

QUANTITATIVE RISK CHARACTERIZATION

Welsh Reservoir

Titus County, TX

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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 Brandy Branch, Welsh, and Martin Creek reservoirs in 1992 because samples from those waterbodies contained selenium at levels considered excessive by some health risk managers. Consequent to that consumption advisory, the Texas Commission on Environmental Quality (TCEQ) included these waterbodies 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 for 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 continue to 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 the Texas Parks and Wildlife Department (TPWD) met to discuss water quality issues and fish consumption advisories associated with the Welsh, Brandy Branch, and Martin Creek reservoirs. Participants agreed that TDH should reevaluate the fish consumption advisory for Welsh Reservoir, Brandy Branch Reservoir, and Martin Creek Reservoir before TCEQ commenced developing TMDLs for these 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. The present report summarizes the findings of the 2002 assessment of Welsh Reservoir and characterizes current and past risks from consumption of fish from this reservoir considered likely to contain excess selenium or other environmental contaminants.

Welsh Reservoir– lying within the Piney Woods natural region is a 1,465 acre impoundment of Swauano Creek located 5 miles west of Daingerfield (population- 2,517) and 10 miles southeast of Mount Pleasant (population- 13,935) in Titus County (population- 28,118) [2]. The reservoir was impounded in 1976 to serve a source of cooling water for the Welsh Power Plant, a lignite-fired power plant operated by Southwestern Electric Power Company (SWEPCO), a subsidiary of American Electric Power (AEP). A once-through cooling water process is used for power generating operations. Although AEP provides a single public boat ramp at the reservoir, no camping, picnic, or restroom facilities are available. Nonetheless, boating and fishing opportunities attract many people to Welsh Reservoir, as other state parks (Caddo, Martin Creek Lake State Parks) in the near vicinity provide facilities to encourage recreational activities. Subsistence fishing may also occur at Welsh Reservoir.

During 1978 and 1979, releases occurred from power plant ash settling ponds into Martin Creek Reservoir. Analyses of water from the Martin Creek Reservoir power plant settling ponds after the releases showed those waters to contain selenium in excess of two parts selenium per million parts water (ppm) [3]. Subsequent to the 1978-1979 discharges, researchers from the Texas Parks and Wildlife Department (TPWD) analyzed fish and water samples from Martin Creek Reservoir, finding excess selenium in both media. Fish muscle tissue from Martin Creek

Reservoir contained selenium at levels exceeding those commonly found in freshwater fish [4]. The Texas Parks and Wildlife Department (TPWD) implicated excess selenium in a series of fish kills occurring in Martin Creek Reservoir in the late 1970's and early 1980's [3,5]. Those fish kills, along with research documenting excess selenium in Martin Creek Reservoir water and in fish tissue from the reservoir led TPWD to analyze and review selenium in water and biota from several Texas power cooling reservoirs [3]. From 1986 to 1989, TPWD monitored selenium in largemouth bass muscle tissue from Welsh Reservoir, observing mean concentrations ranging from 2.28 mg selenium per kg tissue to 4.41 mg/kg. Mean selenium concentrations in bluegill muscle tissue ranged from 2.21 to 3.77 mg/kg [6].

TDH issued ADV-4 – covering Martin Creek, Brandy Branch, and Welsh Reservoirs in 1992 – a time when no reference dose (RfD) or minimal risk level (MRL) existed for 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 (2) mg/kg of selenium in any food [7]. The California Department of Health Services had similarly established guidelines for consumption of fish or waterfowl containing excess selenium [8] to address the human health implications of exposure to selenium through consumption of such game species. California health authorities thereafter issued health advisories if the mean 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) of approximately 0.400 mg/day (5.71 µg/kg/day for a 70 kg adult) for dietary selenium [9]. Assuming the average adult ingests 0.200 mg/day (2.86 µg/kg/day) of selenium from dietary sources other than fish from an affected waterbody, or approximately 50% of the TDH-developed UL, the Texas health department specified that adults could safely ingest up to 0.20 mg selenium per day in *fish* or *shellfish* from affected waterbodies [9]. 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 [7, 8]. At the same time, TDH re-evaluated selenium data from fish collected from Welsh Reservoir between 1986 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 Welsh Reservoir potentially posed a risk to public health [9]. Consequently, the (1992) consumption advisory for Martin Creek, Welsh, and Brandy Branch Reservoirs (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 Welsh Reservoir. ADV-4 also recommends 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 Welsh Reservoir should not further supplement their selenium intake with dietary supplements containing selenium in excess of 0.5 milligrams per dose [10].

The Texas Department of Health first sampled fish from Welsh Reservoir in 1998 to re-evaluate the 1992 fish consumption advisory with intra-agency data. Fish collected from Welsh (TDH) in 1998 contained an average of 2.68 mg selenium/kg edible tissue [11] while fish collected and analyzed by AEP from Welsh Reservoir in that same year as a condition of the company's discharge permit contained selenium at a mean concentration of 4.3 mg/kg. [12]. Consequently, TDH elected to retain the consumption advisory (ADV-4) on fish from Welsh Reservoir.

The present report – while addressing a suite of potential toxicants in fish that TDH collected in 2003 from Welsh Reservoir – concentrates on selenium in fish collected from this reservoir.

Selenium as a Nutrient and as a Toxicant

TDH toxicologists reviewed the biology of selenium to produce this risk assessment. The following paragraphs describe the nutritional roles of selenium in humans and its human toxicity.

The Roles of Selenium in Nutrition

Selenium is a naturally occurring non-metallic 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 [13], both of which are water-soluble compounds [13]. 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 organic selenium compounds are more readily used by animal systems.

Selenium is an essential dietary element for humans and animals [13]. 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 the amino acid 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 [13], including four selenium-dependent glutathione peroxidases [13]. Glutathione peroxidases minimize cellular damage [13] by breaking down peroxides and other toxic byproducts of cellular metabolism before those substances can injure a cell [13]. Selenoproteins P and W may also protect against oxidative stress. Selenium-dependent iodothyronine deiodinases regulate thyroid hormone metabolism [13]. Thioredoxin reductases repair cellular constituents by hydrolyzing intramolecular disulfide bonds [13]. These same enzymes regenerate ascorbic acid from its oxidized metabolites [13]. Finally, a selenium-dependent selenophosphate synthetase participates in selenium metabolism [13]. 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 [13].

According to the ATSDR, people in the U.S. consume, on average, 0.70 to 0.150 milligrams of selenium each day [14]. The NHANES III survey of dietary habits estimates average dietary intake of selenium to be 0.114 mg/day. NHANES III estimates that individuals taking dietary supplements take in about 0.116 mg/day. Those in the 50th percentile of survey respondents who do not take selenium supplements ingest about 0.106 mg/day, while 50 percent of those who do take such supplements ingest about 0.109 mg/day. Of all individuals surveyed, ninety-nine percent of those who do not take supplements ingest less than 0.250 mg of selenium each day. Those in the 99th percentile of individuals taking selenium supplements consume an estimated 0.250 mg of selenium per day [15]. While the NHANES III data may be subject to recall bias, studies independent of NHANES support its conclusions on upper limits of consumption. For instance, only about three percent (3%) of Maryland residents consumed more than 0.20 mg selenium per day [13]. Such studies thereby support the notion that dietary selenium intakes in the U.S. exceed the amount necessary for optimal health but that intake is well below tolerable upper intake levels (UL's) established to protect humans from the effects of excess selenium. Similarly, supplementation of dietary intake with mineral supplements containing selenium is probably not a major source of this micronutrient for the U.S. population. It is possible, but unlikely, that formula fed infants take in more selenium than do breast-fed infants because some commercial infant formulas may contain selenium [13]. The National Academy of Sciences (NAS) has promulgated RDA's recommended dietary allowances) for selenium (Table 2). According to the NAS, infants should take in about 0.002 mg selenium per kg body weight. Children between the ages of 1 and 8 should consume between 0.20 and 0.30 mg/day, while boys and girls between 9 and 18 years of age should ingest 0.40-to 0.55 mg/ day of selenium. Adult men – and women who are not pregnant or lactating – should ingest a minimum of 0.55 mg selenium each day. The RDA for pregnant women is 0.60 mg/day, while that for lactating women is 0.70 mg/day [13]. The RDA is not a toxicity value, but is the dietary intake level that will meet the nutritional requirement for selenium of nearly all (97-98%) individuals in a specific age and gender group [13].

Most foods in the human diet supply some quantity of selenium: fruits and vegetables (0.02 mg/kg average concentration) are generally low in this mineral. Other foodstuffs containing selenium include 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 origin of food and the meat content of the diet are major determinants of selenium intake. Although selenium intake may vary by region, extensive transport of foods throughout the U.S. and Canada protects people in low-selenium geographic areas from suffering low dietary selenium intakes [13]. Similarly, the USDA prohibits commercial sale of agricultural products grown in seleniferous soils, preventing entry of those foodstuffs into the U.S. food supply [13]. Drinking water does not supply nutritionally significant amounts of selenium except in limited locales [13].

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 [16] but respiratory and fecal excretion also occurs [16]. 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 [16]. When intake regularly exceeds use or excretion, selenium accumulates in body tissues, including the liver, kidneys, hair, and nails [16]. The clinical syndrome associated with excess body burdens of selenium is selenosis [16]. 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 [16]. The breath may have a garlic-like or sour-milk odor from expiration of volatile organic selenium-containing compounds [16]. Thus, in addition to the RDAs, the NAS has developed tolerable upper intake levels (UL) for selenium. 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"* [13]. In infants, the UL is 0.045 to 0.060 mg per day, depending on body weight; in children between 1 and 3 years of age, 0.090 mg/day; at ages 4-8, the UL is between 0.150 and 0.280 mg/day; for adolescents, and all adults, the UL is 0.400 mg/day. The USEPA's reference dose (RfD) is 0.350 mg/day for a 70-kg adult (0.005 mg/kg/day), as is the minimal risk level (MRL) promulgated by the ATSDR [13, 14, 17]. The RfD, MRL, and UL are compatible concepts and, when expressed as mg/kg/day, doses are comparable (0.005 mg/kg/day), having come from the same Chinese studies [13, 14, 17].

To enhance its assessment of selenium in fish collected in 2003 from Welsh Reservoir and to further support conclusions drawn from the 2003 selenium data from this reservoir, TDH reviewed selenium data collected over seventeen (17) years by TDH, TPWD, and AEP [12, 18, 19]. TDH also contacted states that have issued selenium consumption advisories to gather information about sentinel advisory concentrations used to regulate consumption of fish and shellfish containing excess selenium. California, North Carolina, and Idaho responded to requests for information [20, 21, 22, 23, 24]. In the past, the California Environmental Protection Agency (CEPA) utilized a concentration of two (2) mg selenium/kg edible tissue to formulate selenium consumption advice. Currently, California does not have a health advisory level, but is reviewing NHANES data on daily selenium intake for use in revising that state's comparison concentration for this contaminant [20]. A spokesperson from the CEPA indicated that California will likely utilize the oral RfD for selenium and will incorporate relative source contribution methodology to account for dietary selenium from sources other than recreationally caught freshwater fish [20]. The North Carolina Department of Health and Human Services (NCDHHS) recently rescinded two selenium advisories [21, 24]. The spokesperson at NCDHHS could not state the selenium concentration in fish used for the 1993 advisories. However, this spokesperson also recommended use of the oral RfD along with USEPA guidance for developing consumption advice [21]. The Idaho Bureau of Health and Safety currently employs the oral RfD and USEPA's guidelines to formulate consumption advisories. Idaho's advisory concentrations for selenium in freshwater fish tissues are 6.2, 5.4, and 3.1 mg selenium/kg edible tissue for the public in general, pregnant women, and children, respectively [22, 23].

METHODS

Fish Tissue Collection and Analysis

The Texas Department of Health (TDH) collects and analyzes edible fish and shellfish tissues from the state's public waters to evaluate potential health risks to recreational and subsistence fishers and other who consume environmentally contaminated seafood. These samples usually represent the species, trophic levels, and legal-sized specimens available for consumption. When practical, TDH collects samples from two or more 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 (crab and oyster) 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; analyzed as Aroclors 1016, 1221, 1224, 1232, 1248, 1254, and 1260).

Description of the Welsh Reservoir Sample Set

In March 2003, personnel from the Seafood Safety Division of the TDH collected a total of twenty-five (25) fish from Welsh Reservoir (see appendix for map): three (3) black crappie; five (5) channel catfish; two (2) common carp; two (2) flathead catfish, (1) spotted gar, and twelve (12) largemouth bass. All fish collected were of legal size for possession according to Texas Parks and Wildlife Department (TPWD) regulations [25].

The TDH laboratory analyzed all twenty-five (25) samples for metals. Five (5) of those 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 contaminants in all submitted fish tissue samples.

Data Analysis

TDH performed all statistical procedures on IBM-compatible microcomputers using SPSS software [26]. TDH generated descriptive statistics (mean, standard deviation, median, range, and minimum and maximum concentrations) for each reported contaminant in each species at each sampling site. TDH utilized Microsoft Excel [27] spreadsheets to generate health-based assessment comparison values (HAC values) and to calculate hazard quotients, hazard indices, cancer risk values, and allowable consumption of each fish species from the two Welsh Reservoir sites. Statistical analyses included all samples containing contaminants.

¹Nearly all mercury in upper trophic-level fish over three years of age is methylmercury [38]. 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 [39]. TDH may utilize the terms "mercury" and "methylmercury" interchangeably to refer to methylmercury in fish.

Derivation of Health-Based Assessment Comparison Values (HACs)

People who regularly eat contaminated fish are generally exposed to 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. Presuming that people eat a variety of fish, TDH routinely evaluates mean contaminant concentrations across species and locations within a specific water body because this approach best reflects the likely exposure pattern of consumers over time. However, the agency also may examine the risks associated with ingestion of individual species of fish from individual collection sites at higher concentrations (e.g., 95th percentiles on mean concentrations), should the need arise.

TDH evaluates chemical contaminants in fish by comparing 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) [17] 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}) [14]. 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 [28].”* The cancer risk comparison values (HAC_{ca}) used at TDH to assess carcinogenic potential from consumption of fish containing carcinogenic chemicals are calculated from the USEPA's chemical-specific cancer slope factors (SFs) [17, 29], using standard weights and consumption rates, acceptable lifetime risk levels (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, or those who consume exceptionally large quantities of fish or shellfish – who eat environmentally contaminated seafood [17]. Although comparison values used for assessing the probability of cancer do not contain “uncertainty” factors as such, conclusions derived from those probability determinations do have substantial safety margins. Therefore, adverse health effects are very unlikely to occur, even at concentrations approaching 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 by risk managers to assure protection of public health. TDH finds it unacceptable when consumption of four or fewer meals per month would result in exposures that exceed a HAC value or other measure of risk. TDH advises people who wish to minimize their exposure to environmental contaminants in seafood to eat a variety of fish and shellfish and to limit consumption of those species that are most likely to contain environmental toxicants.

Addressing the Potential for 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 [28]. Therefore, TDH conservatively assumes that each time people eat seafood from an affected water body, they will be exposed to all of the chemicals present in any sample and, further, that accumulative potential adverse systemic or carcinogenic effects will be additive in nature.

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 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 [30]. 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 [31]. 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 [31], 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 [31]. Children may also be more prone to developing certain cancers from chemical exposures than are adults. If a chemical – or a class of chemicals – is shown to 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* [32] and USEPA’s *National Agenda to Protect Children’s Health from Environmental Threats* [31], 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 Welsh 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 from the RfD² (0.005 mg/kg/day) to use in assessing selenium concentrations in fish tissue [33]. 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 dietary selenium intake apportions a health-based comparison value to ensure sufficient protection, given other anticipated exposure sources. In the case in point, those exposures are primarily of dietary origin. The RSC method of accounting for sources of selenium other than recreationally caught fish results in a more stringent health-based assessment comparison value (HAC value) for selenium than would be applied to fish if other dietary sources were not considered. Adult intake of selenium from all foods is around 0.10-0.25 mg/day for adults in the general population [13, 14, 17] – 25% to 70 % of the RfD. Applying relative source contribution (RSC) methods to the RfD for selenium suggests that people may ingest an additional 0.20 mg/day of selenium from recreationally caught fish containing selenium. Thus, to derive the health-based assessment comparison value (HAC value) for selenium and its compounds, TDH assumed 50% of daily selenium intake to come from other foodstuffs (0.10 to

² The ATSDR minimal risk level (MRL) and the National Academy of Sciences UL are equivalent to the USEPA chronic oral RfD for selenium. Like the RfD, the MRL and the UL for selenium are 0.005 mg/kg/day. All can be used interchangeably to derive the health-based assessment comparison value for noncancerous effects of selenium.

0.20 mg/day for a 70-kg adult and subtracted this amount from the RfD for selenium published in the IRIS database. TDH used the remainder of the RfD (0.0025 mg/kg/day) to calculate a tissue residue concentration (HAC_{nonca}), daily consumption of which will not exceed the RfD after accounting for other sources of exposure.

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

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

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 selenium at concentrations considered above those normally observed in freshwater fish, assuming consumption of one eight-ounce meal per week. TDH does not recommend further reductions in tissue concentration to protect children because not only is the RfD protective of pregnant women, and therefore, their fetuses, 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 [17].

RESULTS

Seafood Safety Division personnel collected samples from Welsh Reservoir on March 11 and 12, 2003, submitting the samples to the TDH laboratory for analysis on March 17, 2003.

Analytical and Statistical Results

Organic Contaminants

Two of five samples analyzed for volatile organic compounds contained acetone – a common post-collection contaminant – at a level near the laboratory’s reporting limit (data not shown). The TDH laboratory reported no other organic contaminants at measurable concentrations in any sample.

Inorganic or metalloid Contaminants, including Selenium, in 2003 Samples

Fish tissue samples from Welsh Reservoir collected in 2003 contained copper, lead mercury, selenium, and zinc. Table 1 shows mean concentration, standard deviation, minimum concentration, maximum concentration, number of samples of each species containing a contaminant, along with the total number of samples of each species. Selenium and zinc were present in all samples. Mean selenium and zinc concentrations were 1.85 ± 0.874 and 4.13 ± 2.35 mg/kg, respectively. Ten samples contained copper (0.169 ± 0.34 mg/kg). Nine of twenty-five samples contained measurable mercury (0.049 ± 0.082 mg/kg). A single sample of the twenty-five samples analyzed for this metalloid contaminant contained lead (0.0469 mg/kg).

Historical Selenium Data

At various times since 1986, the Texas Parks and Wildlife Department, Texas Department of Health, and/or American Electric Power (owner and manager of record of Welsh Reservoir power plant) have measured selenium concentrations in fish from Welsh Reservoir, finding the element present in all tissue samples collected through 2003. TDH performed statistical analyses on 1,393 selenium measurements in fish (collected between 1986 and 2003) for measures of central tendency and variance (Figures 1 and 2). For the seventeen (17) years’ observations, selenium concentrations in fish tissue ranged from a minimum of 0.162 mg/kg to a maximum of 9.99 mg/kg. The mean concentration of selenium for 1,393 samples (17 years’ observations) was 3.6 mg/kg (99% CI = 0.09 mg/kg) (Figures 1 and 2). The mean concentration reached an apex in 1999 (5.95 mg/kg), showing an apparent decline thereafter (statistics not performed) (Figure 2). Statistically speaking, the mean tissue selenium concentration in a random sample from Welsh Reservoir would be very unlikely to exceed 3.70 mg per kilogram edible tissue. Analysis indicated that concentrations greater than 6.8 mg/kg are extreme values or “outliers” (three standard deviations above the mean selenium concentration). Outliers were retained in the dataset as no scientifically valid reasons for removing those data points were found. It is notable, that, despite the fact that several laboratories analyzed the specimens and that those laboratories may have utilized different methodologies, only thirty-one (2.22%) of 1,393 selenium measurements were three or more standard deviations above the mean and thus unlikely to be representative of the concentration of selenium in most fish from Welsh Reservoir.

DISCUSSION

Risk Characterization

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

Organic compounds

Organic contaminants were not prominent in fish samples from Welsh Reservoir. Two samples contained acetone at concentrations near the laboratory's reporting limit. The absence of toxicologically significant organic contaminants in these samples obviates the necessity for further discussion.

Inorganic or metalloid Components other than Selenium

Along with selenium, TDH analyzed the 2003 fish tissue samples from Welsh Reservoir for six additional metalloid contaminants, finding some copper, lead, mercury, and zinc along with selenium. No metalloid contaminant observed exceeded its respective HAC value (Table 1), the hazard quotient for each being less than 1.0. Therefore, consumption of fish from Welsh Reservoir that contain copper, mercury, zinc, lead, or selenium is unlikely to result in adverse effects. Nonetheless, the present report addresses selenium in more detail than other contaminants because, historically, selenium has been the only contaminant of concern in fish from Welsh Reservoir.

Selenium

The mean concentration of selenium in fish collected by TDH from Welsh Reservoir in the March 2003 was 1.85mg/kg (95% UCL = 2.34 mg/kg). Moreover, despite a few high selenium measurements in fish from this reservoir (maximum observed concentration = 9.99 mg/kg in a largemouth bass collected in 1993), the mean selenium concentration for all samples collected by TDH, TPWD, or AEP over seventeen years was 3.6 mg/kg (99% UCL = 3.70 mg/kg). Historically, the mean sample concentration only once equaled the selenium HAC_{nonca} established in this risk characterization (6 mg/kg), in 1999. It is, therefore, unlikely that selenium in fish from Welsh Reservoir will regularly exceed the HAC_{nonca} (6 mg/kg) derived from current toxicity values. Thus, those who regularly consume fish from Welsh Reservoir are unlikely to chronically exceed the tolerable upper intake level or the RfD for selenium. TDH further notes that some states have rescinded consumption advisories for selenium (North Carolina) while others are re-evaluating those advisories (California) and that the State of Idaho uses a screening value of 6.2 mg/kg for adults eating fish containing excessive selenium and 3.1 mg/kg for children.

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), equivalent to a tissue concentration of 12 mg/kg for one standard adult meal per week (8 ounces). The NAS established tolerable upper intake levels (UL) based on age and body weight that culminates in a tolerable upper level (UL)

for most adults of 0.400 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 higher at each life stage than is the RfD. The RfD, MRL, and UL are each derived from a study of a Chinese population with selenosis [13, 14, 17]. All three toxicity values contain safety factors for sensitive subpopulations, although no subpopulation has proven more sensitive to the toxic effects of selenium than have others. In fact, some authorities have suggested that children may need more selenium for proper growth and development than do adults [17].

Hazard quotients for the 2003 samples from Welsh Reservoir were calculated from both the mean concentration of selenium in fish tissues and the 95% UCL concentration using the current RfD for selenium (Table 3), as were allowable numbers of meals for fish from the reservoir. Hazard quotients for selenium in fish from Welsh Reservoir ranged from 0.15 to 1.3 in people of different ages and body weights, depending on daily consumption rates. (Note: in the calculations for 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 Welsh Reservoir). Comparisons of mean and 95% UCL concentrations of selenium in fish collected from Welsh Reservoir in 2003 with the health-based assessment comparison value (HAC_{nonca}) – derived from the reference dose using relative source contribution methods – suggest that people who eat fish from this reservoir are unlikely to experience adverse health outcomes – even if very young or of low body weight.

Characterizing Cancer Risk from Consumption of Fish from Welsh Reservoir

Cancer potency factors (slope factors) are not available for copper, lead, mercury, selenium, or zinc [17]. Thus, TDH was unable to determine the probability of excess cancers from consuming these contaminants in fish from Welsh Reservoir. Since no organic carcinogens were observed in fish collected in 2003 from Welsh Reservoir, TDH found it unnecessary to further address carcinogenic potential from eating fish from this reservoir.

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

Organic Contaminants

Fish from Welsh Reservoir contained no organic contaminants of toxicologic significance. Thus, TDH expects no cumulative adverse effects from organic contaminants, either carcinogenic or systemic, from consumption of fish from Welsh Reservoir.

Metalloid Contaminants

Fish collected in 2003 from Welsh Reservoir contained several metalloid contaminants. However, those contaminants 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 Welsh Reservoir. It was not possible to assess the likelihood of cumulative carcinogenic effects of metalloid contaminants because slope factors are unavailable for the observed metal-containing inorganic contaminants [17].

Conclusions

Dietary selenium intakes of up to 0.853 mg/day (the “no observed adverse effects level or NOAEL”) do not usually produce signs of toxicity [13, 17]. Furthermore, the known functions of selenium at the cellular level support the notion that supplementing the diet with as much as 0.20 mg selenium/day may reduce the occurrence of certain high-rate cancers [34]. Nonetheless, at some chronic ingestion rate, selenium concentrations in excess of the NOAEL become toxic to humans. However, advances in knowledge of the biology of selenium, levels that cause toxicity, benefits of selenium consumption, availability of nationally promulgated reference doses, and research indicating that most people do not consume exceptionally large quantities of selenium in their food contributed to the decision to increase the HAC_{nonca} from 2 mg/kg to 6 mg/kg.

The mean and 95th percentile on the mean selenium concentration in fish from Welsh Reservoir collected in 2003 did not exceed the HAC_{nonca} for selenium; nor did selenium in any individual sample exceed the HAC_{nonca} . At an average concentration of 1.85 mg/kg, a 70-kg adult could eat about one hundred (100) ounces of fish per month (13 eight-ounce meals per month). A 20-kg (44-lb) child could consume up to 29 ounces per month – seven (7) four-ounce meals – of fish from Welsh Reservoir. Similarly, a 35-kg (77-lb) child could consume 50 ounces per month (12 four-ounce meals per month or six (6) eight-ounce meals per month). At a concentration equivalent to the 95% upper confidence limit on the mean (2.34 mg/kg), an adult could consume 80 ounces per month or ten (10) eight-ounce meals per month while a 20-kg child could eat 23 ounces or six (6) four-ounce fish meals per month from Welsh Reservoir – in addition to selenium obtained from other dietary sources. At both the mean concentration and the 95th percentile concentration, TDH has determined that these meal quantities are equivalent to unlimited consumption of fish from this reservoir.

Public Health Implications

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. Risk managers must weigh the disadvantages associated with consumption of too little selenium (increases in the probability 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.

Based upon this assessment of current sampling data and upon many years’ monitoring data, the TDH concludes that consumption of fish from Welsh Reservoir **poses no apparent public health hazard.**

Recommendations

TDH risk managers have established certain criteria for issuing fish consumption advisories based on approaches suggested by the USEPA [35]. 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 the department's health-based 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) that defines a species of aquatic life adulterated if taken from an area declared prohibited for possession by the director (commissioner of health) [36]. Consumption advisories are not enforceable by law and carry no penalties for noncompliance. Rather, TDH formulates consumption advisories to tell the public of health hazards from consuming environmentally contaminated fish or shellfish to allow people to make informed decisions about eating environmentally contaminated fish or shellfish. Based on the information in the present risk characterization, the Seafood Safety Division (SSD) and the Environmental Epidemiology and

Toxicology Division (EE&TD) of the Texas Department of Health (TDH), find that fish from Welsh Reservoir do not contain excess selenium or other toxicants and that consumption of such fish poses no threat to public health. Therefore, these divisions recommend:

That TDH *rescind* the fish consumption advisory (ADV-4) presently in place for fish from Welsh Reservoir.

Risk Communication

TDH publishes fish consumption advisories and bans in a booklet available to the public through the Seafood Safety Division: (512-719-0215) [37]. 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 [25], 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 from Welsh Reservoir collected in 2003.				
Contaminant	# Detected/ # Sampled	Average Concentration ± S.D. (Min-Max)*	Health-based Assessment Comparison Value (HAC)	Basis for Comparison Value[†]
Copper				
Black crappie	1/3	0.09 ± 0.156 (nd-0.270)	333	NAS UL: 0.143 mg/kg –day
Channel catfish	2/5	0.104 ± 0.143 (nd-0.281)		
Largemouth bass	4/12	0.082 ± 0.127 (nd-0.345)		
Common carp	2/2	1.20 ± 0.072 (1.15-1.25)		
All Species	9/25	0.167 ± 0.333 (nd-1.25)		
Lead				
Spotted gar	1/1	0.047		None available
Mercury				
Largemouth bass	7/12	0.089 ± 0.096 (nd-0.284)	0.7	ATSDR chronic oral MRL: 0.0003 mg/kg –day
Spotted gar	1/1	0.16		
All Species	8/25	0.049 ± 0.082 (nd-0.284)		
Selenium				
Black crappie	3/3	3.31 ± 0.354 (2.91-3.59)	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)
Channel catfish	5/5	1.12 ± 0.497 (0.36-1.75)		
Common carp	2/2	3.16 ± 0.184 (3.03-3.29)		
Flathead catfish	2/2	1.44 ± 0.453 (1.12-1.76)		
Largemouth bass	12/12	1.68 ± 0.562 (1.22-2.72)		
Spotted gar	1/1	1.32		
All Species	25/25	1.85 ± 0.874 (0.36-3.59)		
Zinc				
Black crappie	3/3	3.93 ± 0.193 (3.72-4.10)	700	EPA chronic oral RfD: 0.3 mg/kg–day ATSDR chronic oral MRL: 0.3 mg/kg–day
Channel catfish	5/5	4.07 ± 0.534 (3.44-4.70)		
Common carp	2/2	10.18 ± 6.54 (5.55-14.80)		
Flathead catfish	2/2	4.85 ± 0.339 (4.61-5.09)		
Largemouth bass	12/12	3.23 ± 0.314 (2.93-4.15)		
Spotted gar	1/1	2.32		
All Species	25/25	4.14 ± 2.41 (2.32-15.10)		

*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.
^{**}HAC_{nonca} reflects the contribution of other sources to the total amount of selenium ingested per day (50% of total intake is attributed to sources other than fish from Welsh Reservoir; therefore, the HAC^{nonca} is ½ what it would be if all selenium were assumed to come from fish from this reservoir.

Table 2. Reference Dietary Intake Levels for Selenium from All Sources at Various Life Stages (µg/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 Welsh Reservoir.

Table 3. Hazard Quotients (HQ) and Allowable Number of Meals per Month of Fish Collected from Welsh Reservoir in 2003.

Age or Condition	Average Weight (kg) During Period	Hazard Quotient at Mean Concentration (95% UCL on Mean)	Meals/Month at Mean Selenium Concentration (1.85 mg/kg)	Meals/Month at the 95% UCL on Mean Concentration (2.34 mg/kg)
Infants, 0-6 Months	5.5	1.0 (1.28)	4	3
Infants 7-12 Mo	8.8	0.63 (0.8)	6.4	5
Children, 1-3	12	0.46 (0.59)	8.7	3
Children, 4-8	20	0.56 (0.7)	7	5.7
Children, 9-13	36	0.15 (0.39)	13 (6.5)*	10 (5)
Adolescents, 14-18	58	0.38 (0.48)	10.5	8
Adults, 19-70+	70	0.32 (0.4)	12.7	10
Pregnant Women, 14-50	62	0.36 (0.45)	11	9
Lactating Women, 14-50	62	0.36 (0.45)	11	9

* Numbers in parentheses represent hazard quotients and meal sizes at eight-ounce meal size.

FIGURES

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Appendix
(Map of Welsh Reservoir Sampling Sites)