.18 points lost. The predicted IQ points lost in model 2 for the baseline scenario ranged from 0 to 4.53, with the mean IQ points lost predicted to be 0.32 points and the median predicted to be 0.19 points lost. The distribution of IQ points lost from the simulation of Model 2 is shown in figure 3.6 below:

Figure 3.6 Distribution of I.Q. Points Lost to Children of Women 16 to 49 Who Consume Fish from the Survey Rivers

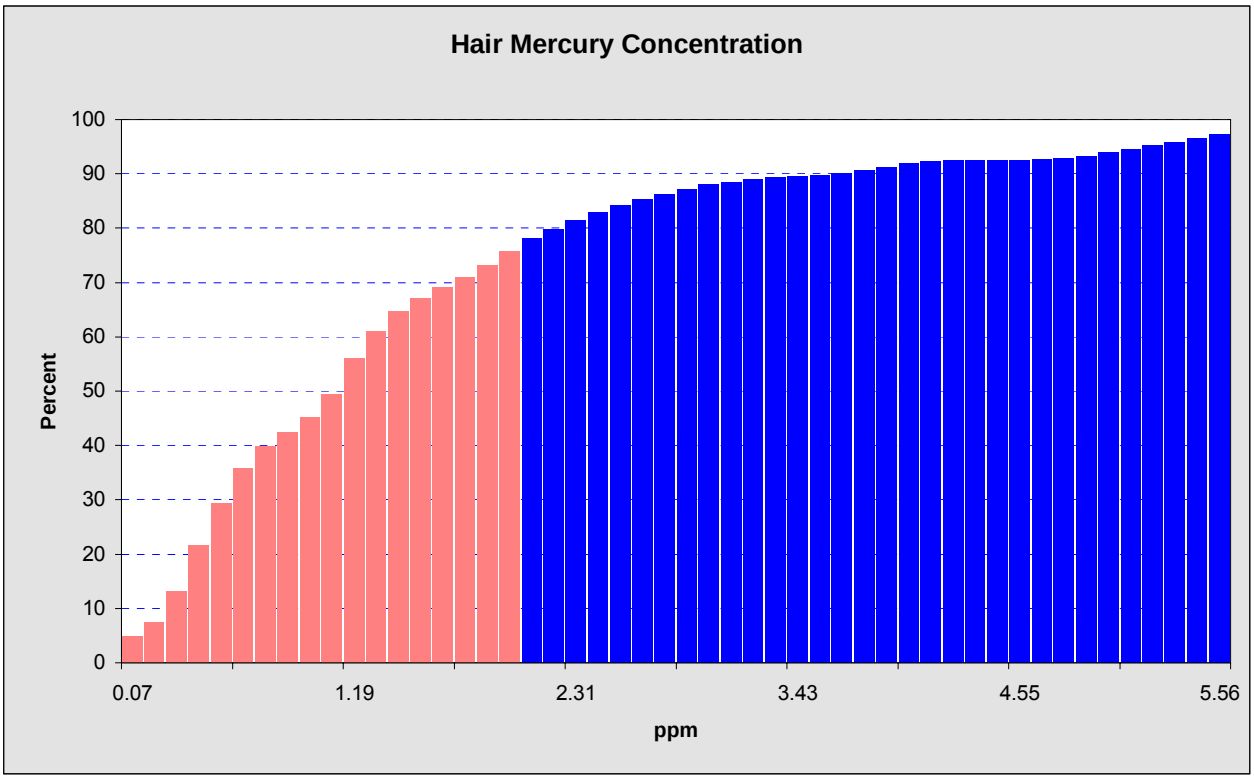


Changes in IQ points lost were then calculated for both models under scenarios 1 and 2. The mean of scenario 1 for both models was an improvement of 0.03 IQ points over the baseline scenario; the median was 0.01 IQ points. Under scenario 2 the mean IQ improvement was 0.03 over the baseline scenario for model 1 and 0.04 for model 2; the median was again 0.01 for both models.

3.2.3 Increased Risk of Acute Myocardial Infarction

To calculate the increased risk of Acute Myocardial Infarction we focused on the percent of adults over 50 that the model predicted would have greater than 2 ppm of hair mercury.

Figure 3.7 Distribution of Mercury Hair Concentrations of People Over 50 Who Consume Fish from the Survey Rivers



Under the baseline scenario, 22% of the adults 50 and over are predicted to have hair mercury concentrations over 2 ppm. This percentage drops by 2% to 20% exceeding 2 ppm with the lower fish tissue mercury concentrations predicted starting in 2010.

3.3 SENSITIVITY ANALYSIS

The sensitivity of the models to the variability of the parameters was tested by setting each parameter value, in turn, to a fixed value (the mean), and then comparing the results of

that run of the model to the results of the full model. The sensitivity analysis was done on the Women 16 to 49 model 2, since it had the largest number of variable model parameters. Sensitivity was determined by calculating the percentage difference in the 99th to 50th percentile ratio of the Improvement in I.Q. points in 2010 between the results with each parameter frozen and with the full model. The self-caught fish meal frequency, meal size, and mercury concentration of Virginia fish contributed most to the variability of the model as seen in table 3.20.

Table 3.20 Sensitivity Analysis

Parameter	Contribution to Variability
blood volume	5.13%
blood fraction	-1.14%
fraction abosorbed	0.46%
elimination rate	2.98%
body weight	10.39%
hair-to-blood ratio	6.96%
caught fish Hg	32.15%
caught meal frequency	76.27%
caught meal size	36.84%
purchased fish Hg	4.57%
purchased fish freq.	-0.15%
purchased meal size	4.43%
tuna Hg	3.71%
tuna meal freq.	-0.37%
tuna meal size	1.82%

4 DISCUSSION

4.1 OBSERVATIONS FROM SURVEY

Several qualitative observations from the survey were not captured in the statistical results or risk assessment results. Although we only recorded 3 anglers who could not complete the survey because of a language barrier, the number of non-English speakers is potentially greater as these men were accompanied by 4 -8 people (women and children) who were assumed to

be family members). At other times at Ancarrows Landing, one member of a group of 4 or more people who were Spanish speakers was able to speak English, and volunteered to translate the survey. In these circumstances we only obtained one survey for the group, as translation was time consuming and the group identified themselves as all living in the same household with one person doing most of the fishing. Awareness of fish consumption advisories was very low among the Spanish-speakers at Ancarrows; we also did not see any consumption advisory signs written in Spanish. Also, during the time that we visited the survey sites (May through September of 2007) we observed that almost all of the posted signs did not have the current fish consumption advisory; the exceptions being the bridge crossings on the Dragon Run and at West Point.

Regardless of whether or not there was a consumption advisory sign posted, many of the anglers had similar comments on their perception of the risk of fish consumption. Several anglers told us that if it were dangerous to eat fish, there would be a sign along the river bank (when in fact, the signs were at the boat ramp or in the parking lot). Also, there was a perception that the "water is dirty in Richmond, but clean downstream," (or on the other rivers). Some anglers acknowledged that the fish may be contaminated, but they were convinced that proper cleaning of the fish would remove the contaminants.

Many of the anglers wanted to talk about other environmental problems, and several (especially at West Point) mentioned that they perceived a decline in the quality and quantity of fish over the last decade. However, other anglers on the James River talked about the great improvements in water quality since they were children.

At least two anglers expressed a concern that the results of the survey could be used to put restrictions on recreational fishing. The survey team responded with a non-committal explanation that repeated the initial information about the purpose of the survey.

Many of the anglers who said they did not eat the fish they caught on the river where the interview was conducted reported that they <u>did</u> eat salt-water fish they caught in salt water

estuaries, the Chesapeake Bay or in the Atlantic Ocean. The survey was not designed to capture information about self-caught fish consumed from other regions. A longer and more detailed survey would be necessary to compare recreationally caught freshwater and salt-water fish.

4.2 UNCERTAINTY

Any risk assessment has areas of uncertainty that include the data, assumptions and equations that make up the quantitative inputs. Uncertainty can be expressed either qualitatively or quantitatively and we present here a qualitative discussion of the uncertainties that complements the preceding sensitivity analysis (section 3.3). The three basic areas of uncertainty in this risk assessment are the empirical data, the equations used to estimate biological processing of MeHg, and the assumptions about mercury processes in the environment.

Empirical data: fish tissue MeHg levels

VA DEQ collects fish tissue samples and has the tissues analyzed for total mercury, Hg. The tissues contain mercury in both the metallic form, Hg, and the organic or methylated form, MeHg. Detailed chemical analysis indicates that on average, more than 90% of the total mercury is in the methylated form, MeHg, and VA DEQ makes the simplifying and conservative assumption that all mercury is MeHg. Some of the samples will actually have more than 90% and other samples less than 90% MeHg. A proportion of the samples will have close to 100% MeHg. The assumption of 100% is a source of uncertainty as a systematic over-estimate of exposure.

The fish sampling effort is able to collect enough fish to provide a general trend for the species and sizes collected. The sampling effort is not able to collect and analyze enough samples for a comprehensive description of the mercury contamination

for all sizes and ages of species in all the rivers of interest. The result of using these empirical data is the inherent uncertainty of the data. One of the areas of uncertainty in the data set is the relationship between fish age and MeHg levels. This uncertainty represents possible changes in both directions- actual MeHg levels may be both higher and lower than the reported values.

Empirical data: fish consumption surveys

The analysis assumes that the women in the household ate as much fish as did the men, yet there were limited direct information from the surveys on women's fish consumption. This assumption is most likely an error of overestimate of exposure. The assumption of all members of the angler families eating the same canned tuna is also likely wrong and the nature of that error is unknown. The fact that the consumption advisory for women of child-bearing age to limit tuna intake has been in place for some time may have changed their behavior and not be reflected in the survey. By the same token, men's consumption of canned tuna may be less than reported. One problem with creel surveys is gathering data on family behaviors based on one member of the group. Most of the anglers were men and the target group of women of child bearing age were not highly represented in the angler group.

Creel surveys also rely on recall of fish consumption over an entire year. There will be some error in these data because of imperfect recall.

Equations:

The equations assume that the processes as described are accurately represented. The equation for MeHg accumulation and distribution assumes steady-

state and a one compartment distribution. Although these assumptions seem to be met for many conditions, both assumptions may not represent actual events in all people in the groups of interest.

Environmental processes:

This analysis assumes that the processes causing MeHg start with elemental mercury emissions that cause deposition into the watersheds of the eastern waters of Virginia. The assessment further assumes that mercury deposited is converted to MeHg under the reducing conditions present in the rivers surveyed. The analysis also ssumes that MeHg is taken up via ingestion of food and water intake and accumulates in tissues of fish and other aquatic animals. The projections of mercury levels in 2010 and 2018 assume that there is a direct relationship between emission reductions and fish tissue concentrations. These assumptions are based on research in other ecosystems that are not identical to those in the eastern Virginia rivers studied here. The mercury in fish tissues may have a larger component from direct discharge sources in the James River, or from legacy sediment accumulation in any of the rivers. The systems may not be as responsive to the emission reductions and greater or lesser fish tissue concentrations may result.

4.3 RECOMMENDATIONS

The Department of Environmental Quality (VA DEQ) may want to consider several efforts to expand and complement the work conducted here on methylmercury in fish from Virginia waters. The areas for VA DEQ to consider include the following:

- This survey had limited direct response from a target group- women of child bearing age and none from children; additional survey data could be obtained directly from these groups.
- Design and conduct a fish consumption survey for non-English speaking anglers, concentrating on the James River below Richmond.
- Extend the survey area to include regions such as near the Blackwater River and the Dismal Swamp and the waters that have more recently come under consumption advisories for methylmercury contamination.
- Contact the appropriate Native American tribes and work cooperatively with their leaders in conducting a fishing survey for tribal members.
- Conduct a cumulative risk assessment for the angler group most at risk from methylmercury contamination. The cumulative risk assessment should include, but not be limited to, the interactions of multiple chemicals in fish, existing health conditions, and socio-economic status.
- There is an advantage to continuing to survey in the regions covered by this study – portions of the James, Chickahominy, Piankatank, Pamunkey, Mattaponi. Additional data could reduce the uncertainties in this investigation as well as increase sample size for the groups and areas with the lowest representation.

The present study was able to survey more than 150 recreational anglers and gather information on their fishing and fish consumption patterns in areas east of Interstate 95 that are under fish advisories for methylmercury. The scope of this investigation did not permit surveying family members, more individuals or a wider range of waters or for a longer period. As a result, it is necessary to estimate fishing efforts and consumption rates for the entire year and for other areas. These estimates are a source of uncertainty in the fish consumption estimates and

subsequent exposures. Additional survey data would reduce the uncertainties resulting from limiting the surveys in time and space.

Family members:

Anglers were predominantly male, and one target group is women of child bearing age. The survey did ask for information on fish consumption by family members, but this information is still second-hand and was not obtained directly from the family members. A modified survey of a different nature (not an intercept survey) would need to be used to obtain information directly from the family members of the anglers who fish the rivers in the area of interest.

Another target group is children of the anglers and there are limited data in the literature on this group. The EPA Exposure Factors Handbook is the most widely used source, but direct data could be obtained through a survey that obtained food consumption information from families of anglers in eastern Virginia.

Non- English speaking anglers:

During the field survey, the investigators identified a number of people fishing who did not speak English, or who spoke English so poorly that the survey instrument could not be administered. These anglers were fishing on the James River at Ancarrow's Landing and their native language was Spanish or a Spanish-based language. Surveyors identified only a few of these anglers who could speak English sufficiently well to administer the questionnaire. Important information could not be collected because of the language barrier and the survey team observed that these anglers seemed to be catching a variety of species. We believe that there is a population of Spanish speaking people who are catching and consuming fish with

higher levels of methylmercury, and an investigation into this group would provide important information to help VA DEQ estimate methylmercury exposure via fish consumption.

Survey Additional Waters:

The present study was able to survey more than 150 recreational anglers and gather information on their fishing and fish consumption patterns in areas east of Interstate 95 that are under fish advisories for methylmercury. The scope of this investigation did not permit surveying more individuals or a wider range of waters or for a longer period. As a result, it is necessary to estimate fishing efforts and consumption rates for the entire year and for other areas. These estimates to other waters and groups are a source of uncertainty in the fish consumption estimates and subsequent exposures. Additional survey data would reduce the uncertainties resulting from limiting the surveys in time and space.

Fish consumption advisories for mercury (specifically methylmercury) are presently in place for the waters survey in this investigation (James, Chickahominy, Pamunkey, Mattaponi and Piankatank Rivers) and several other waters or waters bodies. The other waters include Harrison Lake, Blackwater River, Dismal Swamp/Lake Drummond, Herring Creek, Lake Gordonsville, Lakes Trashmore and Whitehurst and the Nottoway River. The present investigation did not survey these other waters because the warnings were issued only recently or the budget did not permit more survey sites, or both. Further investigations of fishing and fish consumption from these waters would provide a more complete understanding of the nature and extent of the situation in Eastern Virginia.

Native Americans:

Investigators attempted to survey the Native American tribes who reside in the affected areas specifically, in addition to the general survey of anglers on the rivers. This effort was not successful, and only 2 of the survey respondents identified themselves as Native Americans.

Three tribes have historically used local waters for fishing, and the Pamunkey and Mattaponi have reservations on the respective rivers, where the tribal members use of the river is expected to be substantial. The information gained from surveying the tribes would make an important addition to understanding the effects of methylmercury on the health of anglers in eastern Virginia.

Cumulative Risks:

The present assessment was a single chemical, single scenario risk assessment. We used a field survey of fishing behaviors with measurements of methylmercury levels in fish to estimate health risks to people consuming fish caught in waters where we surveyed. This type of risk assessment estimates risks from a single chemical and examines the single exposures pathway- fish consumption. Other factors that influence how methylmercury in fish affects the health of the consumers were not examined. Methylmercury exposures from fish consumption were not examined within the context of other chemical contaminants, life style issues or other existing conditions that affect health (i.e., nutrition).

Risks in the context of how an individual, group or population is affected by aggregate conditions and exposures are classified as cumulative risk, an area that U.S. EPA is presently developing in response to input and comments from the National Academy of Sciences, Congress and the U.S. EPA Science Advisory Board (see U.S. EPA 2003). U.S. EPA published initial processes for examining cumulative risk in the Framework for Cumulative Risk Assessment (U.S. EPA 2003). In the Framework, U.S. EPA (2003) defines cumulative risk as "the combined risks from aggregate exposures to multiple agents or stressors." U.S. EPA further notes that cumulative risk assessment deals with multiple stresses, that all stresses need not be chemical and that the risks from the different stresses are combined. In the context of the present assessment, cumulative risk assessment could include multiple chemical contaminants in the fish caught from Virginia waters, existing disease burden in the group of people

consuming the fish, psycho-social stress of the consumers, and other factors combining to increase the risks to fish consumers. Cumulative risk assessment was outside the scope of the present investigation. VA DEQ could pursue the matter of a cumulative risk assessment for the anglers in the highest risk category- those who are consuming catfish and large mouth bass from the affected areas in Eastern Virginia.

The experience of health risk assessment in the US has demonstrated that some individuals or groups may respond to a given stress with more adverse responses than would ordinarily be anticipated. Some individuals are more sensitive due to their biological/genetic make-up, and other people simply cannot cope or respond to a stress situation. The greater sensitivity is the case for children because of their developmental stage. Taken together, these types of responses are considered vulnerability.

Risk assessment procedures generally account for greater sensitivity in many cases by applying a safety factor that essentially lowers the threshold concentration for effects. In other words, if the general population is protected from effects of methylmercury at a daily dose of 1.0 ug/kg-day, then applying a safety factor of 10 would lower that daily dose to 0.1 ug/kg-day (as done by U.S. EPA). The basis for using this approach has been that sensitive individuals respond with an adverse effect at a lower dose (or at a lower concentration). U.S. EPA-derived reference doses attempt to incorporate safety factors for sensitive individuals as possible, and state criteria likewise include some provision for protecting sensitive individuals and groups.

Vulnerability goes beyond biological or toxicological sensitivity and has four major elements: multiple exposures (i.e., chemical), differential exposures, inability to respond, and inability to recover (Kasperson et al., 1995; see also U.S. EPA 2003.) Multiple and differential exposures are aspects of the environmental conditions to which an individual or group is subjected. Vulnerability is an important element of risk assessment that is exposed. Response and recovery deal with properties of the group or individual and are frequently inherent, such as genetic disposition, immune responsiveness or psychological makeup (see deFur et al., 2007).

Vulnerability is an important element of risk assessment that has not been well investigated for either single chemical or cumulative risk assessments (deFur et al., 2006, Kasperson et al., 1995; see also U.S. EPA 2003). In the present investigation, some groups or individuals may be more vulnerable to the effects of methylmercury as a result of poor nutrition (Chapman and Chan 2000)

Multiple chemical exposures:

This investigation and the resulting estimated risks address only the health consequences from exposure to one chemical, methylmercury via consumption of fish. In this regard, the investigation was simplistic by intentionally limiting the work to a single chemical and a single exposure pathway. Data from VA DEQ's fish tissue monitoring program indicate that other chemicals (http://www.deq.virginia.gov/fishtissue/fishtissue.html) are also found in some fish tissues of some fish. A review of the VA DEQ website that provides data on some chemical contaminants in fish tissues indicates that several other chemicals co-occur with methylmercury in fish in Eastern Virginia. Specifically, specifically PCB's occur in catfish in the James River at levels that warrant fish consumption advisories. Kepone is still found in some James River fish species at low levels and arsenic has been reported in several areas. These results are summarized in the following Table of data from the VA DEQ web site.

Table 4.1 Compounds found in mercury-contaminated fish in southeastern Virginia waterways
Data from http://www.deq.state.va.us/fishtissue/fishtissue.html
Searched data for James, Chickahominy, Mattaponi, Pamunkey, Piankatank, Blackwater Rivers, Harrison Lake, Dismal swamp

Waterbody	Location	Species	Contaminants Co-occuring w/ Hg
James River	I-95 Bridge	Striped Bass Blueback Herring Hickory Shad	Arsenic
		Striped Bass Blueback Herring	PCBs

		Hickory Shad	
	Richmond	White Perch Striped Bass	Kepone
Pamunkey Creek	Lake Anna near State Park	Largemouth Bass	Arsenic
		Channel Catfish Striped Bass	PCBs
Blackwater River	Near VA state-line	Bowfin	Arsenic

In addition, Garman et al. (1998) reported that catfish from the tidal freshwater James River in the vicinity of Hopewell had elevated levels of DDT, PCBs, and TBT, in addition to MeHg. These chemicals all target the nervous system and/or reproductive system in fish, mammals and other animals.

The most significant issue regarding the co-occurrence of multiple chemicals is likely that some of the chemicals act on the same target, especially the developing brain or reproductive system. PCBs (Schantz, Widholm and Rice, 2003) and methylmercury (see discussion above, and NRC 2000), two contaminants found in fish in Eastern Virginia; both affect the developing brain, each causing a reduction in cognitive function. The effects of combined exposure to both PCBs and methylmercury on neurological function, including I.Q. have been investigated in a few laboratory studies and in two epidemiological investigations (Grandjean et al., Stewart et al., 2003). The results suggest but do not confirm the combined exposures add to the impact on the developing brain of young children and fetuses. This exposure scenario likely occurs in Virginia anglers who catch fish from waters with fish advisors for both PCBs and methylmercury. The effects may be additive, synergistic (the combination greater than additive) or one may reduce the effect of the other. Future work could assess the combined effects by considering each option as a possible scenario in estimating health outcomes from such exposures.

Continue 2007 Surveys:

Uncertainties in the present work result from the limited sample size, period over which the surveys were conducted and the few locations that could be surveyed (sampled). Most of the uncertainty is sampling uncertainty, meaning whether the data obtained here are truly able to represent the range of responses and central tendency of the responses (averages). Larger sample sizes could be obtained by using the same survey instrument in subsequent years with the intent of interviewing new anglers who were not survey in 2007 in this investigation.

Another goal of continuing surveys in the same waterbodies next year could be to confirm the data from 2007 by administering a confirmation survey to anglers who had participated in the 2007 survey. Such a confirming survey would be designed differently and would have to be newly designed to ask new questions to obtain information that can act to confirm the 2007 information.

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6 Appendix

6.1 Angler Survey (Example from the Mattaponi River)

Surveyor Name: **SURVEY NUMBER:**
Survey Location: Time Begin:
Date: Time End:
Day of Week: Length of Interview:
Gender: Fishing Mode?
☐Male ☐Female ☐Shore ☐Pier ☐Boat

My name is _____ *(first name).* **I'm with the VCU fishing survey team. We're talking to people who fish here to learn how Virginia's rivers are used for fishing. Can I have about 10 minutes of your time to ask you some questions? All of your answers will be confidential and anonymous.**

Thank you! Before we start, I just want to make sure that you haven't already been interviewed by our team sometime this summer. Have you been interviewed by one of us before?
IF YES, TERMINATE INTERVIEW. IF NO, CONTINUE

FOR ALL QUESTIONS: UNLESS OTHERWISE NOTED, READ RESPONSE OPTIONS ONLY IF RESPONDENT HAS TROUBLE ANSWERING.

1. How many miles did you travel to get here today?

_____ miles

2a. During this season or last season, have you fished on… *(read locations)*

Harrison Lake	☐Yes ☐No
the James River	☐Yes ☐No
the Chickhominy	☐Yes ☐No
the Pamunkey River	☐Yes ☐No
the Dragon Run	☐Yes ☐No
Blackwater River	☐Yes ☐No

b. Where else in Virginia have you fished this season or last season?

_____

3. How often do you fish on the Mattaponi River?

_____ times per ☐week ☐month ☐year

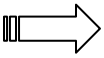
4. Think back to the first time you fished on the Mattaponi River. Can you tell me how many years you have fished on the Mattaponi River?

_____ ☐months ☐years

We are also interested in knowing how much fish you eat. In this survey, when I talk about fish meals I mean any fish that is consumed for breakfast, lunch, dinner, or snacks.

5. Do you eat any of the fish that you catch in the Mattaponi River?

☐Yes ☐No *(skip to question 10)*



6. On average throughout the year, how many of your meals include fish that you catch in the Mattaponi River?

_____ meals per ☐week ☐month ☐year

☐ Don't Know

7. Is the primary reason you come fishing here to get food to eat?

☐Yes ☐No

8. When fishing on the Mattaponi River, what types of fish do you catch and eat most frequently? You can name up to four. I have pictures of some of the fish, but you can name any fish that you catch here and eat frequently. *(show fish species visual aid)*

What fish do you catch and eat most frequently?	**Which months of the year do you catch and eat the *MOST* _____?**	**and how frequently do you eat a meal of _____ during these months?**	**How much_____ do you typically eat during a meal?**
a)	☐Jan ☐Feb ☐Mar ☐Apr ☐May ☐ all the same ☐Jun ☐ don't know ☐ Jul ☐Aug ☐Sep ☐Oct ☐Nov ☐Dec	_____ meals per ☐ week ☐month *(refer to fish species visual aid)*	_____ oz. per meal *(show meal size visual aid)*
b)	☐Jan ☐Feb ☐Mar ☐Apr ☐May ☐ all the same ☐Jun ☐ don't know ☐ Jul ☐Aug ☐Sep ☐Oct ☐Nov ☐Dec	_____ meals per ☐ week ☐month *(refer to fish species visual aid)*	_____ oz. per meal *(show meal size visual aid)*
c)	☐Jan ☐Feb ☐Mar ☐Apr ☐May ☐ all the same ☐Jun ☐ don't know ☐ Jul ☐Aug ☐Sep ☐Oct ☐Nov ☐Dec	_____ meals per ☐ week ☐month *(refer to fish species visual aid)*	_____ oz. per meal *(show meal size visual aid)*

d)

☐Jan
☐Feb
☐Mar
☐Apr
☐May
☐Jun
☐ Jul
☐Aug
☐Sep
☐Oct
☐Nov
☐Dec

_____ meals per

☐ week ☐month

☐ all the same

☐ don't know

_____ oz. per meal *(show meal size visual aid)*

(refer to fish species visual aid)

9. Are there any kinds of fish from this river that you won't eat?

☐Yes *(CONTINUE)* ☐No
If yes, **what kind?**

_____

10. *(Ask about these specific fish if they were not mentioned in the question above and point to their pictures on the visual aid)*

Do you ever eat bowfin? ☐Yes ☐No

…chain pickerel? ☐Yes ☐No

…longnose gar? ☐Yes ☐No

…gizzard shad? ☐Yes ☐No

…alewife? ☐Yes ☐No

11. We also want to know if anyone else in your household eats the fish that you catch in the Mattaponi River, so I am going to ask you how many people are in your household. Please include yourself in this count.

A. How many people in your household are…
B. …and how many eat fish from the Mattaponi River?

	A.	**B.**
a) children 5 or younger?		
b) children between the age of 6 and 15?		
c) adults aged 50 or older?		
d) men between the ages of 16 and 49?		
e) women between the ages of 16 and 49?		
f) women who have been pregnant in the last year?		

13. Do you give away any of the fish that you catch in the Mattaponi River?
☐Yes ☐No

14. We would also like to know how often you eat fish that you buy in a store, a market, or a restaurant.

a. On average throughout the year, how often do you eat a meal of fresh or frozen fish or shellfish that you bought in a store, a market, or a restaurant?

_____ meals per ☐week ☐month ☐year ☐ Don't Know

b. How much fresh or frozen fish or shellfish do you typically eat during a meal? *(show visual aid)*

_____ oz. per meal

15a. On average throughout the year, how often do you eat a meal of canned tuna fish?

_____ meals per ☐week ☐month ☐year ☐ Don't Know

b. Do you eat light tuna or white tuna? White tuna is also called albacore tuna.

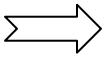
☐light ☐white ☐both ☐ don't know

c. How much canned tuna fish do you typically eat during a meal? *(show visual aid)*

_____ oz. per meal

16. Do you know that there is a fish consumption advisory on this river?

☐Yes ☐No *(skip questions 17 and 18)*



17. How do you know about the advisory?

☐posted signs
☐word of mouth
☐newspaper
☐radio
☐other _____

18. Do you know what the advisory is on this river?

[Because of Mercury No more than two meals/month: Largemouth Bass]

[Because of PCBs] No more than two meals/month: Anadromous (coastal) Striped Bass, White perch, Gizzard Shad]

[High risk individuals such as women who are pregnant or may become pregnant, nursing mothers, and young children are advised not to eat any fish contaminated either with polychlorinated biphenyls (PCBs) or mercury from the respective advisory areas.]

☐Answered correctly ☐Answered incorrectly

⇨ **We are almost done with the survey, but we would like to get information to classify your answers. Remember that all your answers are entirely confidential and anonymous.**

19. What is your zip code? _____

20. How old are you? _____

21. How would you describe your race or ethnicity? *(check all boxes respondent says)*

- ☐ White/Caucasian
- ☐ Black/ African American
- ☐ Asian
- ☐ American Indian/ Native American
- ☐ Other:
- ☐ Hispanic/ Latino

22. What is the highest degree or level of school that you have completed?

- ☐ Less than high school
  if yes **Did you leave school after the eight grade?**
  ☐ Yes ☐ No
- ☐ High School
- ☐ Some College
- ☐ Associates degree
- ☐ Bachelor's degree
- ☐ Master's degree
- ☐ PhD, M.D., or professional degree

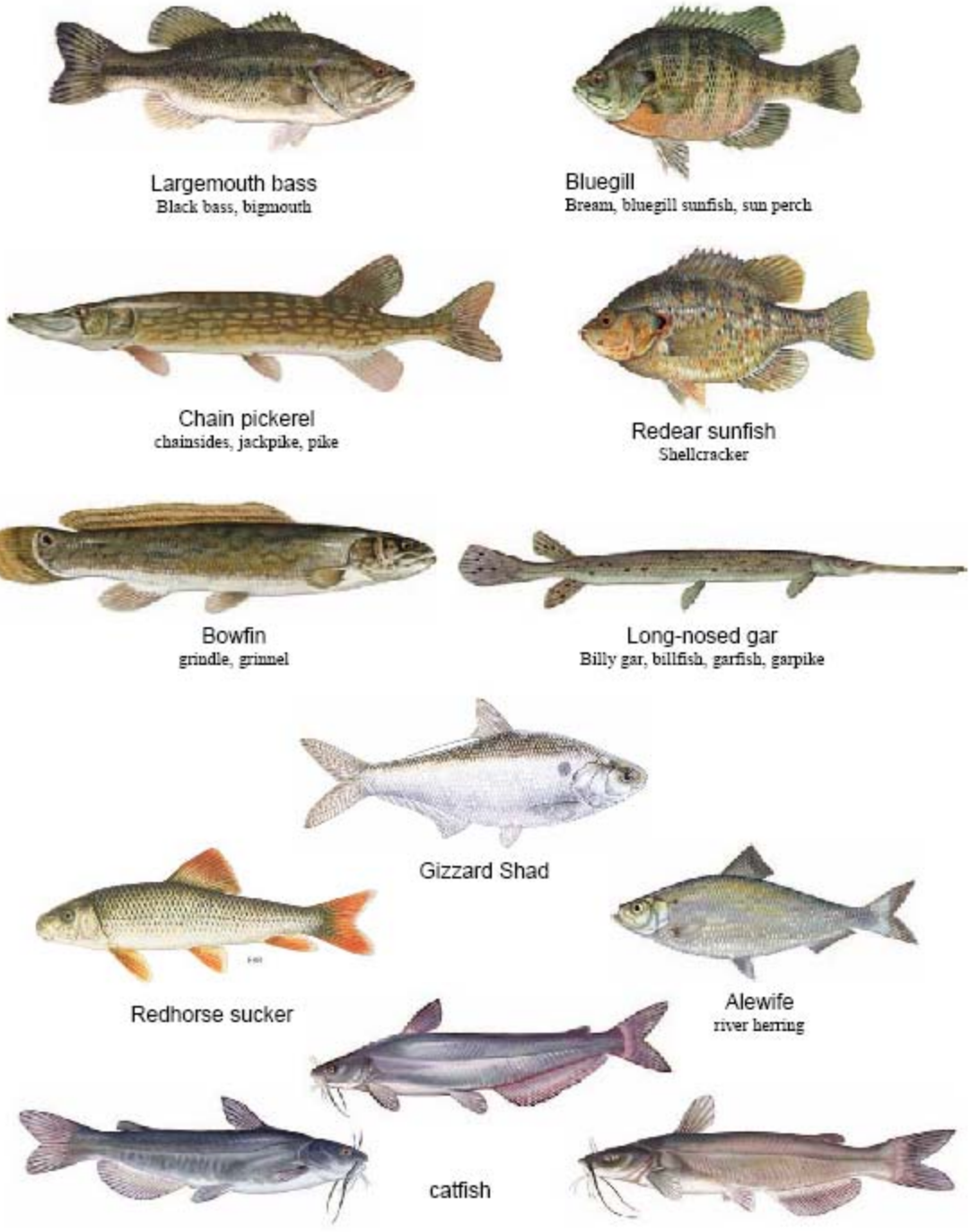
23. What was the total income of your household before taxes last year? Please count all sources, such as wages, salaries, dividends, rents, royalties, etc. If it makes you feel more comfortable, you can look at our categories and indicate what range your household falls in. *(show the page to the respondent)*

- ☐ less than $14,999
- ☐ $15,000 to $24,999
- ☐ $25,000 to $49,999
- ☐ $50,000 to $74,999
- ☐ $75,000 or more

Thank you for participating in the survey.

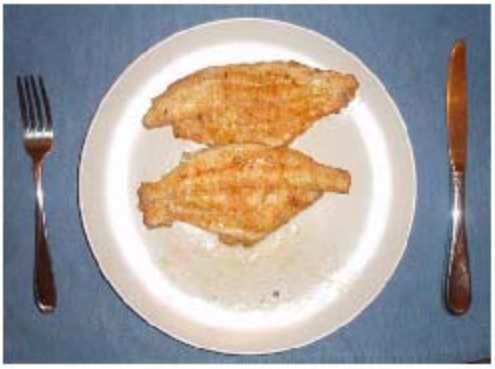
***END OF INTERVIEW*.**

6.2 Fish Species Visual Aid



6.3 Fish Meal Visual Aid

4 oz.



8 oz.

12 oz.

6.4 FORMULAS USED IN ANALYSIS:

Average Daily Intake (µg/kg day $^{-1}$):

$$D = \frac{\sum_{i}^{n} (c_i \times s_i \times f_i)}{W \times a}$$

Where n = number of types (species) of fish eaten
c_i = MeHg concentration for the i^{th} species (ug/g)
s_i = meal size for the i^{th} species (g/meal)
f_i = meal frequency for the i^{th} species (meals/year)
W = body weight (kg)
a = averaging time (365 days)

Blood concentration (µg/L):

$$C = \frac{D \times W \times A \times F}{b \times v}$$

Where D = average daily intake (µg/kg day $^{-1}$)
W = body weight (kg)
A = fraction of ingested MeHg that is absorbed (unitless)
F = fraction of absorbed MeHg that is distributed in the blood (unitless)
b = elimination rate constant (fraction of the concentration eliminated per day (day $^{-1}$)
v = blood volume (L)

Hair Concentration (µg/g):

$$H = C \; x \; R$$

Where C = blood concentration
R = conversion ratio ((µg/g)/(µg/L))

IQ points lost:

$$IQ = \beta \times H_{m0}$$

Where β = slope of the dose response function
H_{m0} = maternal hair concentrations in time 0 (baseline)

Change in IQ points:

$$\Delta IQ = \beta \times \left(H_{m1} - H_{m0}\right)$$

Where β = slope of the dose response function
H_{m1} = maternal hair concentrations in time 1(future)
H_{m0} = maternal hair concentrations in time 0

Conversion Factors:
1 ounce = 28.35 grams
1 month = 4.35 weeks
1 month = 30.44 days
1 year = 365 days

6.5 FISH GROUPINGS USED IN ANALYSIS

Entered Name	Group Name
bass	largemouth bass
blue gill	sunfish
bluegill	sunfish
brim	sunfish
catfish	catfish
crab	blue crab
crappie	sunfish
croaker	spot or croaker
large mouth bass	largemouth bass
largemouth bass	largemouth bass
largemouth small bass	largemouth bass
perch	yellow perch
redear	sunfish
Redhorse sucker	sucker
rockfish	striped bass
sea trout	spot or croaker
spot	spot or croaker
stiffback perch	white perch
striped bass	striped bass
striper	striped bass
sunfish family	sunfish
white perch	white perch

6.6 FISH TISSUE MERCURY CONCENTRATIONS

River	Fish	Hg	2010	2018
James	catfish	0.223	0.16	0.153
James	catfish	0.411	0.295	0.282
James	catfish	0.261	0.188	0.179
James	catfish	0.01	0.007	0.007
James	catfish	0.04	0.029	0.027
James	catfish	0.02	0.014	0.014
James	catfish	0.143	0.103	0.098
James	catfish	0.11	0.079	0.075
James	catfish	0.21	0.151	0.144
James	catfish	0.06	0.043	0.041
James	catfish	0.16	0.115	0.11
James	catfish	0.12	0.086	0.082
James	catfish	0.02	0.014	0.014
James	catfish	0.737	0.53	0.505
James	catfish	0.07	0.05	0.048
James	catfish	0.09	0.065	0.062
James	catfish	0.13	0.093	0.089
James	catfish	0.12	0.086	0.082
James	catfish	0.1	0.072	0.069
James	catfish	0.08	0.057	0.055
James	catfish	0.08	0.057	0.055
James	catfish	0.06	0.043	0.041
James	catfish	0.16	0.115	0.11
James	catfish	0.05	0.036	0.034
James	catfish	0.05	0.036	0.034
Chickahominy	catfish	0.73	0.591	0.576
Chickahominy	catfish	0.05	0.04	0.039
Chickahominy	catfish	0.05	0.04	0.039
Pamunkey	catfish	0.01	0.008	0.008
Pamunkey	catfish	0.1	0.081	0.078
Pamunkey	catfish	0.73	0.589	0.572
Pamunkey	catfish	0.01	0.008	0.008
Pamunkey	catfish	0.063	0.051	0.049
Pamunkey	catfish	0.483	0.389	0.378
Pamunkey	catfish	0.01	0.008	0.008
Pamunkey	catfish	0.256	0.206	0.2
Pamunkey	catfish	0.038	0.031	0.03
Pamunkey	catfish	0.233	0.188	0.182
Mattaponi	catfish	0.013	0.011	0.01
Mattaponi	catfish	0.376	0.305	0.295
Mattaponi	catfish	0.077	0.063	0.06
Mattaponi	catfish	0.142	0.115	0.112
Mattaponi	catfish	0.143	0.116	0.112
Dragon-Piank	catfish	0.06	0.049	0.048
Dragon-Piank	catfish	0.22	0.18	0.175
Dragon-Piank	catfish	0.3	0.246	0.239
Dragon-Piank	catfish	0.047	0.039	0.037
Dragon-Piank	catfish	0.01	0.008	0.008
Dragon-Piank	catfish	0.26	0.213	0.207
Dragon-Piank	catfish	0.31	0.254	0.247
Dragon-Piank	catfish	0.078	0.064	0.062
Dragon-Piank	catfish	0.21	0.172	0.167
Dragon-Piank	catfish	0.1	0.082	0.08
Dragon-Piank	catfish	0.288	0.236	0.23
Dragon-Piank	catfish	0.209	0.171	0.167
Dragon-Piank	catfish	0.211	0.173	0.168

River	Fish	Hg	2010	2018
James	largemouth bass	0.102	0.073	0.07
James	largemouth bass	0.06	0.043	0.041
James	largemouth bass	0.44	0.316	0.301
James	largemouth bass	0.52	0.374	0.356
Chickahominy	largemouth bass	0.08	0.065	0.063
Chickahominy	largemouth bass	0.72	0.583	0.568
Chickahominy	largemouth bass	0.56	0.453	0.442
Chickahominy	largemouth bass	0.72	0.583	0.568
Chickahominy	largemouth bass	0.14	0.113	0.11
Chickahominy	largemouth bass	0.17	0.138	0.134
Chickahominy	largemouth bass	0.7	0.567	0.552
Chickahominy	largemouth bass	0.58	0.47	0.457
Chickahominy	largemouth bass	0.03	0.024	0.024
Chickahominy	largemouth bass	0.14	0.113	0.11
Pamunkey	largemouth bass	0.211	0.17	0.165
Pamunkey	largemouth bass	0.303	0.244	0.237
Pamunkey	largemouth bass	0.088	0.071	0.069
Pamunkey	largemouth bass	0.477	0.385	0.373
Pamunkey	largemouth bass	0.925	0.746	0.724
Mattaponi	largemouth bass	1.47	1.194	1.154
Mattaponi	largemouth bass	0.577	0.469	0.453
Mattaponi	largemouth bass	0.896	0.728	0.704
Dragon-Piank	largemouth bass	0.34	0.279	0.271
Dragon-Piank	largemouth bass	0.7	0.574	0.558
Dragon-Piank	largemouth bass	0.72	0.59	0.574
Dragon-Piank	largemouth bass	0.54	0.443	0.43
Dragon-Piank	largemouth bass	0.16	0.131	0.128
Dragon-Piank	largemouth bass	0.79	0.648	0.63
Dragon-Piank	largemouth bass	0.71	0.582	0.566
Dragon-Piank	largemouth bass	0.53	0.435	0.423
Dragon-Piank	largemouth bass	0.08	0.066	0.064
Dragon-Piank	largemouth bass	0.91	0.746	0.725
Dragon-Piank	largemouth bass	0.58	0.476	0.462
Dragon-Piank	largemouth bass	0.15	0.123	0.12
Dragon-Piank	largemouth bass	1.9	1.558	1.515
Dragon-Piank	largemouth bass	0.59	0.484	0.47
Dragon-Piank	largemouth bass	0.57	0.467	0.454
Dragon-Piank	largemouth bass	0.1	0.082	0.08
Dragon-Piank	largemouth bass	0.047	0.039	0.037
Dragon-Piank	largemouth bass	0.09	0.074	0.072
Dragon-Piank	largemouth bass	0.71	0.582	0.566
Dragon-Piank	largemouth bass	0.05	0.041	0.04
Dragon-Piank	largemouth bass	0.7	0.574	0.558
Dragon-Piank	largemouth bass	0.14	0.115	0.112
Dragon-Piank	largemouth bass	0.37	0.303	0.295
Dragon-Piank	largemouth bass	0.41	0.336	0.327
Dragon-Piank	largemouth bass	0.29	0.238	0.231
Dragon-Piank	largemouth bass	0.35	0.287	0.279
Dragon-Piank	largemouth bass	0.72	0.59	0.574
Dragon-Piank	largemouth bass	0.21	0.172	0.167
Dragon-Piank	largemouth bass	0.48	0.394	0.383
Dragon-Piank	largemouth bass	0.14	0.115	0.112
Dragon-Piank	largemouth bass	0.25	0.205	0.199
Dragon-Piank	largemouth bass	0.1	0.082	0.08
Dragon-Piank	largemouth bass	0.48	0.394	0.383
Dragon-Piank	largemouth bass	0.31	0.254	0.247
Dragon-Piank	largemouth bass	0.08	0.066	0.064
Dragon-Piank	largemouth bass	0.06	0.049	0.048
Dragon-Piank	largemouth bass	0.149	0.122	0.119

River	Fish	Hg	2010	2018
Pamunkey	spot-croaker	0.246	0.198	0.193
Mattaponi	spot-croaker	0.024	0.019	0.019
Mattaponi	spot-croaker	0.022	0.018	0.017
Mattaponi	spot-croaker	0.062	0.051	0.049
Mattaponi	spot-croaker	0.131	0.106	0.102
Mattaponi	spot-croaker	0.051	0.041	0.04

River	Fish	Hg	2010	2018
James	sucker	0.13	0.093	0.089
James	sucker	0.284	0.204	0.195
James	sucker	0.169	0.121	0.116
James	sucker	0.159	0.114	0.109
Chickahominy	sucker	0.25	0.202	0.197
Chickahominy	sucker	0.21	0.17	0.166
Pamunkey	sucker	0.02	0.016	0.016
Dragon-Piank	sucker	0.17	0.139	0.136
Dragon-Piank	sucker	0.27	0.221	0.215
Dragon-Piank	sucker	0.07	0.057	0.056
Dragon-Piank	sucker	0.15	0.123	0.12

River	Fish	Hg	2010	2018
James	sunfish	0.087	0.063	0.06
James	sunfish	0.01	0.007	0.007
James	sunfish	0.01	0.007	0.007
James	sunfish	0.04	0.029	0.027
James	sunfish	0.01	0.007	0.007
James	sunfish	0.01	0.007	0.007
Chickahominy	sunfish	0.13	0.105	0.103
Chickahominy	sunfish	0.31	0.251	0.244
Chickahominy	sunfish	0.09	0.073	0.071
Chickahominy	sunfish	0.1	0.081	0.079
Chickahominy	sunfish	0.08	0.065	0.063
Chickahominy	sunfish	0.36	0.291	0.284
Chickahominy	sunfish	0.01	0.008	0.008
Chickahominy	sunfish	0.05	0.04	0.039
Pamunkey	sunfish	0.01	0.008	0.008
Pamunkey	sunfish	0.367	0.296	0.287
Pamunkey	sunfish	0.01	0.008	0.008
Pamunkey	sunfish	0.013	0.01	0.01
Pamunkey	sunfish	0.038	0.031	0.03
Pamunkey	sunfish	0.109	0.088	0.085
Mattaponi	sunfish	0.24	0.195	0.188
Mattaponi	sunfish	0.21	0.171	0.165
Dragon-Piank	sunfish	0.39	0.32	0.311
Dragon-Piank	sunfish	0.2	0.164	0.159
Dragon-Piank	sunfish	0.42	0.344	0.335
Dragon-Piank	sunfish	0.27	0.221	0.215
Dragon-Piank	sunfish	0.31	0.254	0.247
Dragon-Piank	sunfish	0.089	0.073	0.071
Dragon-Piank	sunfish	0.082	0.067	0.065
Dragon-Piank	sunfish	0.14	0.115	0.112
Dragon-Piank	sunfish	0.21	0.172	0.167
Dragon-Piank	sunfish	0.17	0.139	0.136
Dragon-Piank	sunfish	0.07	0.057	0.056
Dragon-Piank	sunfish	0.01	0.008	0.008
Dragon-Piank	sunfish	0.155	0.127	0.124

River	Fish	Hg	2010	2018
James	striped bass	0.435	0.313	0.298
James	striped bass	0.314	0.226	0.215
James	striped bass	0.284	0.204	0.195
James	striped bass	0.147	0.106	0.101
James	striped bass	0.11	0.079	0.075
James	striped bass	0.09	0.065	0.062
James	striped bass	0.18	0.129	0.123
James	striped bass	0.21	0.151	0.144
James	striped bass	0.43	0.309	0.295
James	striped bass	0.01	0.007	0.007
James	striped bass	0.01	0.007	0.007
James	striped bass	0.64	0.46	0.438
James	striped bass	0.11	0.079	0.075
James	striped bass	0.09	0.065	0.062
James	striped bass	0.07	0.05	0.048
James	striped bass	0.13	0.093	0.089
James	striped bass	0.1	0.072	0.069
James	striped bass	0.09	0.065	0.062
James	striped bass	0.15	0.108	0.103
James	striped bass	0.14	0.101	0.096
James	striped bass	0.09	0.065	0.062
James	striped bass	0.11	0.079	0.075
James	striped bass	0.24	0.172	0.164
James	striped bass	0.09	0.065	0.062
James	striped bass	0.14	0.101	0.096
James	striped bass	0.12	0.086	0.082
James	striped bass	0.16	0.115	0.11
James	striped bass	0.04	0.029	0.027
James	striped bass	0.12	0.086	0.082
James	striped bass	0.12	0.086	0.082
James	striped bass	0.12	0.086	0.082
James	striped bass	0.15	0.108	0.103
James	striped bass	0.19	0.137	0.13
James	striped bass	0.11	0.079	0.075
James	striped bass	0.19	0.137	0.13
James	striped bass	0.07	0.05	0.048
James	striped bass	0.17	0.122	0.116
James	striped bass	0.08	0.057	0.055
James	striped bass	0.27	0.194	0.185
James	striped bass	0.09	0.065	0.062
James	striped bass	0.09	0.065	0.062
James	striped bass	0.07	0.05	0.048
James	striped bass	0.09	0.065	0.062
James	striped bass	0.08	0.057	0.055
James	striped bass	0.05	0.036	0.034
James	striped bass	0.04	0.029	0.027
James	striped bass	0.04	0.029	0.027
James	striped bass	0.04	0.029	0.027
James	striped bass	0.08	0.057	0.055
Chickahominy	striped bass	0.06	0.049	0.047
Chickahominy	striped bass	0.15	0.121	0.118
Chickahominy	striped bass	0.12	0.097	0.095
Chickahominy	striped bass	0.07	0.057	0.055
Chickahominy	striped bass	0.08	0.065	0.063
Mattaponi	striped bass	0.144	0.117	0.113
Mattaponi	striped bass	0.01	0.008	0.008

River	Fish	Hg	2010	2018
James	white perch	0.01	0.01	0.01
James	white perch	0.03	0.02	0.02
Pamunkey	white perch	0.02	0.02	0.02
Pamunkey	white perch	0.02	0.01	0.01
Pamunkey	white perch	0.01	0.01	0.01
Pamunkey	white perch	0.35	0.28	0.27
Mattaponi	white perch	0.03	0.02	0.02
Mattaponi	white perch	0.16	0.13	0.13
Dragon-Piank	white perch	0.05	0.04	0.04
Dragon-Piank	white perch	0.36	0.3	0.29
Dragon-Piank	white perch	0.22	0.18	0.18
Dragon-Piank	white perch	0.01	0.01	0.01
Dragon-Piank	white perch	0.09	0.07	0.07
Dragon-Piank	white perch	0.22	0.18	0.17

River	Fish	Hg	2010	2018
Mattaponi	yellow perch	0.375	0.3045	0.294
Dragon-Piank	yellow perch	0.2	0.164	0.159
Dragon-Piank	yellow perch	0.21	0.1722	0.167
Dragon-Piank	yellow perch	0.26	0.2132	0.207
Dragon-Piank	yellow perch	0.269	0.2206	0.214

Tuna Concentrations

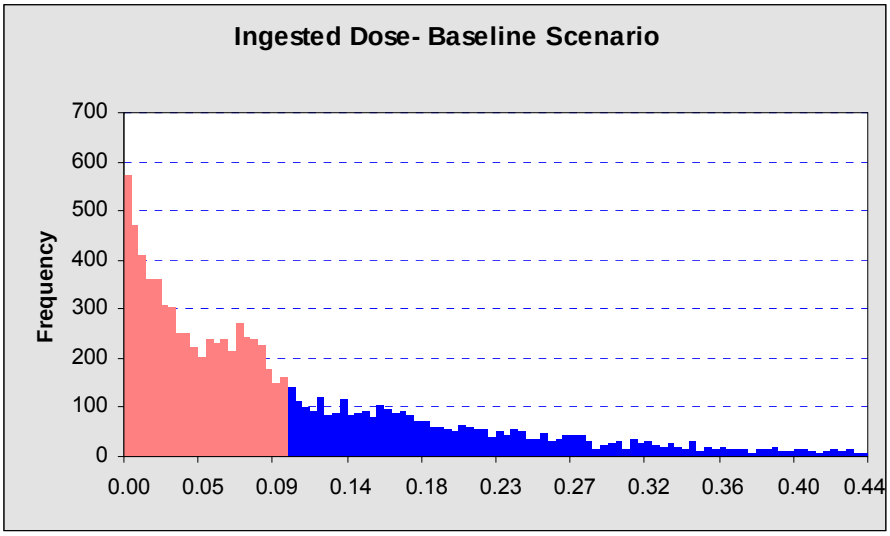
light	albacore
0.007	0.015
0.007	0.015
0.007	0.030
0.007	0.035
0.007	0.046
0.013	0.070
0.028	0.090
0.030	0.090
0.032	0.100
0.035	0.169
0.040	0.172
0.040	0.188
0.040	0.190
0.040	0.207
0.040	0.216
0.040	0.220
0.043	0.229
0.043	0.230
0.043	0.231
0.044	0.232
0.044	0.236
0.045	0.240
0.048	0.240
0.048	0.250
0.048	0.250
0.050	0.250
0.050	0.252
0.050	0.258
0.050	0.260
0.050	0.260
0.050	0.260
0.050	0.260
0.050	0.260
0.050	0.260
0.051	0.260
0.052	0.263
0.052	0.264
0.053	0.265
0.053	0.267
0.054	0.268
0.057	0.269
0.059	0.270
0.059	0.270
0.060	0.270
0.060	0.272
0.060	0.273
0.060	0.274
0.060	0.280
0.060	0.280
0.060	0.280
0.061	0.280
0.061	0.282
0.062	0.285
0.069	0.286
0.070	0.288
0.070	0.289
0.070	0.290
0.070	0.290
0.070	0.290
0.070	0.290
0.070	0.290
0.070	0.294
0.071	0.296
0.073	0.296
0.076	0.298
0.077	0.300
0.080	0.300
0.080	0.300
0.080	0.300
0.080	0.300
0.080	0.308
0.080	0.310
0.080	0.310
0.080	0.314

MARKET SHARE AND MERCURY CONCENTRATION OF PURCHASED FISH

SPECIES	% OF SEAFOOD MARKET	cumulative frequency	MEAN HG CONC PPM
Shrimp	0.18610	0.186096	0.012
Pollock	0.13582	0.321919	0.067
Salmon	0.10128	0.423202	0.028
Haddock, Hake, and Monkfish	0.06576	0.488963	0.17
Catfish	0.05863	0.547594	0.066
Cod	0.05789	0.605488	0.143
Crabs	0.05777	0.663258	0.063
Flatfish	0.04437	0.707631	0.059
Anchovies, Herring, and Shad	0.03761	0.745244	0.05
Tilapia	0.02299	0.768229	0.02
Tuna, Fresh	0.02200	0.790231	0.378
Clams	0.02077	0.811004	0.017
Lobsters, American	0.01586	0.826861	0.31
Oysters and Mussels	0.01524	0.842102	0.017
Sardines	0.01512	0.857221	0.016
Squid	0.01266	0.869881	0.07
Other	0.01192	0.881804	0.085
Lingcod and Scorpionfish	0.01131	0.893113	0.286
Halibut	0.01106	0.904175	0.217
Lobsters, Spiny	0.01008	0.914254	0.121
Scallops	0.00983	0.924088	0.017
Perch, Ocean and Mullet	0.00848	0.932569	0.04
Trout, Freshwater	0.00848	0.941050	0.030
Bass, Saltwater	0.00750	0.948548	0.263
Crawfish	0.00688	0.955431	0.027
Snapper, Porgy, and Sheepshead	0.00664	0.962069	0.141
Swordfish	0.00516	0.967231	0.969
Skate	0.00418	0.971411	0.137
Croaker, Atlantic	0.00369	0.975098	0.055
Mackerel, Atlantic	0.00350	0.978601	0.049
Sablefish	0.00307	0.981674	0.273
Whitefish	0.00270	0.984378	0.068
Orange Roughy	0.00246	0.986837	0.540
Grouper	0.00209	0.988926	0.549
Mackerel, Chub	0.00207	0.990991	0.088
Butterfish	0.00172	0.992712	0.0580
Shark	0.00160	0.994310	0.988
Pike	0.00123	0.995539	0.056
Bluefish	0.00111	0.996645	0.324
Trout, Saltwater	0.00074	0.997383	0.269
Mackerel, King	0.00061	0.997997	0.73
Mackerel, Spanish	0.00058	0.998575	0.368
Perch, Freshwater	0.00049	0.999067	0.162
Tilefish, Atlantic	0.00032	0.999386	0.123
Marlin	0.00025	0.999632	0.489
Carp and Buffalofish	0.00025	0.999878	0.203
Tilefish, Gulf	0.00007	0.999951	1.450
Croaker, Pacific	0.00002	0.999975	0.303
Bass, Freshwater	0.00001	0.999988	0.318
Smelt	0.00001	1.000000	0.092

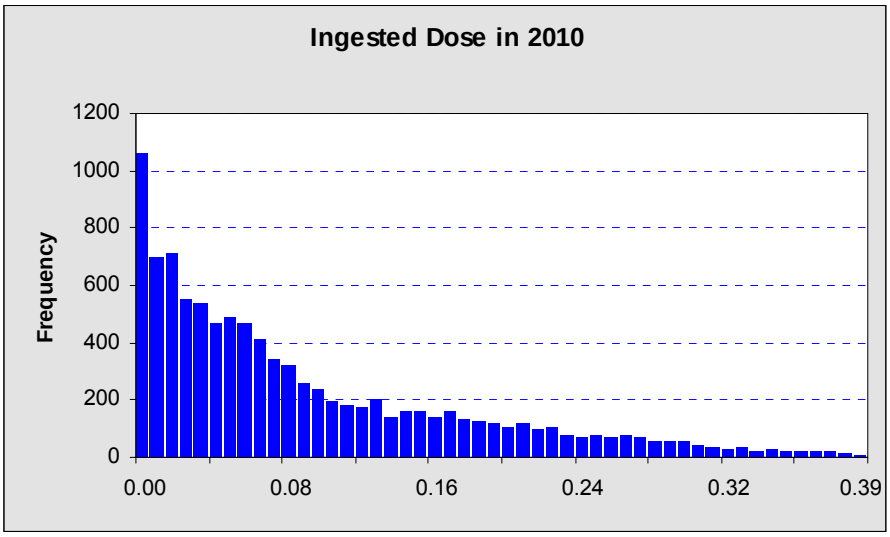
6.7 EXAMPLE OF DISTRIBUTIONS FROM CRYSTAL BALL ®

Results for Model 2:
Women 16 – 49, assumptions from Stern 2005, Outcome = Loss of IQ points



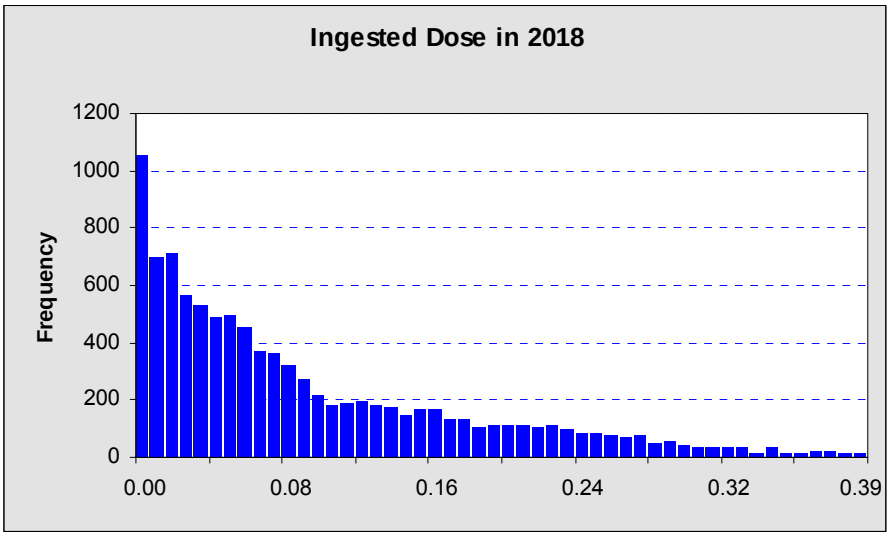
Statistics:	Forecast values
Trials	10,000
Mean	0.11
Median	0.07
Mode	---
Standard Deviation	0.12
Variance	0.01
Skewness	1.78
Kurtosis	6.56
Coeff. of Variability	1.06
Minimum	0.00
Maximum	0.92
Range Width	0.92
Mean Std. Error	0.00

Percentiles:	Forecast values
0%	0.00
10%	0.01
20%	0.02
30%	0.03
40%	0.05
50%	0.07
60%	0.10
70%	0.13
80%	0.19
90%	0.28
100%	0.92



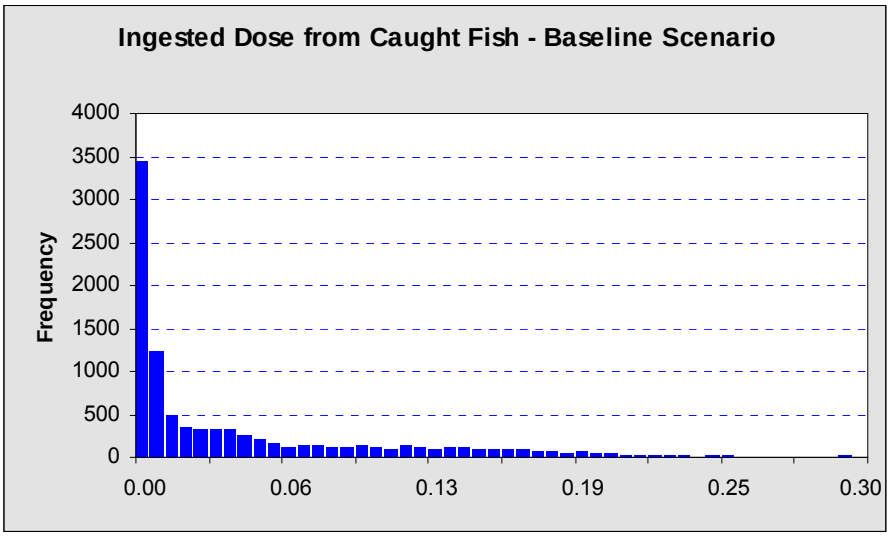
Statistics:	Forecast values
Trials	10,000
Mean	0.10
Median	0.06
Mode	---
Standard Deviation	0.11
Variance	0.01
Skewness	1.90
Kurtosis	7.83
Coeff. of Variability	1.05
Minimum	0.00
Maximum	0.91
Range Width	0.91
Mean Std. Error	0.00

Percentiles:	Forecast values
0%	0.00
10%	0.01
20%	0.02
30%	0.03
40%	0.05
50%	0.06
60%	0.09
70%	0.12
80%	0.17
90%	0.24
100%	0.91



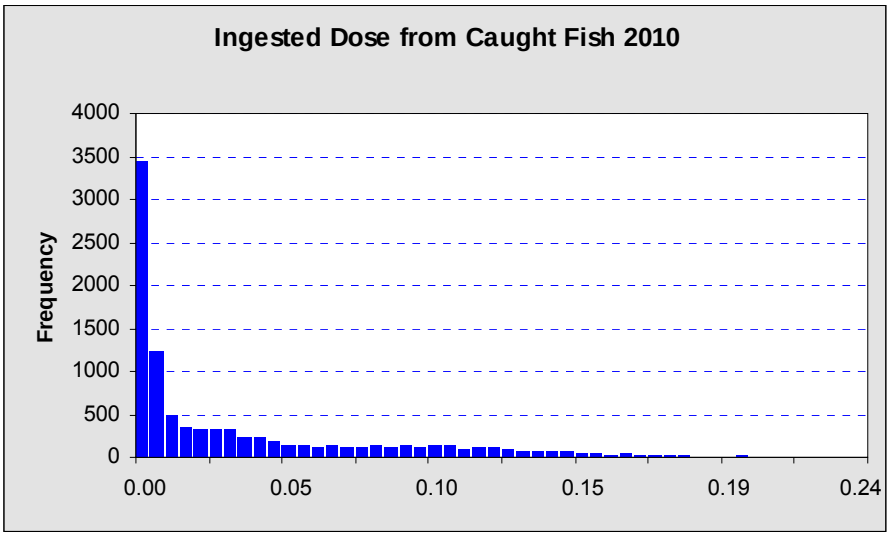
Statistics:	Forecast values
Trials	10,000
Mean	0.10
Median	0.06
Mode	---
Standard Deviation	0.10
Variance	0.01
Skewness	1.92
Kurtosis	8.08
Coeff. of Variability	1.05
Minimum	0.00
Maximum	0.91
Range Width	0.91
Mean Std. Error	0.00

Percentiles:	Forecast values
0%	0.00
10%	0.01
20%	0.02
30%	0.03
40%	0.05
50%	0.06
60%	0.09
70%	0.12
80%	0.17
90%	0.24
100%	0.91



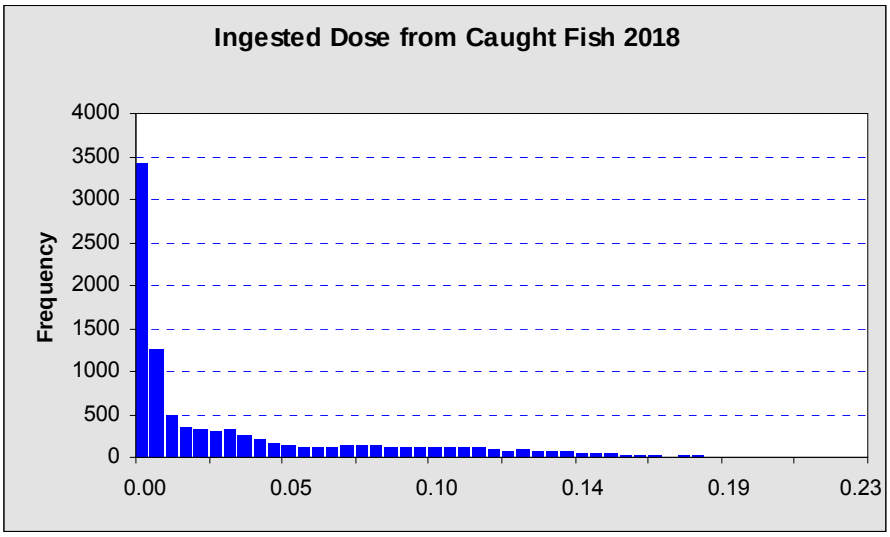
Statistics:	Forecast values
Trials	10,000
Mean	0.06
Median	0.02
Mode	---
Standard Deviation	0.09
Variance	0.01
Skewness	2.74
Kurtosis	12.17
Coeff. of Variability	1.57
Minimum	0.00
Maximum	0.73
Range Width	0.73
Mean Std. Error	0.00

Percentiles:	Forecast values
0%	0.00
10%	0.00
20%	0.00
30%	0.01
40%	0.01
50%	0.02
60%	0.03
70%	0.06
80%	0.10
90%	0.16
100%	0.73



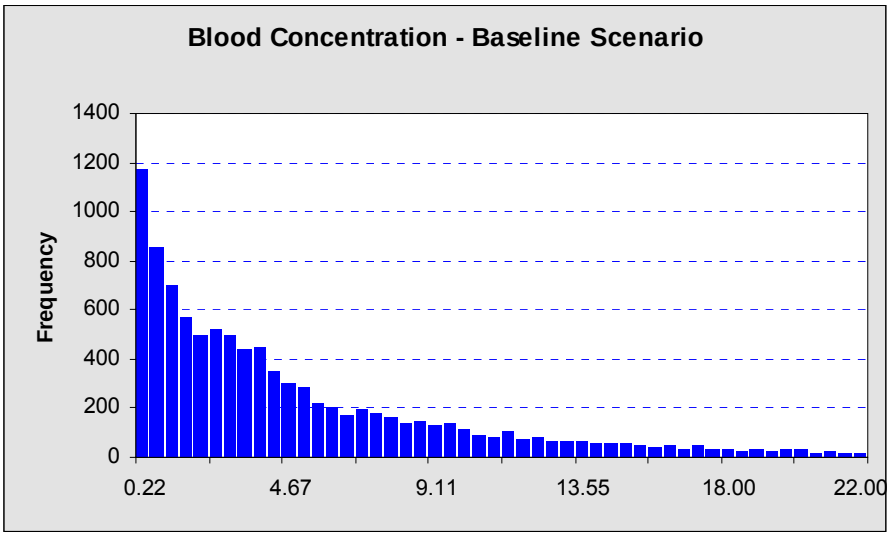
	Forecast values
Trials	10,000
Mean	0.04
Median	0.01
Mode	---
Standard Deviation	0.07
Variance	0.00
Skewness	2.76
Kurtosis	12.28
Coeff. of Variability	1.56
Minimum	0.00
Maximum	0.55
Range Width	0.55
Mean Std. Error	0.00

	Forecast values
0%	0.00
10%	0.00
20%	0.00
30%	0.00
40%	0.01
50%	0.01
60%	0.03
70%	0.04
80%	0.08
90%	0.12
100%	0.55



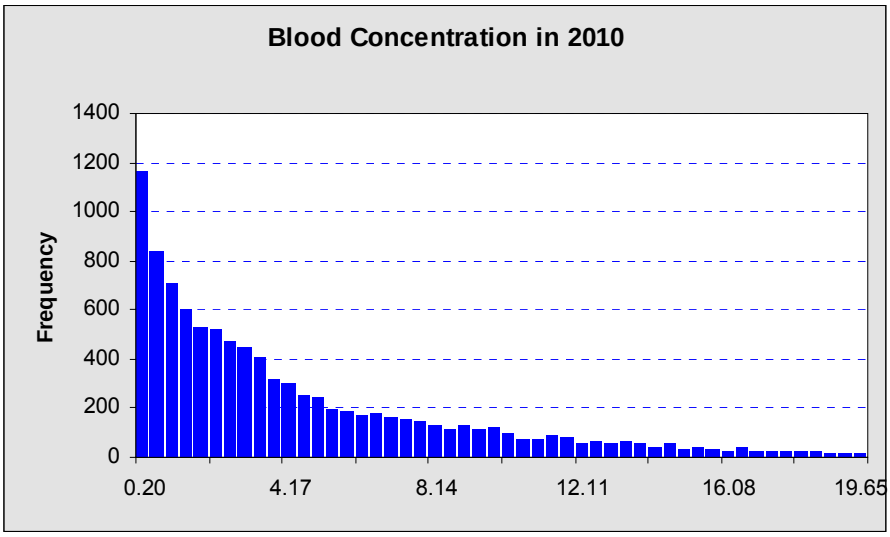
	Forecast values
Trials	10,000
Mean	0.04
Median	0.01
Mode	---
Standard Deviation	0.07
Variance	0.00
Skewness	2.74
Kurtosis	12.20
Coeff. of Variability	1.56
Minimum	0.00
Maximum	0.53
Range Width	0.53
Mean Std. Error	0.00

	Forecast values
0%	0.00
10%	0.00
20%	0.00
30%	0.00
40%	0.01
50%	0.01
60%	0.03
70%	0.04
80%	0.08
90%	0.12
100%	0.53



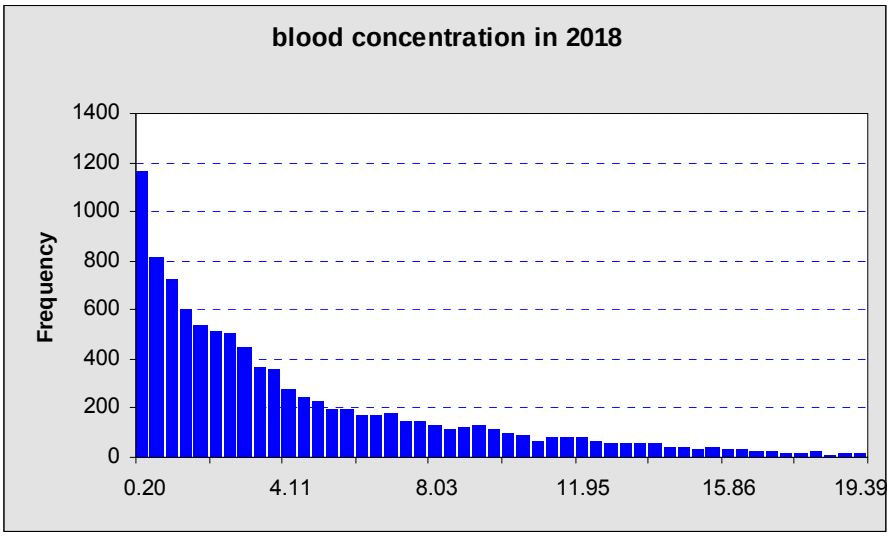
	Forecast values
Trials	10,000
Mean	5.34
Median	3.31
Mode	---
Standard Deviation	6.03
Variance	36.32
Skewness	2.11
Kurtosis	8.74
Coeff. of Variability	1.13
Minimum	0.00
Maximum	54.07
Range Width	54.07
Mean Std. Error	0.06

	Forecast values
0%	0.00
10%	0.37
20%	0.88
30%	1.55
40%	2.39
50%	3.31
60%	4.35
70%	6.07
80%	8.71
90%	13.31
100%	54.07



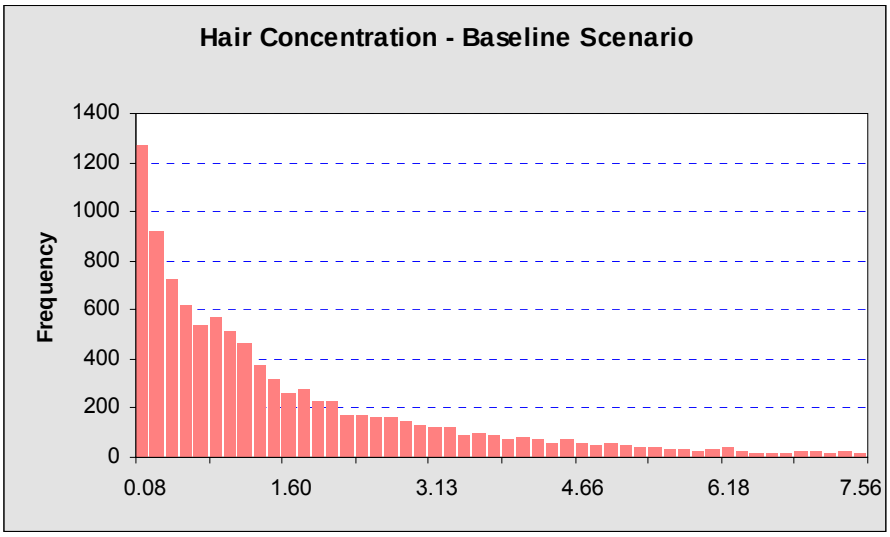
	Forecast values
Trials	10,000
Mean	4.77
Median	2.92
Mode	---
Standard Deviation	5.39
Variance	29.01
Skewness	2.28
Kurtosis	10.73
Coeff. of Variability	1.13
Minimum	0.00
Maximum	54.33
Range Width	54.32
Mean Std. Error	0.05

	Forecast values
0%	0.00
10%	0.32
20%	0.80
30%	1.39
40%	2.09
50%	2.92
60%	3.96
70%	5.54
80%	7.92
90%	11.79
100%	54.33



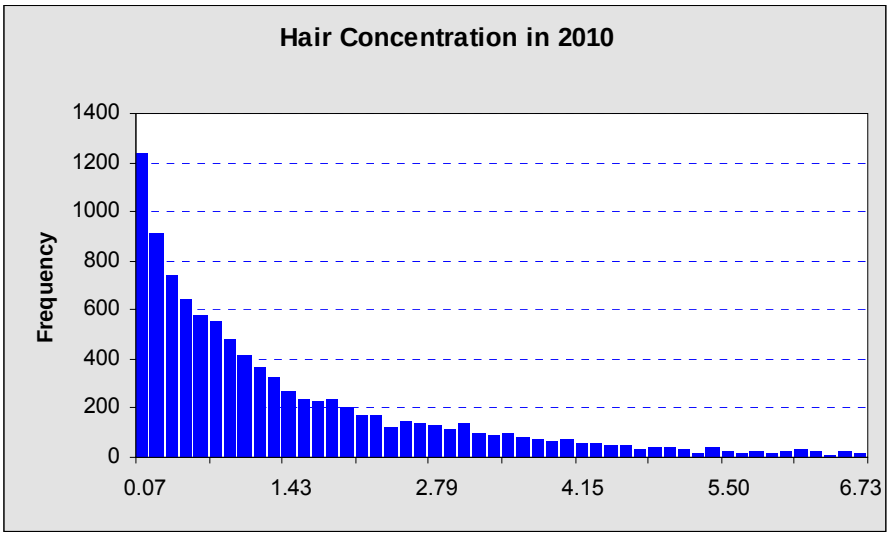
	Forecast values
Trials	10,000
Mean	4.71
Median	2.86
Mode	---
Standard Deviation	5.31
Variance	28.23
Skewness	2.30
Kurtosis	10.94
Coeff. of Variability	1.13
Minimum	0.00
Maximum	54.09
Range Width	54.09
Mean Std. Error	0.05

	Forecast values
0%	0.00
10%	0.32
20%	0.79
30%	1.36
40%	2.09
50%	2.86
60%	3.89
70%	5.51
80%	7.83
90%	11.59
100%	54.09



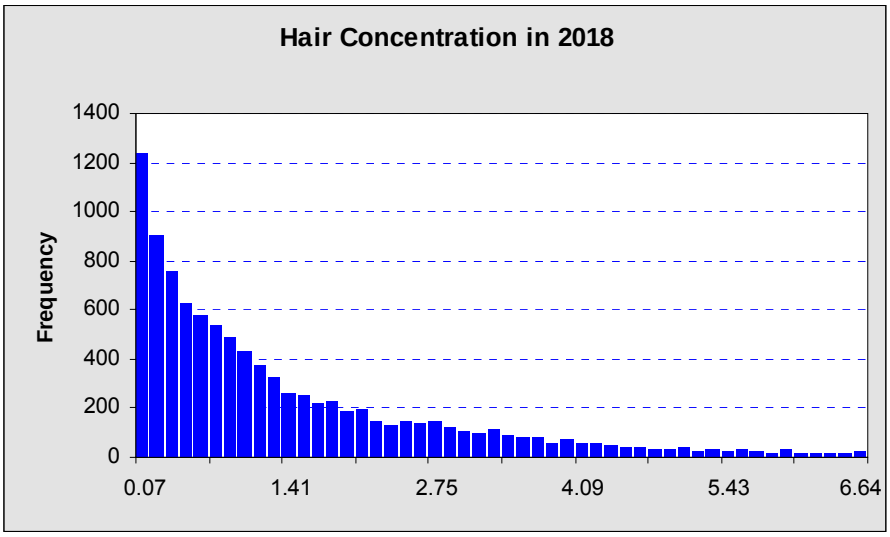
	Forecast values
Trials	10,000
Mean	1.75
Median	1.03
Mode	---
Standard Deviation	2.10
Variance	4.41
Skewness	2.54
Kurtosis	12.52
Coeff. of Variability	1.20
Minimum	0.00
Maximum	22.08
Range Width	22.08
Mean Std. Error	0.02

	Forecast values
0%	0.00
10%	0.11
20%	0.27
30%	0.48
40%	0.74
50%	1.03
60%	1.39
70%	1.94
80%	2.80
90%	4.34
100%	22.08



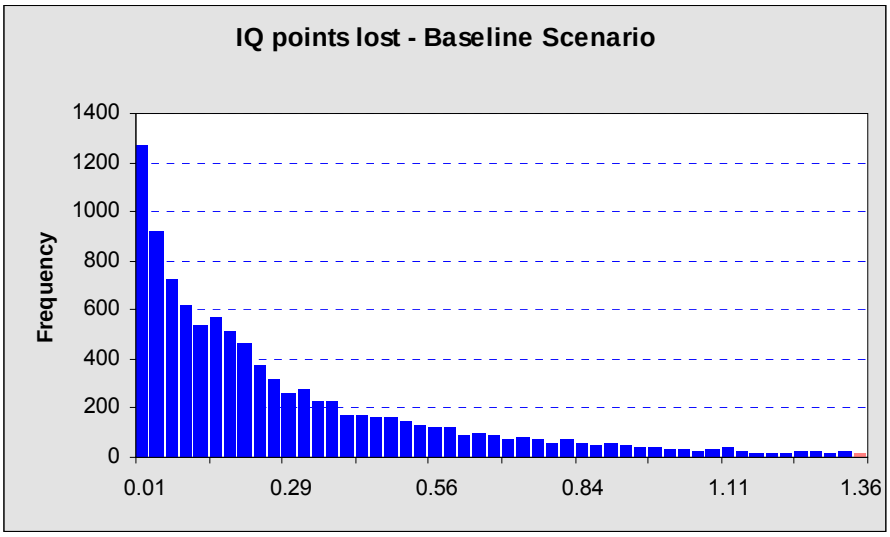
	Forecast values
Trials	10,000
Mean	1.56
Median	0.91
Mode	---
Standard Deviation	1.87
Variance	3.49
Skewness	2.65
Kurtosis	14.05
Coeff. of Variability	1.20
Minimum	0.00
Maximum	21.99
Range Width	21.99
Mean Std. Error	0.02

	Forecast values
0%	0.00
10%	0.10
20%	0.25
30%	0.43
40%	0.65
50%	0.91
60%	1.25
70%	1.78
80%	2.55
90%	3.83
100%	21.99



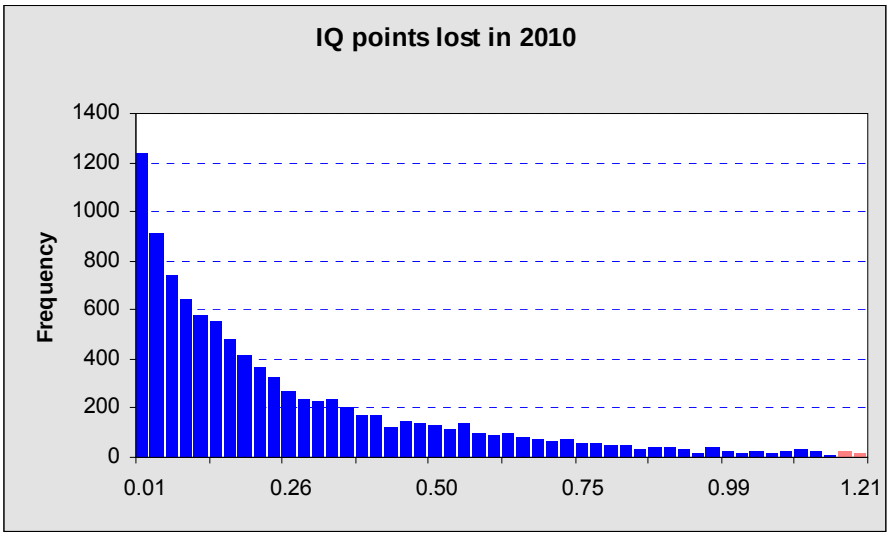
	Forecast values
Trials	10,000
Mean	1.54
Median	0.90
Mode	---
Standard Deviation	1.85
Variance	3.41
Skewness	2.70
Kurtosis	14.74
Coeff. of Variability	1.20
Minimum	0.00
Maximum	22.03
Range Width	22.03
Mean Std. Error	0.02

	Forecast values
0%	0.00
10%	0.10
20%	0.24
30%	0.42
40%	0.65
50%	0.90
60%	1.24
70%	1.75
80%	2.53
90%	3.74
100%	22.03



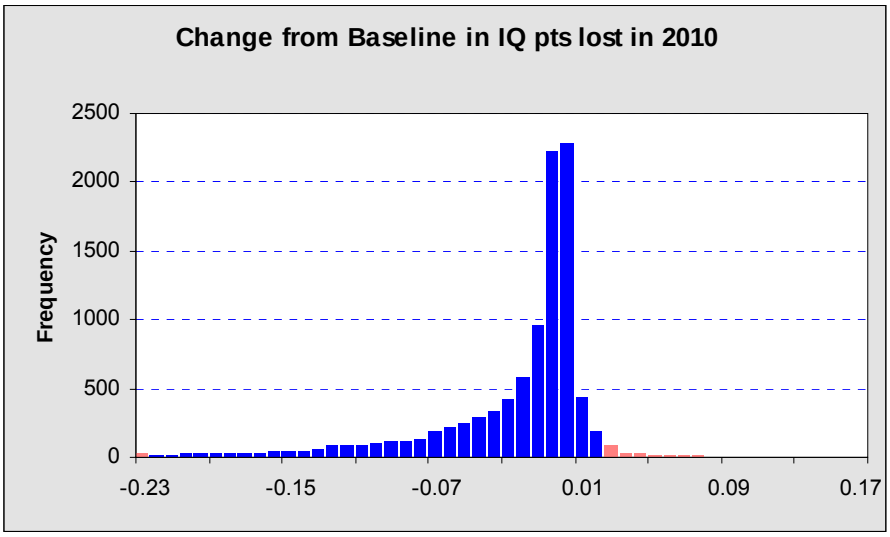
	Forecast values
Trials	10,000
Mean	0.32
Median	0.19
Mode	---
Standard Deviation	0.38
Variance	0.14
Skewness	2.54
Kurtosis	12.52
Coeff. of Variability	1.20
Minimum	0.00
Maximum	3.98
Range Width	3.97
Mean Std. Error	0.00

	Forecast values
0%	0.00
10%	0.02
20%	0.05
30%	0.09
40%	0.13
50%	0.19
60%	0.25
70%	0.35
80%	0.50
90%	0.78
100%	3.98



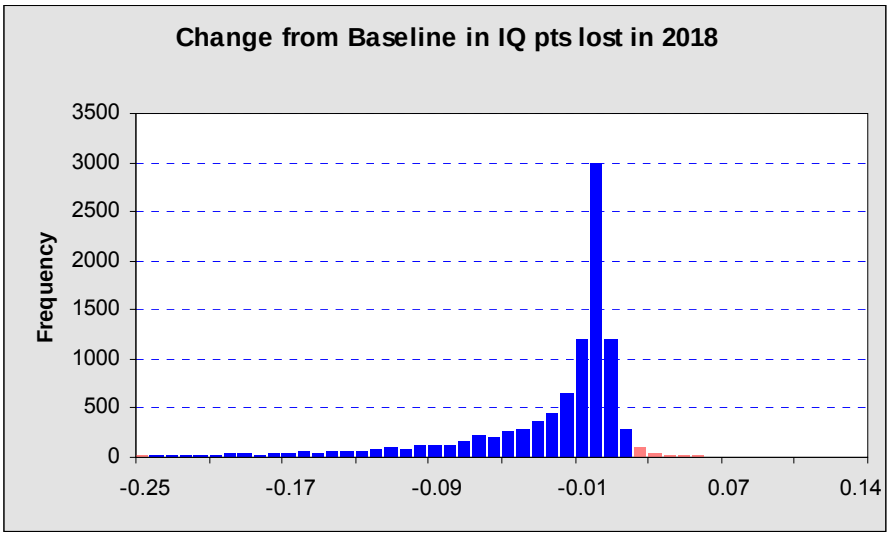
	Forecast values
Trials	10,000
Mean	0.28
Median	0.16
Mode	---
Standard Deviation	0.34
Variance	0.11
Skewness	2.65
Kurtosis	14.05
Coeff. of Variability	1.20
Minimum	0.00
Maximum	3.96
Range Width	3.96
Mean Std. Error	0.00

	Forecast values
0%	0.00
10%	0.02
20%	0.04
30%	0.08
40%	0.12
50%	0.16
60%	0.22
70%	0.32
80%	0.46
90%	0.69
100%	3.96



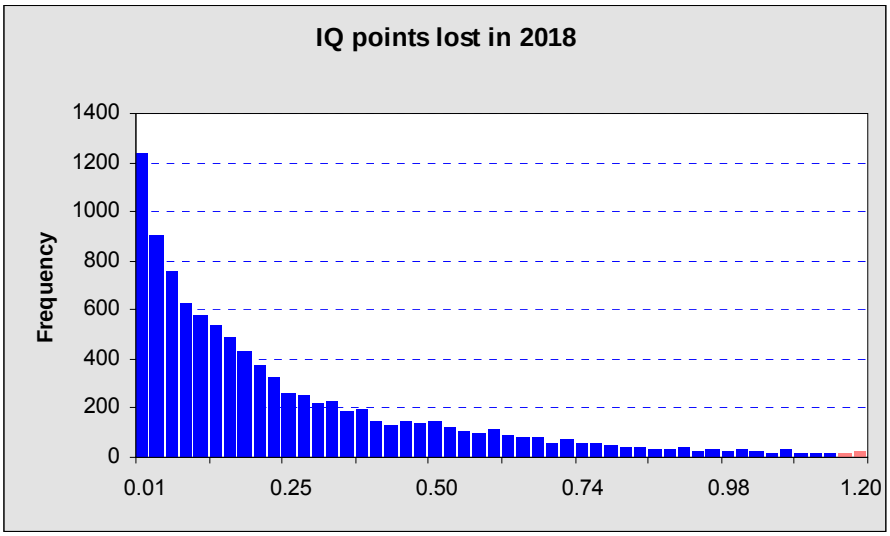
	Forecast values
Trials	10,000
Mean	-0.03
Median	-0.01
Mode	---
Standard Deviation	0.07
Variance	0.01
Skewness	-4.24
Kurtosis	32.08
Coeff. of Variability	-2.15
Minimum	-1.07
Maximum	0.24
Range Width	1.31
Mean Std. Error	0.00

	Forecast values
0%	-1.07
10%	-0.11
20%	-0.05
30%	-0.03
40%	-0.01
50%	-0.01
60%	0.00
70%	0.00
80%	0.00
90%	0.01
100%	0.24



	Forecast values
Trials	10,000
Mean	-0.04
Median	-0.01
Mode	---
Standard Deviation	0.08
Variance	0.01
Skewness	-3.91
Kurtosis	26.39
Coeff. of Variability	-2.07
Minimum	-1.04
Maximum	0.15
Range Width	1.19
Mean Std. Error	0.00

	Forecast values
0%	-1.04
10%	-0.12
20%	-0.06
30%	-0.03
40%	-0.02
50%	-0.01
60%	0.00
70%	0.00
80%	0.00
90%	0.00
100%	0.15



	Forecast values
Trials	10,000
Mean	0.28
Median	0.16
Mode	---
Standard Deviation	0.33
Variance	0.11
Skewness	2.70
Kurtosis	14.74
Coeff. of Variability	1.20
Minimum	0.00
Maximum	3.96
Range Width	3.96
Mean Std. Error	0.00

	Forecast values
0%	0.00
10%	0.02
20%	0.04
30%	0.08
40%	0.12
50%	0.16
60%	0.22
70%	0.32
80%	0.46
90%	0.67
100%	3.96