

QUANTITATIVE RISK CHARACTERIZATION

Martin Creek Reservoir

Rusk and Panola Counties, TX

September 24, 2003

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INTRODUCTION

Background and Statement of the Issues

The Texas Department of Health (TDH) issued consumption advice (ADV-4) for people eating fish from Martin Creek Reservoir, Brandy Branch Reservoir, and Welsh Reservoir in 1992 because samples from those waterbodies contained selenium at levels considered excessive by some health risk managers. Consequent to the consumption advisory, the Texas Commission on Environmental Quality (TCEQ) placed Martin Creek, Brandy Branch, and Welsh Reservoirs on the state's 303(d) list of impaired waters. Section 303(d) of the Clean Water Act requires that all states identify waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a total maximum daily load (TMDL) for each pollutant contributing to impairment of water quality in the water body in question. A TMDL is a quantitative plan that determines the amount of each pollutant that a particular water body can receive daily and still meet its applicable water quality standards and/or beneficial uses [1]. The TCEQ is responsible for developing TMDLs for impaired surface waters in Texas.

In 2001, staff from TCEQ, TDH, and TPWD met to discuss water quality issues and fish consumption advisories associated with Martin Creek Reservoir, Brandy Branch Reservoir, and Welsh Reservoir. Participants agreed that TDH should reevaluate the fish consumption advisory for the Martin Creek, Brandy Branch, and Welsh reservoirs before TCEQ commenced developing TMDLs for those water bodies. TDH received a grant in 2002 from the United States Environmental Protection Agency (USEPA) – through the TCEQ TMDL program – to reevaluate potential health risks from consuming fish from any one of the three reservoirs. This report summarizes the findings of the 2002 assessment of Martin Creek Reservoir and characterizes current and past risks from consumption of fish from this reservoir considered likely to contain selenium or other environmental contaminants.

Martin Creek Reservoir – situated within the northeast Texas piney woods natural region and the Sabine River basin – is a 5,000 acre impoundment of Martin Creek located 17 miles northeast of Henderson (population- 11,273) and 3 miles southwest of Tatum (pop. 1,175), on the border of Rusk (pop. 47,384) and Panola (pop. 22,719) counties [2, 3, 4]. The reservoir, constructed in 1974 to serve as a source of cooling water for the Martin Creek Reservoir Steam Electric Station, a three-unit lignite-fired power plant owned and operated by Texas Utilities (TXU), has a drainage area of 148 square miles. With a generating capacity of 2,250,000 kilowatts, the Martin Creek Reservoir Steam Electric Station is the largest lignite-fired power plant in the world [5]. Public access to the reservoir is through Martin Creek Lake State Park, which provides cabins, campsites, playground, amphitheater, hiking and biking trails, picnic tables, boat ramps, fishing piers, and fish cleaning sites that encourage fishing from the reservoir. Recreational and sport fishing has been a popular pastime at Martin Creek Reservoir. Subsistence fishing may also occur.

During 1978 and 1979, releases of water occurred from power plant ash settling ponds into Martin Creek Reservoir. Analyses of settling pond water subsequent to those releases revealed mean selenium concentrations in excess of two parts selenium per million parts water (ppm) [6]. Subsequent to the 1978-1979 discharges, researchers from the Texas Parks and Wildlife

Department (TPWD) analyzed fish and water samples from Martin Creek Reservoir. Those analyses revealed selenium in both media. Fish muscle tissue contained selenium at levels greater than commonly found in freshwater fish [7]. Average selenium concentrations in largemouth bass muscle tissue ranged from 7.1 to 8.3 milligrams per kilogram (mg/kg). In bluegill muscle tissue, the average selenium concentration was 6.9 mg/kg [8]. In the late 1970's and early 1980's, TPWD implicated excess selenium in a series of fish kills [6,8]. In 1984, the TPWD requested that TDH collect additional fish to examine a wider range of species and size classes for selenium. Selenium in largemouth bass muscle tissue analyzed in 1984 ranged from 2.5 to 4.5 mg/kg (mean = 3.25 mg/kg) [9]. From 1985 to 1989, TPWD monitored selenium in largemouth bass muscle tissue, observing mean concentrations between 1.94 and 3.57 mg/kg. Average selenium concentrations in bluegill muscle tissue ranged from 1.66 to 2.68 mg/kg [6].

In 1992 – the year TDH issued ADV-4 – no reference dose (RfD) or minimal risk level (MRL) was available for use in comparing environmental selenium or its compounds with experimentally derived concentrations capable of toxicity. Nevertheless, TDH reviewed the extant literature on selenium, finding that, in 1974, the Australian National Health and Medical Research Council approved a maximum of two mg/kg for selenium in any food [10]. The California Department of Health Services had similarly established guidelines for consumption of fish and waterfowl containing selenium at concentrations higher than physiological levels [11] to address the human health implications of exposure to selenium through consumption of these foods. California health authorities thereafter issued health advisories if the average selenium concentration in edible tissues from fish and waterfowl exceeded 2.0 mg selenium per kg tissue.

From its review of the literature on human nutritional requirements for selenium and the toxicologic consequences of consuming excess selenium, TDH estimated a “safe” upper intake level (UL) for dietary selenium as approximately 400 µg/day (5.71 µg/kg/day for a 70 kg adult) [12]. Assuming the average adult ingests 200 µg/day (2.86 µg/kg/day) of selenium from dietary sources other than fish from an affected waterbody, or approximately 50% of TDH's UL, TDH specified that adults could safely ingest up to 200 µg/day of selenium in *fish* or *shellfish* from affected waterbodies [12]. Acknowledging the uncertainty inherent in attributing risks and benefits of consuming essential micronutrients that may also be toxic to humans, TDH stipulated two (2) milligrams selenium per kilogram as a concentration in tissue at which the agency might consider action to protect health and safety. That stipulation was consistent with contemporaneous decisions by the state of California and by Australia [10, 11]. At the same time, TDH re-evaluated selenium data from fish collected from Martin Creek Reservoir between 1984 and 1989. Based upon these data and a UL of 200 µg selenium/day from affected fish, TDH determined that regular or frequent consumption of fish from Martin Creek Reservoir potentially posed a risk to public health [12]. Consequently, the (1992) consumption advisory for Martin Creek Reservoir (ADV-4) suggested that adults consume no more than one eight-ounce meal each week and children seven years of age and older consume no more than one four-ounce meal each week of fish from Martin Creek Reservoir. ADV-4 suggests that children six years of age and under, pregnant women, or women who could become pregnant not consume the fish from this reservoir. TDH also advises that persons consuming fish from Martin Creek Reservoir should not further supplement their selenium intake with dietary supplements containing selenium in excess of 50 micrograms per dose [13].

TDH sampled fish from Martin Creek Reservoir again in 1996 and 1997 to re-evaluate the 1992 fish consumption advisory. The 1996-97 data revealed an apparent decline in selenium concentrations in fish from Martin Creek Reservoir from earlier years (range: 0.7 to 4.0 mg/kg) [14]. However, the average concentration of selenium in fish combined across species (2.3 mg/kg) remained slightly higher than the comparison value of 2 mg/kg employed since 1992 by TDH to evaluate selenium in fish tissue [12]. Data collected around this time by the utility company as a requirement for discharge permits revealed selenium concentrations in fish from Martin Creek Reservoir that were substantially greater than 2 mg/kg [15]. Consequently, TDH elected in 1998 to retain the consumption advisory (ADV-4) on fish from Martin Creek Reservoir.

The present report – while addressing a suite of potential toxicants in fish from Martin Creek Reservoir – concentrates on selenium levels in fish collected from this reservoir.

Selenium as a Nutrient and as a Toxicant

The Roles of Selenium in Nutrition

Selenium is a naturally occurring element belonging to the sulfur group of the periodic table. Although selenium is considerably more rare than sulfur (ranking in abundance between silver and gold), the element is widely if unevenly distributed in the earth's crust. Sedimentary rocks may contain minerals composed of selenium in combination with other metallic and non-metallic elements such as copper, lead, nickel, silver, and sulfur. When rocks decompose into soils, selenium in those rocks often combines with sodium and oxygen to form sodium selenate, or, with hydration, sodium selenite [16], both of which are water-soluble compounds [16]. Plants absorb dissolved inorganic selenium compounds from soils, converting these compounds to selenomethionine and other organic selenium-containing compounds. Humans and animals absorb and utilize both organic and inorganic forms of selenium from food and water, but animal systems more readily use organic selenium compounds than inorganic forms of selenium.

Selenium is an essential dietary element for humans and animals [16]. In both, selenomethionine – produced by plants and absorbed by the animal's GI tract – is incorporated randomly into selenoproteins in place of the amino acid methionine. Selenomethionine has no known physiological functions differing from those of methionine. Selenocysteine, absorbed from food and water or formed *in vivo*, accounts for the biological activity of selenium. Investigators have characterized more than a dozen functional selenoproteins [16], including four selenium-dependent glutathione peroxidases [16]. Glutathione peroxidases minimize cellular damage [16] by breaking down peroxides and other toxic byproducts of cellular metabolism before those substances can injure a cell [16]. Selenoproteins P and W may also protect against oxidative stress. Selenium-dependent iodothyronine deiodinases regulate thyroid hormone metabolism [16]. Thioredoxin reductases repair cellular constituents by hydrolyzing intra-molecular disulfide bonds [16]. These same enzymes regenerate ascorbic acid from its oxidized metabolites [16]. Finally, a selenium-dependent selenophosphate synthetase participates in selenium metabolism [16]. Signs and symptoms of dietary selenium deficiency include myalgias, muscle tenderness, cardiomyopathy, cardiomegaly, increased red blood cell fragility, and pancreatic degeneration. Cardiomyopathy and cardiomegaly (Keshan disease) is observed almost exclusively in children

living in areas of the world that have low soil selenium levels and whose diet consists of locally produced foods [16].

According to the ATSDR, the average intake of selenium by U.S. residents is 70 to 150 µg per day [17]. The NHANES III survey of dietary habits estimates average dietary intake of selenium to be 113.5 µg/day, while that of individuals taking dietary supplements is 116.1 µg/day. Those in the 50th percentile of survey respondents who do not take supplements ingest about 106 µg/day, while 50 percent of those who do take dietary supplements containing selenium ingest about 108.5 µg/day. Of all individuals surveyed, ninety-nine percent of those not taking supplements take in less than 250 µg selenium per day. Those who do take selenium supplements consume an estimated 250.4 µg of selenium per day [18]. NHANES III data may be subject to recall bias. Nonetheless, studies independent of NHANES verify its conclusions on upper limits of consumption. For instance, only about three percent of Maryland residents consumed diets containing more than 200 µg selenium per day [16]. Such studies support the notion that dietary selenium intakes in the U.S. are above the amounts necessary for optimal health but well below tolerable upper intake levels established to protect humans from the adverse health effects of excess selenium. Similarly, dietary supplementation with selenium is probably not a major source of this micronutrient for the U.S. adult population. It is possible, but unlikely, that formula fed infants could get more selenium than do breast-fed infants because commercial formulas may contain selenium [16]. The National Academy of Sciences (NAS) has established recommended dietary allowances (RDA) for selenium (Table 2). The RDA is not a toxicity value, but is the dietary intake level that will likely meet the nutritional requirement for selenium of nearly all (97-98%) individuals in a specific age and gender group [16]. According to the NAS, infants should take in about 2.1 µg selenium per kg body weight. Children between the ages of one and 8 should consume between 20 and 30 µg/day, while boys and girls between 9 and 18 years of age should ingest 40 to 55 µg/day of selenium. Adult men – and women who are not pregnant or lactating – should take in a minimum of 55 µg selenium each day. The RDA for pregnant women is 60 µg/day, while that for lactating women is 70 µg/day [16].

Many foods in the human diet supply selenium: fruits and vegetables – which are generally low in this micronutrient (0.02 mg/kg); dairy products (0.02-0.1 mg/kg); poultry, eggs, and red meat (0.1-0.4 mg/kg); organ meats (0.4-0.5 mg/kg); seafood (0.5 to 1.5 mg/kg; swordfish may contain as much as 3.5 mg/kg). Brazil nuts contain large quantities of selenium (up to 16 mg/kg) but are not a significant source of selenium for most people. The geographic origins of food and the meat content of the diet are major determinants of selenium intake. Although selenium intake varies by region, extensive transport of foods throughout Canada and the U.S. protects people in low-selenium geographic areas from suffering low dietary selenium intakes [16]. Similarly, the USDA prohibits commercial sale of agricultural products grown in seleniferous soils, preventing entry of those foodstuffs into the U.S. or Canadian food supply [16]. Drinking water does not supply nutritionally significant amounts of selenium except in limited locales [16].

Selenium Toxicity

Although an essential micronutrient, selenium is toxic at levels not much higher than required for optimum nutrition. Mammalian systems maintain selenium homeostasis primarily through renal excretion of excess absorbed selenium [19] but respiratory and fecal excretion also occurs [19].

Selenium may be acutely toxic when taken in large doses but toxicity is more likely when intakes chronically exceed the body's need for selenium or its ability to excrete the element [19]. When intake exceeds use or excretion, selenium accumulates in body tissues, including the liver, kidneys, hair, and nails [19]. The clinical syndrome associated with excess body burdens of selenium is selenosis [19]. In humans, signs and symptoms of sub-acute or chronic toxicity from accumulated selenium include brittle nails and hair; nail and hair loss; skin blisters and eruptions; mottled, pitted and decayed teeth; fatigue; and episodic nausea and vomiting. Neurologic findings may include peripheral anesthesia, paresthesias, hyper-reflexia, paralysis, and, in severe cases, hemiplegia [19]. The breath may have a garlic-like or sour-milk odor from expiration of volatile organic selenium-containing compounds [19]. Because of selenium's potential toxicity, the NAS developed tolerable upper intake levels (UL) for selenium in addition to the RDA for this element. The UL is "*the highest level of daily nutrient intake that is likely to pose no risk of adverse health effects in almost all individuals*" [16]. In infants, the UL is 45 to 60 µg per day, depending on body weight; in children between 1 and 3 years of age, 90 µg/day; at ages 4-8, the UL is between 150 and 280 µg/day; for adolescents, and all adults, the UL is 400 µg/day. The United States Environmental Protection Agency (USEPA) has also developed a reference dose (RfD) for selenium; the RfD is 350 µg/day for a 70-kg adult (5 µg/kg/day), as is the minimal risk level (MRL) promulgated by the ATSDR [17]. The RfD, MRL, and UL are compatible concepts and – when normalized to mg/kg/day – doses are comparable (0.005 mg/kg/day), having come from the same Chinese studies [16, 17, 20].

To enhance its examination of selenium concentrations in fish collected in 2002 from Martin Creek Reservoir and to further support conclusions drawn from the 2002 sampling data from Martin Creek Reservoir, TDH reviewed selenium data collected over 19 years by TDH, TPWD, and TXU [9, 15, 21]. TDH also examined prevailing thought on the role of selenium in nutrition and the toxicity of this essential micronutrient. To gather information about sentinel advisory levels used by other states for regulating selenium in fish and shellfish, the Seafood Safety Division (SSD) contacted states known to have issued selenium consumption advisories. California, North Carolina, and Idaho responded [22, 23, 24, 25, 26] to requests for information. The California Environmental Protection Agency (CEPA) previously used a concentration of 2.0 mg selenium per kg edible fish tissue to formulate selenium consumption advice, but, currently, has no set health advisory level [22]. CEPA is reviewing NHANES data on daily selenium intake for use in revising that state's health advisory level for selenium. California will likely utilize the USEPA's oral RfD for selenium, incorporating relative source contribution methods to account for dietary selenium from sources other than recreationally caught freshwater fish [22]. The North Carolina Department of Health and Human Services (NCDHHS) recently rescinded two selenium advisories [23, 26]. The spokesperson at NCDHHS had no information on the selenium concentration in fish used for the 1993 advisories, but recommended that Texas use USEPA guidance for assessing chemical contaminant data in fish along with the oral RfD to develop advisory levels [23]. The Idaho Bureau of Health and Safety currently employs the RfD and USEPA guidelines to formulate consumption advisories. Idaho's advisory values for selenium are 6.2, 5.4, and 3.1 mg/kg edible tissue for the public in general, pregnant women, and children, respectively [24, 26].

METHODS

Fish Tissue Collection and Analysis

To evaluate potential health risks to recreational and subsistence fishers who consume environmentally contaminated seafood, the Texas Department of Health (TDH) collects and analyzes samples of edible fish and shellfish tissues from selected Texas public waters. These samples represent the species, trophic levels, and legal-sized specimens available for consumption. When practical, TDH collects samples from several sites within a water body to characterize the geographical distribution of contaminants. The TDH laboratory utilizes established methodology to analyze edible fillets (skin off) of fish and edible meats of shellfish (crabs, oysters) for seven metals – arsenic, cadmium, copper, lead, total mercury¹, selenium, and zinc – and for volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), pesticides, and polychlorinated biphenyls (PCBs: Aroclors 1016, 1221, 1224, 1232, 1248, 1254, and 1260). TDH may conduct other chemical analyses if samples are suspected to contain toxicants not generally examined.

Description of the Martin Creek Reservoir Sample Set

In November 2002, personnel from the Seafood Safety Division of the TDH collected a total of thirty (30) fish samples from three previously sampled sites around Martin Creek Reservoir (see appendix for map). From Site 1, SSD collected two (2) largemouth bass, five (5) channel catfish, three (3) flathead catfish, one (1) common carp, one (1) black crappie, and one (1) blue tilapia. Five (5) channel catfish, three (3) flathead catfish, and one (1) common carp were collected from Site 2 and, from Site 3, (5) largemouth bass and one (1) flathead catfish. All fish collected were of legal size for possession according to Texas Parks and Wildlife Department (TPWD) regulations [27].

The TDH laboratory analyzed all thirty (30) samples for metals. Ten (10) of the samples were also analyzed for a variety of pesticides, PCBs, volatile organic contaminants, and semivolatile organic contaminants. The TDH laboratory provided analytical results for all requested contaminants fish tissue samples submitted for analysis.

Data Analysis

TDH utilized IBM-compatible microcomputers to perform all statistical procedures with SPSS software [28]. TDH generated descriptive statistics (mean concentration, standard deviation, median, range, confidence intervals, and minimum and maximum concentrations) for each contaminant in each species at each sampling site. TDH utilized Microsoft Excel [29] spreadsheets to generate health-based assessment comparison values (HAC values) and to calculate hazard quotients, hazard indices, cancer risk, and allowable consumption of each fish

¹Nearly all mercury in upper trophic-level fish over three years of age is methylmercury [40]. Total mercury is a surrogate for methylmercury concentration in fish and shellfish. Because of the cost of methylmercury analyses, USEPA recommends that states determine total mercury concentrations in fish and that – to protect human health – states assume that all mercury in fish or shellfish is methylmercury. TDH analyzes fish and shellfish tissues for total mercury. In its risk characterizations, TDH compares total mercury concentrations in tissues to a comparison value derived from the ATSDR's minimal risk level for methylmercury [41]. TDH may utilize the terms "mercury" and "methylmercury" interchangeably to refer to methylmercury in fish.

species from the three sites around Martin Creek Reservoir. Statistical analyses included all samples.

Derivation of Health-Based Assessment Comparison Values (HACs)

Generally, people exposed to environmental toxicants in fish or shellfish eat contaminated fish containing low concentrations of contaminants over an extended time. This exposure pattern seldom results in acute toxicity but may increase the risk of subtle, delayed or chronic adverse health effects or cancer. Presuming that people eat a variety of fish, TDH routinely evaluates average contaminant concentrations across species and locations within water body since this approach best reflects the likely exposure pattern of consumers over time. However, the agency also may examine risks from ingestion of individual species of fish from individual collection sites.

TDH evaluates chemical contaminants in fish by comparing average contaminant concentrations with health-based assessment comparison (HAC) values (in mg contaminant per kg edible tissue or mg/kg) for non-cancer and cancer endpoints. To calculate HAC values for either carcinogenic or systemic effects, TDH assumes that a standard adult weighs 70 kilograms and that adults consume 30 grams of fish per day (about one eight-ounce meal per week). TDH uses the U.S. Environmental Protection Agency's (USEPA) oral reference doses (RfDs) [20] or the Agency for Toxic Substances and Disease Registry's (ATSDR) chronic oral minimal risk levels (MRLs) to derive HAC values for evaluating systemic (noncancerous) adverse health effects (HAC_{nonca}) [17]. The USEPA defines a reference dose (RfD) as an "*estimate of long-term daily exposures that is not likely to cause adverse noncancerous (systemic) health effects even if exposure occurs over a lifetime*" [31]." The cancer risk comparison values (HAC_{ca}) used at TDH to assess carcinogenic potential from consumption of fish containing carcinogenic chemicals are based on the USEPA's chemical-specific cancer slope factors (SFs) [20, 30], an acceptable lifetime risk level (ARL) of 1×10^{-4} persons equally exposed to the toxicant, and an exposure period of 30 years.

Most constants employed to calculate noncancer HAC values contain built-in margins of safety (uncertainty factors). Uncertainty factors are chosen to minimize the potential for systemic adverse health effects in those people – including sensitive subpopulations such as women of childbearing age, pregnant or lactating women, infants, children, the elderly, people who have chronic illnesses, those who consume exceptionally large quantities of fish or shellfish – who eat environmentally contaminated fish and shellfish [20]. Although comparison values used for assessing the probability of cancer do not contain "uncertainty" factors as such, conclusions drawn from those probability determinations do have substantial safety margins. Therefore, adverse health effects, either systemic or carcinogenic, are very unlikely to occur at concentrations approaching, or even greater than, comparison values. Moreover, health-based assessment comparison values (HACs) for systemic or carcinogenic effects do not represent a sharp dividing line between safe and unsafe exposures. The strict demarcation between acceptable and unacceptable exposures or risks is primarily a tool used to make management decisions that assure protection of public health. TDH finds it unacceptable when consumption of four or fewer meals per month would result in exposures to any contaminant or contaminants that exceed a HAC value or other measure of risk. TDH further advises people who wish to

minimize their exposure to environmental contaminants in fish or shellfish to eat a variety of fish and shellfish and to limit consumption of those species that are most likely to contain environmental toxicants.

Addressing Potential Cumulative Effects

When multiple chemicals that affect the same organ or that have the same mechanism of action exist together in one or more samples from a water body, the standard assumption is that potential adverse health effects are cumulative (additive) [31]. Therefore, TDH conservatively assumes that each time people eat seafood from an affected water body, they will be exposed to all of the chemicals and, further, that any potential adverse systemic or carcinogenic effects from any of the contaminants will be additive.

Cumulative Systemic (Noncancerous) Effects

To evaluate the importance of possible cumulative systemic (noncancerous) health effects from consumption of contaminants with similar toxicity profiles, TDH calculates a hazard index (HI) by summing the hazard quotients (HQ) previously calculated for each contaminant. The hazard quotient (HQ) is the ratio of the estimated exposure dose of a contaminant to its RfD or MRL [32]. A HI of less than 1.0 may suggest that no significant hazard is present for the observed combination of contaminants at the observed concentrations. While a HI that exceeds 1.0 may indicate some level of hazard, it does not imply that exposure to the contaminants at observed concentrations will result in adverse health effects. Nonetheless, finding an HI that exceeds 1.0 may prompt the agency to consider public health intervention strategies.

Cumulative Carcinogenic Effects

To estimate the potential additive effects of multiple carcinogens on excess lifetime cancer risk, TDH sums the risks calculated for each carcinogenic contaminant observed in a sample set. TDH recommends limiting consumption of seafood containing multiple carcinogenic chemicals to quantities that would result in an estimated combined theoretical excess lifetime cancer risk of not more than 1 extra cancer in 10,000 persons so exposed.

Children's Health Considerations

TDH recognizes that fetuses, infants, and children may be uniquely susceptible to the effects of toxic chemicals and that any such vulnerabilities demand special attention. Windows of vulnerability (i.e., critical periods) exist during development. These critical periods are particularly evident during early gestation, but may also appear throughout pregnancy, infancy, childhood, and adolescence – indeed, at any time during development, when toxicants can permanently impair or alter the structure or function of vulnerable systems [33]. Unique childhood vulnerabilities may result from the fact that, at birth, most organs and body systems have not achieved structural or functional maturity; rather, these organs continue to develop throughout childhood and adolescence. Because of these structural and functional differences, children may differ from adults in absorption, metabolism, storage, and excretion of toxicants, any one of which factors could increase the concentration of biologically effective toxicant at the target organ(s). Children's exposures to toxicants may be more extensive than adult's exposures

because children consume more food and liquids in proportion to their body weight than do adults [33], a factor that also may increase the concentration of toxicant at the target. Children can ingest toxicants through breast milk – often unrecognized as an exposure pathway. They may also experience toxic effects at a lower exposure dose than adults due to differences in target organ sensitivity. Stated differently, children could respond more severely than would adults to an equivalent exposure dose [33]. Children may also be more prone to developing certain cancers from chemical exposures than are adults. If a chemical – or a class of chemicals – could be more toxic to children than to adults, the RfD or MRL will be commensurately lower to reflect children’s potentially greater susceptibility. Additionally, in accordance with ATSDR’s *Child Health Initiative* [34] and USEPA’s *National Agenda to Protect Children’s Health from Environmental Threats* [33], TDH seeks to further protect children from the potential effects of toxicants in fish and shellfish by suggesting that this sensitive group consume smaller quantities of environmentally contaminated seafood than adults. Therefore, TDH routinely recommends that children who weigh 35 kg or less and/or who are eleven years of age or younger eat no more than four ounces of chemically contaminated fish or shellfish per meal. TDH also recommends that consumers spread these meals out over time. For instance, if the consumption advice recommends eating no more than two meals per month, children consuming fish or shellfish from the affected water body should consume no more than twenty-four meals per year. Ideally, children should not eat such seafood more than twice per month.

Relative Source Contribution Methodology (RSC)

TDH applied standard methodology to assess the risk of adverse health effects of consumption of excess selenium in fish from Martin Creek Reservoir – with one important exception. Because selenium is a nutrient that is also toxic at intake levels possibly not far removed from those needed to fulfill its nutritional functions, TDH applied relative source contribution (RSC) methodology developed by the USEPA to derive a health-based assessment comparison (HAC) value for assessing selenium concentrations in fish tissue [35]. Any value utilized to assess risk of adverse health effects from consumption of a nutritive substance must also account for anticipated exposures from other sources, including foods other than the one in question. For most people, selenium exposures come almost entirely from foods. Because other environmental media such as soil and air contribute relatively little to selenium exposure in general, TDH did not consider these media in developing relative source contributions for selenium.

The RSC approach to toxicant intake apportions a health-based comparison value to ensure sufficient protection given other anticipated exposures or sources. In the case of selenium, other exposures are primarily of dietary origin. The RSC method of accounting for multiple sources of selenium results in a more stringent health-based assessment comparison value (HAC value) than would be necessary if assessors did not consider those other sources of the element. Based on available data, human exposures to selenium from all foods are in the range of 100-250 µg/day for adults in the general population [16, 17, 20], an intake that is approximately 50% of the RfD (MRL, UL). Applying relative source contribution (RSC) methods to the RfD (MRL, UL) for selenium suggests that people may ingest an additional 200 µg/day of selenium from recreationally caught fish containing selenium. To derive a health-based assessment comparison value (HAC) for selenium in fish, TDH thus assumed that 50% of daily selenium intake comes from other foodstuffs (approximately 100 to 200 µg/day for a 70-kg adult – or approximately

one-half the RfD (UL, MRL). TDH subtracted an amount equal to 50% of the RfD (MRL, UL) from the RfD (MRL, UL) to account for other sources or exposures to selenium. The remainder of the RfD (MRL, UL), 0.0025 mg/kg/day, was utilized to calculate a fish tissue residue concentration, daily consumption of which will not exceed the RfD after other sources of exposure are factored into the equation.

The equation used to calculate the health-based assessment comparison (HAC) value for selenium in fish tissue residue is:

$$\text{TRC} = \frac{\text{BW} \times (\text{RfD} - \text{RSC})}{\text{FI}}$$

Where:

- TRC = Fish tissue residue concentration (mg selenium/kg edible tissue)
- RfD = Reference dose (based on noncancerous human health effects) for selenium: 0.005 mg selenium per kilogram body weight per day
- RSC = Relative source contribution (subtracted from the RfD to account for consumption of other foods containing selenium: estimated to be 0.0025 mg selenium per kg body weight per day)
- BW = Adult human body weight: default value, 70 kg
- FI = Fish intake or consumption rate (kg edible tissue/day): default intake, 0.030 kg per day for the general population

This calculation yields a TRC for selenium of 6.0 mg/kg edible tissue, rounded up from 5.84 mg/kg. The TRC of 6 mg selenium/kg fish tissue is the concentration in fish tissue that, if not exceeded, ensures at least a 2-fold margin of safety from consumption of fish containing excess selenium, assuming consumption of no more than .03 kg/day or one eight-ounce meal per week. TDH does not recommend further reductions in tissue concentration to protect children because not only is the RfD (MRL, UL) protective of developing humans, but infants and children may actually need more selenium (for infants, the selenium requirement is 1.67 µg/kg and for children the requirement ranges from 1.07 - 1.53 µg/kg) for optimum development [20].

RESULTS

Seafood Safety Division personnel collected samples from Martin Creek Reservoir on November 18, 19, and 20, 2002 and submitted those samples to the TDH laboratory for analysis on November 21, 2002.

Analytical and Statistical Results

Organic Contaminants

Fish tissue samples from Martin Creek Reservoir were relatively free of organic contaminants. Six of the ten samples analyzed for pesticides contained DDE, the average concentration of which was 0.008 mg/kg. Species differences in DDE concentrations were apparent (Table 1). No other organic contaminants were observed at measurable concentrations in any sample.

Inorganic or metalloid Contaminants, including Selenium, in 2002 Samples

Fish tissue samples contained the following metalloid contaminants: arsenic, cadmium, copper, mercury, selenium, and zinc. Average concentrations, minimum and maximum concentrations and the number of samples of each species containing these contaminants are listed in Table 1. Selenium and zinc were present in all samples. Average selenium and zinc concentrations were 1.61 ± 0.69 and 4.36 ± 1.72 mg/kg, respectively. Twenty-eight of thirty samples contained cadmium (0.117 ± 0.277 mg/kg). Ten of thirty samples contained mercury (mean concentration 0.035 ± 0.077 mg/kg). One of thirty samples contained arsenic (0.036 mg/kg), and one of thirty samples contained copper (0.376 mg/kg). No sample contained measurable levels of lead.

Historical Selenium Data

The Texas Parks and Wildlife Department, Texas Department of Health, and Texas Utilities (owner and manager of record of Martin Creek Reservoir power plant) have monitored selenium concentrations in fish from Martin Creek Reservoir since 1979, finding selenium present in all tissue samples collected through 2003. TDH analyzed one thousand four hundred and forty (1440) selenium measurements in fish collected from 1984 to 2003 for measures of central tendency and variance (Figures 1 and 2). For the nineteen (19) years' observations, selenium concentrations in fish tissue ranged from a minimum of 0.235 mg/kg to a maximum of 6.60 mg/kg with an average concentration of 2.45 mg/kg (99% confidence interval = 0.061 mg/kg) (Figures 1 and 2). Statistically, therefore, one can be 99% certain that the true average selenium concentration in fish from Martin Creek Reservoir is between 2.39 and 2.51 mg per kilogram edible tissue. Statistical analysis showed concentrations greater than 4.8 mg/kg to be extreme values (three standard deviations above mean concentration). Those twenty-seven values were, nevertheless, included in all statistics generated from the dataset, since there were no scientifically valid reasons to exclude outliers. Nevertheless, it is interesting to note that, despite the fact that several laboratories analyzed the specimens and that those laboratories may have utilized different methodologies, only twenty-seven (1.9%) of 1440 selenium measurements were considered statistical outliers.

DISCUSSION

Risk Characterization

Characterizing Systemic (Noncancerous) Health Effects from Consumption of Martin Creek Reservoir Fish

Organic compounds

Organic contaminants were not prominent in fish samples collected in 2002 from Martin Creek Reservoir. In fact, only one organic compound – p,p'-DDE – was observed in those samples; six of ten samples analyzed for organic contaminants contained p,p'-DDE. Neither the average concentration of p,p'-DDE nor the maximum observed concentration exceeded, or even approached, HAC values for this pesticide (Table 1). Therefore, the presence of p,p'-DDE – a metabolite, contaminant, or breakdown product of the legacy pesticide, p,p'-DDT – is of no toxicologic significance in fish from Martin Creek Reservoir. The absence of other organic contaminants in these samples obviates the necessity for further discussion.

Inorganic or metalloid Components other than Selenium

Along with selenium, TDH analyzed the 2002 fish tissue samples from Martin Creek Reservoir for six other metalloid contaminants: cadmium, arsenic, copper, mercury, zinc, and lead. None exceeded its respective HAC value (Tables 1 and 3). The hazard quotient for each metallic element was less than 1.0. Therefore, toxicity from consuming fish from Martin Creek Reservoir that contain cadmium, arsenic, copper, mercury, zinc, lead, or selenium is unlikely. This report addresses selenium separately because, historically, selenium has been the only contaminant of concern in fish from Martin Creek Reservoir.

Selenium

The average concentration of selenium in fish collected from Martin Creek Reservoir in 2002 was 1.61 mg/kg (95% UCL = 1.809 mg/kg). Moreover, despite a few historically high selenium measurements in fish from this reservoir, the average concentration of selenium in samples collected by TDH, TPWD, or TXU over a nineteen-year observation period is 2.45 mg/kg (99% UCL = 2.51 mg/kg). Examination of the historical data from TDH, TPWD, and TXU reveals a periodic oscillation in concentrations attributed to low water levels in the lake during periods of drought. That oscillation obscures any linear trend in the data (Figure 2). Nevertheless, even the highest average selenium concentration – observed in 1997 during drought conditions – did not exceed 4 mg/kg. In fact, the 99% UCL on mean concentration in 1997 was 4.0 mg/kg. Selenium concentrations in fish from Martin Creek Reservoir are stable and are unlikely to regularly exceed the HAC_{nonca} derived from current toxicity values established by agencies such as the USEPA, ATSDR, and the NAS. The USEPA and the ATSDR recommend that people not regularly consume more than 0.005 mg/kg/day of selenium (0.350 mg/day for a 70-kg adult). The NAS further establishes a tolerable upper intake level (UL) based upon age and body weight. Nevertheless, NAS suggests that adults limit their intake of selenium to 400 µg per day (0.4 mg/day). Table 2 lists the RDA and the tolerable upper intake level (UL) for people at

different stages of life: infants, children, and adults. Table 2 compares the UL in mg/kg/day with the RfD (0.005 mg/kg/day). Expressed as a function of body weight, the UL is similar to the RfD (or the MRL from ATSDR). In fact, the UL is somewhat higher at each life stage than is the RfD. The RfD, MRL, and UL were each separately derived from studies on a Chinese population with selenosis [16, 17, 20]. All three agencies account for sensitive subpopulations although no subpopulation has proven more sensitive to the toxic effects of selenium than have other populations. Indeed, some authors have suggested that children may need more selenium for proper growth and development than do adults [20].

TDH predicates recommendations in this risk characterization upon the 2002 data from Martin Creek Reservoir. These recommendations are also supported by many years' monitoring data. TDH calculated hazard quotients (HQ's) for the 2002 samples from Martin Creek Reservoir from both the average concentration of selenium in fish tissues and the 95% UCL concentration using USEPA's RfD for selenium (Table 3). TDH also calculated an allowable number of meals for fish from Martin Creek Reservoir based upon those hazard quotients. Hazard quotients for selenium in fish from Martin Creek Reservoir ranged from 0.1 to 0.4 in people of different ages and body weights, depending on daily fish consumption. In the calculations used to derive the values in Table 3, infants were assumed to consume 0.0075 kg/day, children between the ages of 3 and 8 years, 0.015 kg/day; all other children and adults were assumed to eat 0.03 kg/day of fish from Martin Creek Reservoir. Comparing concentrations of selenium in fish collected in 2002 from Martin Creek Reservoir with the HAC_{nonca} for selenium suggests that consuming fish from Martin Creek Reservoir is unlikely to cause adverse health outcomes, even if people eating those fish belonged to a sensitive subgroup.

Characterizing Cancer Risk from Consumption of Martin Creek Reservoir Fish

Cancer potency factors (slope factors) are not available for oral exposure to cadmium, mercury, selenium, or zinc [20]. Thus, TDH was unable to determine the probability of excess cancers from consuming these contaminants in fish from Martin Creek Reservoir. Although inorganic arsenic is a human carcinogen (EPA classification: Group A), most arsenic in fish occurs as organic arsenic, a form that is virtually nontoxic to humans [20]. Thus, even though a single sample from the 2002 dataset contained arsenic, that arsenic is of no toxicologic significance. Although p,p'-DDE is a probable human carcinogen (Group B2), the increase in lifetime risk of cancer from consuming fish from Martin Creek Reservoir containing p,p'-DDE was approximately 1.6×10^{-6} or one excess cancer in 612,745 persons equally exposed to this contaminant, qualitatively interpreted as an insignificant increase in the risk of cancer.

Characterizing Cumulative Systemic Adverse Health Effects or Cancer Risk from Consumption of Fish from Martin Creek Reservoir

DDE in fish from Martin Creek Reservoir did not exceed the HAC_{nonca} or the HAC_{ca} for this contaminant. Thus, TDH expects no cumulative adverse effects, either carcinogenic or systemic, to occur with consumption of fish from Martin Creek Reservoir containing that single chlorinated organic pesticide.

TDH observed several metalloid contaminants in samples collected in 2002 from Martin Creek Reservoir. However, these contaminants generally affect diverse organs or have different mechanisms of action. Since assessments of cumulative noncancerous effects of toxicants should assume similar mechanisms of action and/or overlapping target organs, TDH concludes that cumulative systemic effects are unlikely to arise from consuming metallic contaminants in fish from Martin Creek Reservoir. It is not possible to assess the likelihood of cumulative carcinogenic effects of metalloid contaminants because slope factors are unavailable for many of those contaminants, including selenium [20].

Conclusions

TDH toxicologists prepare quantitative risk characterizations to determine public health hazards from consumption of fish and shellfish harvested by recreational or subsistence fishers from Texas waters, and, if indicated, suggest risk management strategies to TDH risk managers, including the Texas Commissioner of Health. Consumption of fish from Martin Creek Reservoir **poses no apparent public health risk.**

In particular, consumption of fish from Martin Creek Reservoir containing selenium at concentrations greater than those often quoted for freshwater fish [7] **poses no apparent public health risk.** Dietary selenium intakes of as much as 750 µg/day do not appear to produce signs of toxicity [16, 20]. Furthermore, the known functions of selenium at the cellular level support the notion that selenium supplementation may reduce the occurrence of cancer. At least one large-scale epidemiologic study reported that people who take supplemental selenium have a lower incidence of several high-rate cancers [36]. Other studies of this kind are ongoing. Nevertheless, at some point between 750 and 3200 µg/day, selenium toxicity becomes a distinct possibility for susceptible individuals. An intake of 400 µg/day (i.e., the tolerable upper intake level, RfD, or MRL for a 70-kg adult) provides an eight-fold safety factor below the lowermost level that might reasonably result in selenium toxicity. It is also possible that the reference dose (MRL, UL) is ultra-conservative. Investigators reporting human toxicity from chronic consumption of foods from a seleniferous area of China may have underestimated doses necessary for toxicity because those investigators did not consider possible exposure from airborne selenium [20]. Changes in scientific knowledge of the toxicology of selenium, the benefits of consuming selenium, the availability of nationally promulgated reference doses, and confirmation that most people do not consume exceptionally large quantities of selenium in their food, suggest that consumption of fish from Martin Creek Reservoir is unlikely to result in adverse health effects. The average concentration of selenium in fish collected from Martin Creek Reservoir in 2002 is 25% of the HAC_{nonca} (6 mg/kg) for selenium derived from the RfD (UL, MRL) using relative source contribution (RSC) methodology. People could therefore eat almost four meals per week of fish from Martin Creek Reservoir without exceeding the reference dose. The margin of safety over the NOAEL (no observed adverse effect level) would be at least 9 (the NOAEL is three times the RfD [20] times the amount of selenium in one eight-ounce meal of fish containing 1.61 mg selenium per kg edible tissue). In other words, at an average concentration of 1.61 mg/kg, adults could eat as many as nine 8-ounce meals of fish each week from Martin Creek Reservoir before exceeding the threshold dose for adverse effects and up to three 8-ounce meals per week without exceeding the RSC-adjusted HAC_{nonca} value for selenium. Children could consume nine 4-ounce meals/week before exceeding the NOAEL or three four-

ounce meals per week without exceeding the RfD (MRL, UL). Furthermore, nineteen years' observations of selenium in fish from Martin Creek Reservoir suggest that average concentrations of selenium in fish from this reservoir are unlikely to exceed 3 mg/kg, a level only $\frac{1}{2}$ the HAC_{nonca} for selenium, even after accounting for numerous interdependent variables such as reservoir water level, age, trophic level, or fish size. TDH further notes that some other states have rescinded consumption advisories for selenium (North Carolina) or are re-evaluating those advisories (California). The State of Idaho uses an adult screening value of 6.2 mg/kg edible tissue and 3.1 mg/kg for children.

Finally, risk managers must weigh the disadvantages associated with consumption of too little selenium (increases in the possibility of debilitating or mortal disease) against risks from consuming too much selenium - clinical selenosis, consisting primarily of readily-recognized changes to skin, hair, and nails that are likely reversible when selenium intake is reduced.

Recommendations

TDH risk managers have established certain criteria for issuing fish consumption advisories based on approaches suggested by the USEPA [37]. When a risk characterization confirms that consumption of four or fewer meals per month (adults: eight ounces per meal; children: four ounces per meal) would result in exposures to toxicants that exceed TDH health-based assessment guidelines, risk managers may wish to recommend that the Commissioner of Health issue consumption advice or ban possession of fish from the affected water body. Possession bans are enforceable under subchapter D of the Texas Health and Safety Code, part 436.061(a) which defines a species of aquatic life adulterated if taken from an area declared prohibited for possession by the director (commissioner of health) [38]. Consumption advisories are not enforceable by law and carry no penalties for noncompliance. Rather, TDH formulates consumption advisories to inform the public of health hazards from consuming environmentally contaminated fish or shellfish, issuing these advisories to allow the public to make informed decisions about eating environmentally contaminated fish or shellfish. Based on the information utilized to characterize risks from consumption of fish from Martin Creek Reservoir, the Seafood Safety Division (SSD) and the Environmental Epidemiology and Toxicology Division (EE&TD) of the Texas Department of Health (TDH), have determined that fish from Martin Creek Reservoir are **not** adulterated with selenium or other chemical contaminants, posing no threat to public health. Therefore, these divisions recommend:

That TDH **rescinds** the fish consumption advisory (ADV-4) presently in place for fish from Martin Creek Reservoir.

Public Health Action Plan

TDH publishes fish consumption advisories and bans in a booklet available to the public through the Seafood Safety Division: (512-719-0215) [39]. The Seafood Safety Division (SSD) also posts this information on the Internet at URL: <http://www.tdh.state.tx.us/bfds/ssd>. The SSD regularly updates its web site. Some risk characterizations for water bodies surveyed by the Texas Department of Health may also be available from the Agency for Toxic Substances and Disease Registry (<http://www.atsdr.cdc.gov/HAC/PHA/region6.html>). The Texas Department of

Health provides the U.S. Environmental Protection Agency (URL: <http://fish.rti.org>), the Texas Commission on Environmental Quality (TCEQ; URL: <http://www.tceq.state.tx.us>), and the Texas Parks and Wildlife Department (TPWD; URL: <http://www.tpwd.state.tx.us>) with information on all consumption advisories and bans on possession. Each year, the TPWD informs the fishing and hunting public of fishing bans in an official hunting and fishing regulations booklet [27], available at some state parks and at establishments that sell fishing licenses.

Readers may direct questions about the scientific information or recommendations in this risk characterization to the Seafood Safety Division (512-719-0215) or the Environmental Epidemiology and Toxicology Division (512-458-7269) at the Texas Department of Health. Toxicological information on a variety of environmental contaminants found in seafood and other environmental media may also be obtained from the Agency for Toxic Substances and Disease Registry (ATSDR), Division of Toxicology, by telephoning that agency at the toll free number (800-447-1544) or from the ATSDR website (URL: <http://www.atsdr.cdc.gov>).

TABLES

Table 1. Contaminants (mg/kg) in Fish Species Collected from Martin Creek Reservoir, 2002.				
Contaminant	# Detected/ # Sampled (Detection Limit)	Average Concentration ± S.D. (Min-Max)*	Health-based Assessment Comparison Value (HAC)	Basis for Comparison Value[†]
Arsenic[‡]				
Channel Catfish	1/12	0.001± 0.001 (nd [§] -0.036)	0.6	Maine Health Department
Cadmium				
Channel Catfish	11/12	0.160±0.38 (nd-1.35)	0.47	ATSDR chronic oral MRL: 0.0002 mg/kg/day
Common Carp	2/2	0.007±0.002 (0.006, 0.009)		
Largemouth Bass	6/7	0.123±0.268 (nd-0.731)		
Flathead Catfish	7/7	0.092±0.166 (0.008-0.463)		
Blue Tilapia	1/1	0.049 (Not Applicable)		
Black Crappie	1/1	0.009 (Not Applicable)		
Copper				
Common Carp	1/2	0.188±0.266 (nd, 0.376)	333	NAS UL: 0.143 mg/kg –day
Mercury				
Channel Catfish	6/12	0.036±0.044 (nd-0.131)	0.7	ATSDR chronic oral MRL: 0.0003 mg/kg –day
Common Carp	1/2	0.023±0.032 (nd, 0.045)		
Largemouth Bass	3/7	0.084±0.142 (nd-0.386)		
Selenium				
Channel Catfish	12/12	1.127±0.338 (0.722-1.73)	6	EPA chronic oral RfD: 0.005 mg/kg –day ATSDR chronic oral MRL: 0.005 mg/kg –day NAS UL: 0.400 mg/day (0.005 mg/kg –day)
Common Carp	2/2	2.545±0.389 (2.27, 2.82)		
Largemouth Bass	7/7	2.21±0.53 (1.39-3.14)		
Flathead Catfish	7/7	1.26±0.30 (1.03-1.91)		
Blue Tilapia	1/1	2.34 (Not Applicable)		
Black Crappie	1/1	2.95 (Not Applicable)		
Zinc				
Channel Catfish	12/12	4.059±0.549 (3.35-4.91)	700	EPA chronic oral RfD: 0.3 mg/kg –day ATSDR chronic oral MRL: 0.3 mg/kg –day
Common Carp	2/2	9.43±4.34 (6.36-12.5)		
Largemouth Bass	7/7	3.98±1.04 (3.0-6.11)		
Flathead Catfish	7/7	4.01±0.42 (3.58-4.67)		
Blue Tilapia	1/1	2.94 (Not Applicable)		
Black Crappie	1/1	4.24 (Not Applicable)		
p,p'-DDE (DL=0.005 mg/kg)				
Channel Catfish	3/3	0.007±0.002 (0.006-0.009)	1.17	EPA chronic oral RfD: 0.0005 mg/kg –day
Common Carp	2/2	0.016± 0.01 (0.009-0.023)		
Largemouth Bass	1/3	.004±0.003 (nd-0.0079)		

*Minimum concentration to maximum concentration (to calculate the range, subtract the minimum concentration from the maximum concentration).

[†]Derived from UL, MRL or RfD for noncarcinogens or the USEPA slope factor for carcinogens; assumes a body weight of 70 kg, and a consumption rate of 30 grams per day, and, for cancer, a 30-year exposure period and an excess lifetime cancer risk of 1 in 10,000 equally-exposed persons.

[‡]Most arsenic in fish and shellfish occurs as organic arsenic, considered virtually nontoxic to humans.

[§] Not detected at concentrations above the laboratory's reporting limit.

Table 2. Reference Dietary Intake Levels for Selenium from All Sources at Various Life Stages ($\mu\text{g}/\text{kg}$).				
Life Stage	Average Body Weight (kg) at End of Life Stage (During Life Stage)	Adequate Intake (AI)* or Recommended Dietary Allowance (RDA)	Tolerable Upper Intake Level (UL)[§]	Comparison with RfD/MRL (mg/day)
Infancy				
0-6 months	7.5 (5.54)	0.015	0.045	0.038 (0.028)
7-12 months	9.84 (8.8)	0.020	0.060	0.050 (0.044)
Childhood				
1-3 years	14.4 (12.1)	0.020	0.090	0.072 (0.061)
4-8 years	25.1 (20.4)	0.030	0.15	0.126 (0.102)
9-13 years	45.5 (36.4)	0.040	0.28	0.228 (0.182)
Adolescence				
14-18 years	63.1 (57.6)	0.055	0.4	0.316 (0.288)
Adulthood, general				
19-70 years	70.4 (70.6)	0.055	0.4	0.350 (0.353)
70-100 years	67.6 (68.8)	0.055	0.4	0.338 (0.344)
Women, 14-50 Years of Age, Who are:				
Pregnant, (pre-pregnancy weight)	65 (61.7)	0.060	0.4	0.325 (0.31)
Lactating	65 (61.7)	0.070	0.4	0.325 (0.31)

* No Recommended Dietary Allowance (RDA) is available for infants; Recommendation is based on an adequate intake (AI)

[§] For purposes of regulating consumption of fish containing selenium TDH assumes that people obtain up to 1/2 of their daily intake from sources other than fish from Martin Creek Reservoir.

Age or Condition	Average Weight (kg) During Period	Hazard Quotient at Average Concentration (95% UCL)	Meals/Month at the Arithmetic Average Selenium Concentration (1.61 mg/kg)	Meals/Month at the 95% UCL on the Arithmetic Average Concentration (1.809 mg/kg)
Infants, 0-6 Months	5.5	0.4 (0.5)	9	8
Infants 7-12 Mo	8.8	0.3 (0.3)	15	13
Children, 1-3	12	0.4 (0.45)	20	18
Children, 4-8	20	0.2 (0.3)	33	29
Children, 9-13	36	0.1 (0.2)	60	53
Adolescents, 14-18	58	0.2 (0.2)	96	86
Adults, 19-70+	70	0.1 (0.2)	116	103
Pregnant Women, 14-50	62	0.2 (0.2)	103	92
Lactating Women, 14-50	62	0.2 (0.2)	103	92

Figure 1

1984-2003 Martin Creek Reservoir Selenium Fish Tissue Concentrations

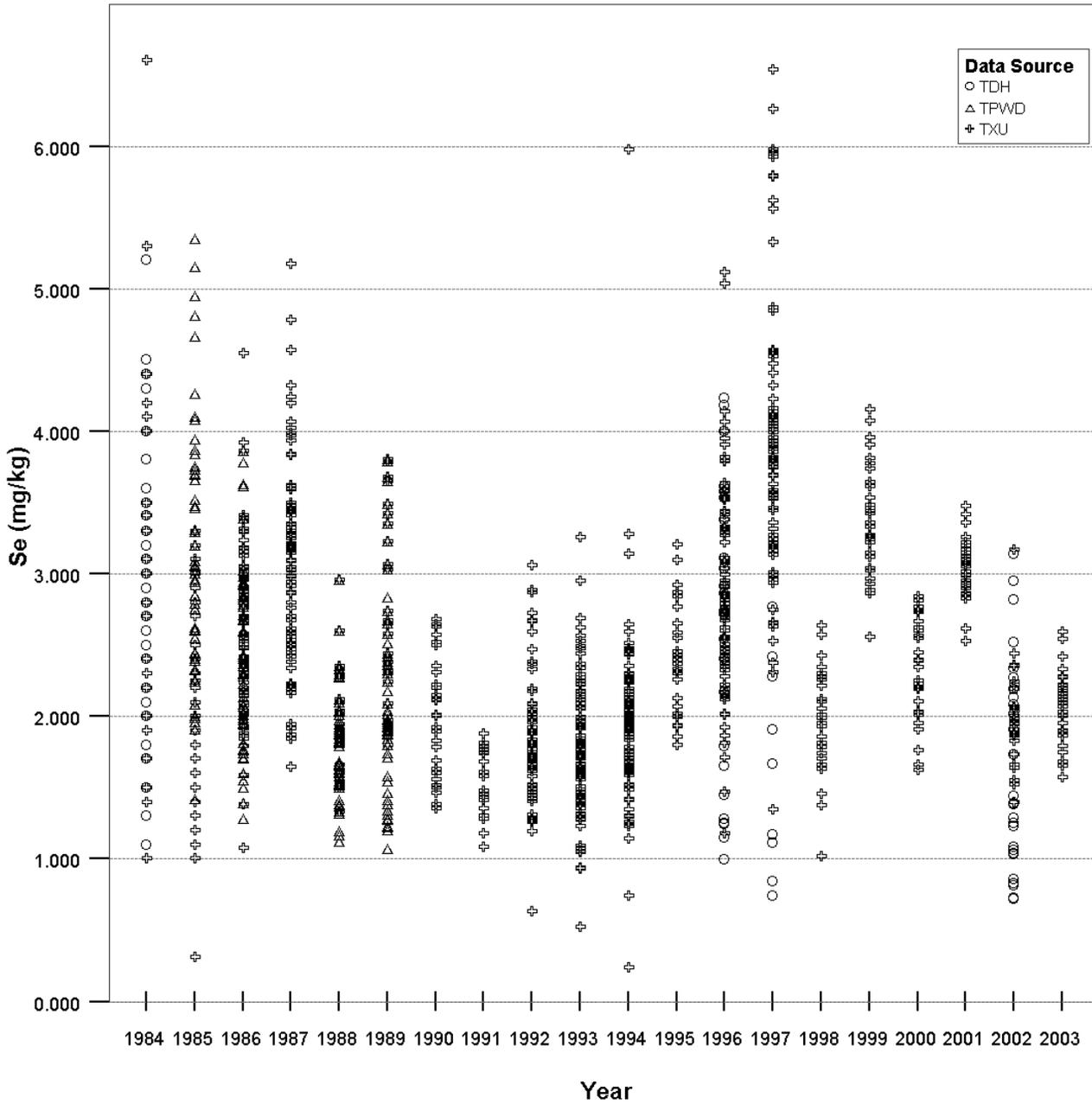
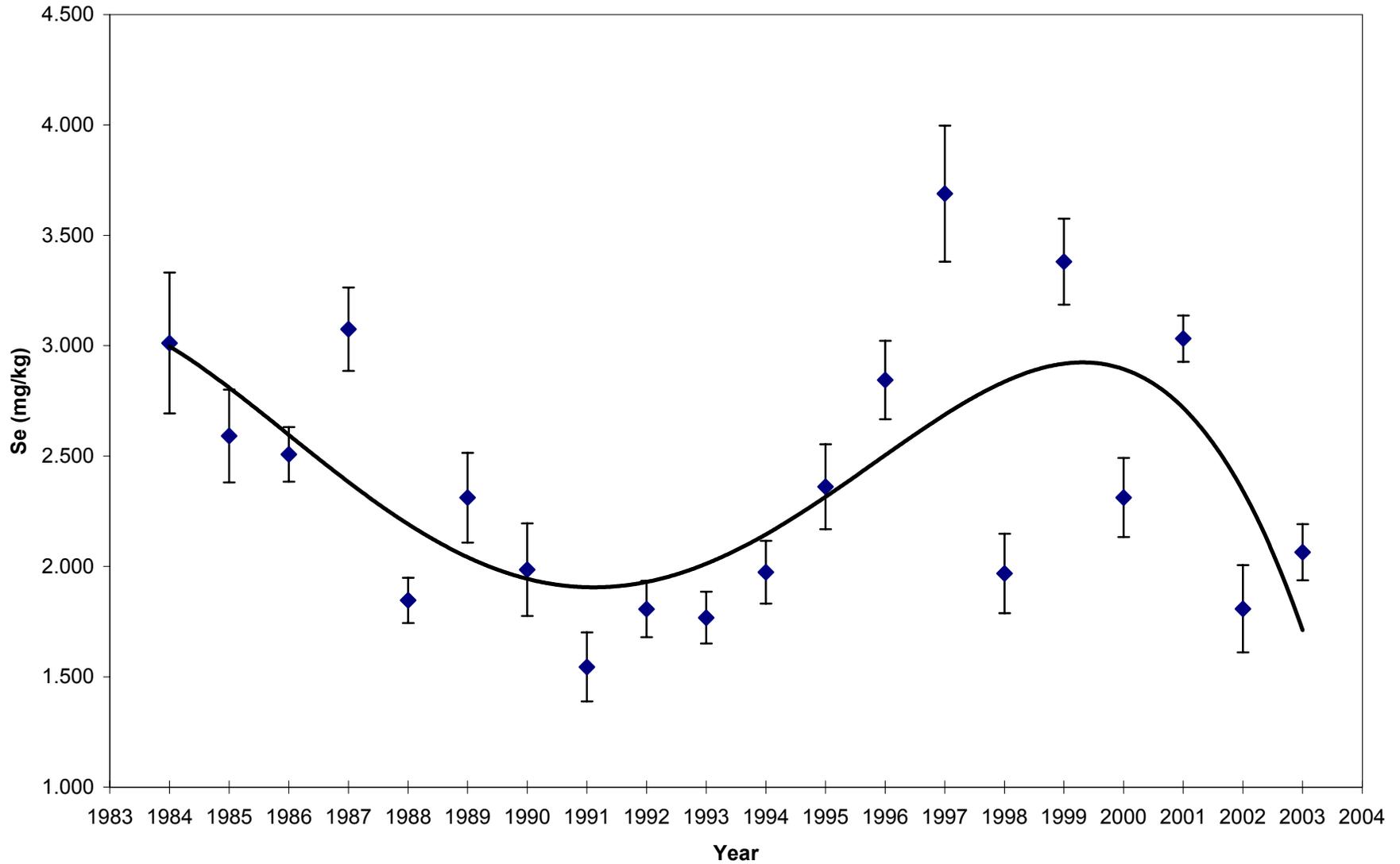


Figure 2

1984-2003 Martin Creek Reservoir Mean Selenium Fish Tissue Concentrations



Data Sources: TDH, TPWD, and TXU

*Error Bars represent 99% confidence interval for means

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Martin Creek Lake Sample Sites

