Characterization of Potential Adverse Health Effects Associated with Consuming Fish from the

Arroyo Colorado

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INTRODUCTION

The primary goal of risk characterization is to provide understanding of the type and magnitude of potential adverse effects of an agent under the particular circumstances of its release[1] or its presence in the environment and the probability that the substance(s) will actually affect a human population. This document attempts to fulfill this goal for chemical contaminants in fish collected in 2006 from the Arroyo Colorado.

Description of the Arroyo Colorado and History of Consumption Advisories (ADV-5, ADV-6, ADV-19)

"The Arroyo Colorado, a stream running through the Rio Grande delta, originates at the Llano Grande in Hidalgo County, flowing northeast for 52 miles through Cameron and southeastern Willacy counties to its mouth opposite Padre Island on Laguna Madre. The Arroyo is navigable to barges through parts of the channel dredged from the Gulf Intracoastal Waterway to the port of Harlingen. From the port of Harlingen to a point near the headwaters of the Arroyo Colorado, the water body is navigable only by small boats. The Arroyo Colorado was likely an early channel of the Rio Grande. As a former outlet of the Rio Grande, the Arroyo Colorado still carries excess water from the Rio Grande to the Laguna Madre. The upper drainage area of the Arroyo Colorado includes rich land used for farming and for growing citrus trees. The Arroyo Colorado also includes the cities of Harlingen and Rio Hondo. The lower arroyo courses through an area of farms, ranches, and coastal playas. Typical bank-side vegetation includes reeds overhung by such trees as the huisache, mesquite, and Texas ebony. The final reaches of the Arroyo Colorado pass through Laguna Atascosa National Wildlife Refuge. In the refuge, the Arroyo Colorado's banks and adjoining thorn forests and marshes shelter various endangered and rare species such as ocelots, jaguarundis, and indigo snakes. The estuary protects roseate spoonbills, brown pelicans, and many other bird species.[2]

The United States Fish and Wildlife Service (USFWS) requested in 1980 that the United States Environmental Protection Agency (USEPA) investigate contamination of the Arroyo Colorado, reporting that fish collected from the Arroyo Colorado as far back as the 1960s consistently contained DDT, DDE, and toxaphene.[3] The EPA referred that request to the Harlingen, TX office of the regional health department affiliated with the Texas Department of Health (TDH) – now known as the Department of State Health Services (DSHS). Oral history has it that, in September 1980, regional staff issued a press release recommending that – based on the USFWS data – people not consume fish from the Arroyo Colorado upstream of the Port of Harlingen", presumably "because fish from this stretch of the Arroyo Colorado likely contained DDT and "other organic substances" that could be harmful to human health.[4] Between the 1980 statement and the state's first trip to sample fish from the Arroyo Colorado, the press release served as a reference for continuing the advice that people not eat fish from this stretch of the Arroyo Colorado. In 1984, the TDH reiterated the advice. Sampling between 1980 and later years repeatedly revealed that fish from the Arroyo Colorado still contained DDE, chlordane, toxaphene, and/or other pesticides that made those fish unfit for consumption.

On June 24, 1993, the TDH issued Advisory #5 (ADV-5), its first numbered consumption advisory for the Arroyo Colorado. ADV-5 covered the Donna Reservoir, the North Floodway, and all irrigation canals in Hidalgo County. The advisory suggested that people not eat any species of fish from these waters because the fish tissues contained PCBs.[5] The TDH issued ADV-6, a modification of ADV-5, on November 17, 1993, after additional sampling of area water bodies confirmed the presence of PCBs and "several types of organic contaminations, including DDE in fish."[6] ADV-6 covered all species in the "Donna Reservoir, its interconnecting canal system, and the Arroyo Colorado upstream of the Port of Harlingen … Cameron, Hidalgo, and Willacy Counties."[6] The un-numbered "advisory for the Arroyo Colorado upstream of the Port of Harlingen dated September, 1980" remained intact.[6] ADV-6 and the un-numbered advisory dated September 1980 were modified on June 4, 2001 when the TDH issued ADV-19[7], which stated, "...samples of fish taken from the Arroyo Colorado indicate that PCBs have decreased to acceptable levels in all species tested and that concentrations of pesticides have decreased to acceptable levels in all species tested except smallmouth buffalo.… Samples of smallmouth buffalo continue to contain elevated levels of chlorinated pesticides; "therefore, consumption of smallmouth buffalo poses a risk to human health." ADV-19 covered "all waters of the Arroyo Colorado, the Llano Grande Lake, and the main floodway upstream of the Port of Harlingen" in Cameron and Hidalgo Counties.[7] ADV-19, still in force along the Arroyo Colorado, suggested that adults eat only two 8-ounce meals per month of smallmouth buffalo from the Arroyo Colorado. Children were to eat no more than two 4-ounce meals per month of fish from this water body.

In 2006, in a follow up to ADV-19, the SALG survey team from the DSHS collaborated with the Total Maximum Daily Load (TMDL) Program of the Texas Commission on Environmental Quality (TCEQ), once again collecting fish from the Arroyo Colorado. The analytical data from those fish are the basis for the present report, which describes the sampling and analysis, presents conclusions from the study, addresses implications to public health from consumption of contaminated fish from the Arroyo Colorado, and recommends public health actions. The report also supplies the TMDL Program with data essential to the TMDL process.

Demographics of Cameron and Hidalgo Counties and the Likelihood of Subsistence Fishing in the Area of the Arroyo Colorado

Cameron County occupies a land area of approximately 905 square miles. The metropolitan statistical area of Cameron County is the Brownsville-Harlingen, TX Metro Area. The population of Cameron County in 2006 was 387,717 persons, an increase of 15% over the 2000 census figure of 335,227. Ninety-seven percent of those living in Cameron County in 2005 were white; 86% of those people claimed Hispanic or Latino origin. Blacks made up less than 1% of the 2005 Cameron County population. The population density of the county in 2000 was 370 persons/square mile. Educational level has a positive correlation with earning capacity. In Cameron County, 55.2% of persons 25 and over are high school graduates, while in Texas as a whole, 75.7% hold a high school diploma. Commensurate with the high school graduation rate in Cameron County, only 13.4% of residents of the county held bachelor's degrees while statewide the percent of people with bachelor's degrees is 23.2%. The median household income of Cameron County residents in 2004 was $26,709. In the state of Texas, the median family income in 2004 was $41,645 – about 1.6 times that of families living in Cameron County. In 2004, 29.9% of persons living in Cameron County lived below the federal poverty line. In Texas, that number was 16.2%.[8]

The estimated land area of Hidalgo County is 1,570 square miles; 0.82% or 13 square miles of the county is water. The estimated population of Hidalgo County in 2006 was 700,634, a 23% increase over the 2000 decennial census count of 569,463 persons. Thus, Hidalgo County is one of the fastest growing counties in the United States – the 7th most populous county in the state of Texas. Hidalgo County sits directly on the border between Mexico and the U.S.A. The Mexican state of Tamaulipas lies to the south of Hidalgo County, TX. The county seat is Edinberg while McAllen is the largest city.[9] Of people living in Hidalgo County in 2000, 97.4 per cent were white, 0.9% were black. Of whites in Hidalgo County, 89.4% claimed Hispanic or Latino descent. More than fifty percent of those persons over the age of 25 years held a high school diploma; 12.9% held a bachelor's degree. The median Hidalgo County household income in 2004, at $26,375, was similar to that of persons living in Cameron County at the time ($26,709). The median family income in Hidalgo County was 63.3% of that of Texas as a whole ($41,645). People living in Hidalgo County in 2004 whose income was below the federal poverty level were 30.5% of that county's population, almost twice that of the poverty rate for the state of Texas (16.2% in 2004).[10] The Arroyo Colorado is a natural recreational area for the some 1,000,000+ people living in the two counties discussed in this report. There are many opportunities and sites for fishing and boating along the Arroyo Colorado. At least ten cities with over 10,000 residents each are located within driving distance of some portion of the Arroyo Colorado.[11]

The USEPA suggests that, along with ethnic characteristics and cultural practices of an area's population, the poverty rate could contribute to the rate of subsistence fishing in an area.[12] The USEPA and the DSHS believe it important to estimate the number of people in an area who are subsistence fishers. The USEPA suggests that states consider subsistence fishing to occur at any water body where fishing occurs, because subsistence fishers (as well as recreational anglers and certain tribal groups or groups of certain ethnicities) may consume more locally caught fish than the general population. Hidalgo and Cameron County residents may have some characteristics of subsistence fishers including those of race, ethnicity, and income. People who live in the same place for many years – whether members of minority or ethnic populations or whose incomes are below the federal poverty guidelines – may harvest fish or shellfish from the same water body for many years, often using their catches to supplement caloric and protein intake. Should local water bodies contain chemically contaminated fish or shellfish, people who regularly fish from those water bodies or those who eat large quantities of fish from the same waters, could increase their chances of adverse health effects. The USEPA suggests that, to capture these populations in estimates of risk, states assume that at least 10% of licensed fishers in any area are subsistence fishers. Subsistence fishing, while not explicitly documented by the DSHS, likely occurs along the Arroyo Colorado. The DSHS assumes this phenomenon to occur and estimates the rate of subsistence fishing at any Texas water body to be near the 10% suggested by the USEPA.[12]

The TMDL Program at the TCEQ and its Relationship to DSHS Consumption Advisories or Possession Bans

The TCEQ enforces federal and state laws that promote judicious use of water bodies under state jurisdiction and protects state-controlled water bodies from pollution. Pursuant to the federal Clean Water Act, Section 303(d),[13] all states must establish a "total maximum daily load" (TMDL) for each pollutant contributing to the impairment of a water body for one or more designated uses. A "TMDL" is the sum of the allowable loads of a single pollutant from all contributing point and non-point sources, and including a margin of safety to ensure the usability of the water body for all designated purposes, accounting for seasonal variation in water quality. States, territories, and tribes define the uses for a specific water body (e.g., drinking water, contact recreation, aquatic life support) along with the scientific criteria designated to support each specified use. Fish consumption is a recognized use for many waters. The TCEQ TMDL program considers a water body impaired if fish from the water body contain contaminants consumption of which has the potential to harm human health. Although a water body and its aquatic life may spontaneously clear toxicants over time with removal of the source(s), it is often necessary to institute some type of remediation such as those devised by the TMDL Program. For example, when the DSHS in Texas prohibits possession of fish or shellfish from a water body because those fish contain unacceptable levels of environmental contaminants, the TMDL Program may place the water body on a draft 303(d) list.[14] TMDL staff members would subsequently prepare a TMDL for each contaminant in fish at concentrations that, if consumed in those fish, could negatively affect human health. Approval of the TMDLs by the TCEQ and the USEPA stimulates the TMDL group to prepare an Implementation Plan – a "remediation" plan, if you will – for each contaminant. Upon execution, Implementation Plans facilitate remediation (rehabilitation) of the water body. Successful remediation of a water body should return the waters to conditions compatible with all stated uses, including that of fish consumption. A common item on an Implementation Plan for a water body on a state's 303(d) list is the periodic reassessment of contaminant levels in fish from that water body. The TMDL Program's Implementation Plan for the Arroyo Colorado does specify periodic reassessments of contaminant levels in fish from the Arroyo Colorado.

Should such reassessment verify contaminants to have decreased to levels that no longer suggest that human health may be adversely affected by consumption of fish from this water body, the DSHS may rescind the advisory or ban. Rescission of advisories or bans by the DSHS means that people may keep and eat the fish from the water body in question. However, because the TMDL program may have placed a water body on its 303(d) list for multiple reasons, rescission of advisories or bans by the DSHS does not guarantee removal of a water body from the TCEQ's 303(d) list.

METHODS

Fish Sampling, Preparation, and Analysis

The DSHS Seafood and Aquatic Life Group (SALG) collects and analyzes edible fish from the state's public waters to evaluate potential risks to the health of people consuming contaminated fish or shellfish. Fish tissue sampling follows standard operating procedures from the DSHS *Seafood and Aquatic Life Group Survey Team Standard Operating Procedures and Quality Control/Assurance Manual*.[15] The SALG bases its sampling and analysis protocols, in part, on procedures recommended by the United States Environmental Protection Agency (EPA) in that agency's *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1*.[16] The SALG team also receives advice and counsel from the legislatively mandated State of Texas Toxic Substances Coordinating Committee (TSCC) Fish Sampling Advisory Subcommittee (FSAS).[17] Samples usually represent species, trophic levels, and legal-sized specimens available for consumption from a water body. When practical, the DSHS collects samples from two or more sites within a water body to better characterize geographical distributions of contaminants.

Fish Sampling Methods and Description of the Arroyo Colorado 2006 Sample Set

In January 2006, the survey team from SALG collected 30 fish samples along the Arroyo Colorado. The SALG selected five sites to provide spatial coverage of the study area (Figure 1). Species collected represent two distinct ecological groups (i.e. predators and bottom-dwellers) that have some potential to bio-accumulate chemical contaminants, have a wide geographic distribution, are of value to local recreational fishers, and/or are species that anglers and their families commonly consume. The 30 fish collected from the Arroyo Colorado in 2006 represented all species targeted for collection. Table 1 shows species, weights, and lengths of collected species as follows: channel catfish (12), smallmouth buffalo (8), blue tilapia (3), common carp (3), longnose gar (2), largemouth bass (1), and red drum (1).[18]

During each day of sampling, staff set gill nets in late afternoon, fishing them overnight and collecting samples early the following morning. Gill nets were set to maximize available cover and habitat. SALG staff stored fish retrieved from the nets on wet ice until processed. The team returned to the Arroyo Colorado any live fish culled from the catch. Staff also properly disposed of fish found dead in the gill nets.[18]

The survey team processed fish from the Arroyo Colorado at the sites from which they were collected. The team weighed each sample to the nearest gram on an electronic scale and measured total length (tip of nose to tip of tail fin) to the nearest millimeter. After weighing and measuring a fish, the team used an aluminum foil-covered cutting board and a clean fillet knife to prepare two skin-off fillets from each fish. The foil was changed and the filleting knife cleaned with distilled water after each sample. The team wrapped the fillet(s) in two layers of fresh aluminum foil, placed the samples in a new, pre-labeled plastic freezer bag, and stored them on wet ice in an insulated chest until further processing. At the end of the sampling trip, the survey team transported the fillets on wet ice to the Austin, TX, headquarters, temporarily storing the samples at -5° Fahrenheit (-20° Celsius) in a locked freezer. The freezer key is accessible only to authorized SALG staff to ensure the integrity of the chain of custody while samples are in the survey team's possession. The week following each collection trip, frozen fish tissue samples were shipped by commercial carrier (UPS next-day air) to the Geochemical and Environmental Research Group (GERG) Laboratory, Texas A&M University, College Station, TX, for contaminant analysis.[18]

Analytical Laboratory Information and Methodologies

The GERG laboratory notified the SALG when samples from the Arroyo Colorado arrived. Upon receipt of the samples, the laboratory recorded the DSHS sample number – assigned by the collection team – and noted the condition of each fillet.

Utilizing USEPA-sanctioned methodology, the GERG laboratory analyzed 30 samples for from the Arroyo Colorado for some of the more common inorganic and organic contaminants. Seven metals – arsenic, cadmium, copper, lead, total mercury, selenium, and zinc – were analyzed, as were panels of 71 volatile organic compounds (VOCs), 123 semivolatile organic compounds (SVOCs), 34 pesticides representing the common pesticide classes: organophosphates, organochlorines, and carbamates, and 209 possible polychlorinated biphenyl congeners (PCBs). All 30 fish were analyzed for metals, pesticides, and PCBs. Five of the submitted samples were analyzed for SVOCs and VOCs.[15]

Arsenic

Almost all arsenic in fish is likely an organic arsenic compound (arsenobetaine) often called "fish arsenic." Some small proportion of arsenic in some fish may be inorganic arsenic which does have some human toxicity (inorganic arsenic + organic arsenic = total arsenic). Although proportions of each form of arsenic may differ among species, under different water conditions, and, perhaps, with other variables, the literature suggests that well over 90% of arsenic in most fish is likely organic arsenic, a form that is virtually non-toxic to humans. Nevertheless, taking a conservative approach, the DSHS estimates that 10% of arsenic in a fish is inorganic arsenic and derives estimates of inorganic arsenic concentrations by multiplying total arsenic concentration in each fish by a factor of 0.1.[19]

Mercury

Methylmercury analyses in environmental samples are difficult to perform, requiring ultra-clean techniques; measurement of methylmercury in environmental samples is also costly. Research has so well established the fact that almost all mercury (>95%) in fish is methylmercury that many, if not most, monitoring programs have discontinued speciation of mercury in fish.[20] Total mercury concentration is, therefore, a viable surrogate for methylmercury in a fish of legal size for possession in Texas. The DSHS SALG thus requests only measurement of total mercury concentrations in fish tissue samples submitted for analysis. To ensure the agency's policy is protective of human health, the DSHS SALG also conservatively assumes that total mercury concentrations reported in fish is 100% methylmercury. Parenthetically, the DSHS SALG may interchangeably utilize the terms "mercury", "total mercury," "methylmercury", or "organic mercury" when referring to methylmercury in its characterization of this contaminant in fish tissues).[20]

PCBs

The DSHS SALG recently switched from analyzing Aroclors® to direct measurement of congeners of PCBs in fish. The present study therefore marks the first instance in which the DSHS SALG reports PCB concentrations in fish from the Arroyo Colorado as congeners of PCBs. In surveys of the Arroyo prior to that survey covered by ADV-19, Aroclors® were detected even though Aroclor® analysis is much less sensitive (MDL – 0.040 mg/kg) than is congener analysis (MDL= 0.001 mg/kg). Additionally, the DSHS SALG utilized a different laboratory for the 2001 analysis that generated ADV-19 – a report that stated that no PCBs were measured in tissues, based upon the Aroclor® method and the present analysis, which did report the presence of PCBs as congeners. Inter-year comparisons of PCBs are therefore inappropriate in this instance. Just as the TDH laboratory found the Aroclor® analysis acceptable, the DSHS SALG finds the results of the present survey an accurate reflection of PCBs in the 2006 samples and that these data do not imply a new or different source of PCBs in the Arroyo Colorado. The difference between the previous analysis and the analysis reported in the present paper is likely the result of the change in methodology. The Aroclor® method is simply less sensitive to PCBs than is the congener method, a difference that likely accounts for the "reappearance" of PCBs in some species than would a new source or an increase in the concentration in PCBs. Until proven otherwise, the difference in methods is the simplest of explanations. Unless and until Aroclors and congeners are measured simultaneously in samples and are found different for reasons other than methodology, those differences will be accepted by risk assessors as the most probable of explanations for the "reappearing" Aroclors®.

The GERG laboratory reports the presence and concentrations of 209 PCB congeners although only about 130 congeners existed in mixtures commonly manufactured and utilized in the U.S. – primarily the Aroclors®. U.S. companies no longer produce PCBs for commercial use, although the government does allow production of very small quantities for use in research and development. During the heyday of PCB manufacturing (PCBs were first commercially produced in 1929)[21] – the Monsanto Chemical Company was the only domestic producer of PCBs, trade-marking the moniker "Aroclor" for its mixtures of PCBs – and manufacturing the overwhelming majority (c. 99%) of all PCBs utilized by U.S. industry. According to the Agency for Toxic Substances and Disease Register (ATSDR; 2000), Monsanto produced around 40 million pounds of PCBs in 1970, alone.[22] PCB volumes produced in the U.S. peaked at 86 million pounds in 1970, decreasing to approximately 41 million pounds by 1974. Other manufacturers existed in other countries that may have produced mixtures with congeners of different formulation or molecular structure that could assist in identification of the origin of the compounds. These manufacturers appear to have produced PCBs in much smaller quantities, in general – mixtures with names ranging from "Aceclor" to "Turbinol" and including the familiar "Clophen" – manufactured in Germany, and "Kanechlor"[23] – made in Japan. In 1979, the U.S. prohibited import or export of PCBs.[22] Such mixtures, perhaps containing congeners not identified in Aroclors® (for example, PCB 169, which was never identified in Aroclors®), and which may have been useful to have measured as the presence of these PCBs might identify the origin of the contaminants or help to determine the weathering patterns of PCBs during their residences in the environment.

Other differences between line samples and those found in the environment – those resulting from weathering, for example –which could explain differences in the profiles between congeners found in fresh or "new" technical standards for Aroclors® and those seen in congener standards. Thus, measurement of all 209 congeners would allow speculation about origin of the PCBs as well as speculation about the effects of metabolism and weathering on the PCB mixtures regarded from Aroclor® studies as having been originally present in the Arroyo Colorado or other water bodies.

Although the DSHS SALG moved from Aroclor® analysis to that of congeners of PCBs as suggested by the USEPA,[24] the toxicity literature compiled and addressed by the EPA in its documents and databases such as IRIS, does not yet reflect this state-of-the-art laboratory science. Thus, it may be somewhat difficult for states to compare the toxicities of congeners in fish tissues with Aroclor® mixtures, from which the federal agencies have derived most minimal risk levels (MRLs), reference doses (RfDs) and cancer potency factors (CPFs). To address this dilemma, DSHS SALG risk assessors adopted recommendations for assessing the toxicity potential of consumed PCBs from the National Oceanic and Atmospheric Administration (NOAA),[25] from McFarland and Clarke,[26] and from the USEPA's guidance documents. [16, 24] Investigators chose each congener for its likelihood of occurrence in fish, the likelihood of significant toxicity – based on structure-activity relationships – and for the relative environmental abundance of the congener.[25, 26] Risk assessors at the DSHS SALG sum concentrations of 43 PCB congeners from the above investigations to derive a "total" PCB concentration in each fish sample. The DSHS SALG then averages the concentration of PCBs in all fish samples to obtain a mean PCB congener concentration. DSHS SALG risk assessors then estimate the toxicity of consuming PCBs in fish from Texas waters by comparing those concentrations to health-based assessment comparison values (HAC values) derived from the USEPA's IRIS database.[27] IRIS does not yet contain toxicity information on individual PCB congeners. Until IRIS does publish that information, the method described herein complies with current expert recommendations on evaluation of PCB toxicity derived from congener analyses.

Statistical Analysis

SALG risk assessors employed SPSS® statistical software, version 13.0 installed on IBM-compatible microcomputers (Dell, Inc) to generate descriptive statistics (mean, standard deviation, median, range, and minimum and maximum concentrations) on all measured compounds in each fish species from the Arroyo Colorado for which there was more than one sample. These same statistics were generated for each site within the Arroyo Colorado and for combined species and sites ("grand means"). SALG risk assessors utilized ½ the detection limit for all analytes not detected (ND) or listed as an estimated concentration (J-value – laboratory nomenclature for an analyte concentration the value of which may not be accurate) in its computation of the descriptive statistics used in this risk characterization. DSHS SALG risk assessors imported previously edited Excel data files into SPSS® to generate descriptive statistics for each measured analyte in each fish species, using those statistics to assess potential adverse human health outcomes from consuming contaminated fish from the Arroyo Colorado. [28] Risk assessors used descriptive statistical interpretations to generate the present report. The DSHS SALG protocols do not require hypothesis testing.[15] Nevertheless, when data are of sufficient quantity and quality, and, should the SALG find it necessary, the group may utilize SPSS® software to determine significant differences in contaminant concentrations among species and/or collection sites.[28] The SALG employs Microsoft Excel® spreadsheets to generate figures, compute HAC values with contaminant concentrations, and to calculate hazard quotients (HQ), hazard indices (HI), cancer risk probabilities, and meal consumption limits for fish from the Arroyo Colorado.[29]

The Centers for Disease Control and Prevention (CDC) considers it of concern when a child's blood lead (PbB) concentration exceeds 10µg/dL and has designated that concentration a "red flag' for lead toxicity.[30] Since almost all lead in children's bodies is from environmental exposure,[30] the USEPA has developed an Interactive Environmental Uptake Bio-Kinetic model to determine whether exposure of a child to lead in environmental media, including food, could result in an increase the child's blood lead (PbB) level.[31] When lead data in fish from a Texas water body are of sufficient quality, concentration, and interest, the SALG utilizes the IEUBK model to determine whether the lead in those fish, if consumed by a child, would increase the child's PbB and especially to determine whether such exposure would cause the child's PbB level to exceed 10 micrograms/deciliter.

Derivation and Application of Health-Based Assessment Comparison Values (HAC_{nonca} or HAC_{ca})

The effects of exposure to any hazardous substance depend on the dose, the duration of exposure, the manner in which one is exposed, one's personal traits and habits, and whether other chemicals are present.[32] People who regularly consume contaminated fish or shellfish conceivably suffer repeated exposures to relatively low concentrations of contaminants over extended times. Such exposures are unlikely to result in acute toxicity but may increase risk of subtle, chronic, and/or delayed adverse health effects that include cancer, benign tumors, birth defects, infertility, blood disorders, brain damage, peripheral nerve damage, lung disease, and kidney disease, to name but a few.[32] Presuming people to eat a diet of diverse fish or shellfish from a water body if species variety is available, the DSHS routinely collapses data across species and sampling sites to evaluate mean contaminant concentrations of toxicants in all samples. This approach intuitively reflects consumers' likely exposure over time to contaminants in fish or shellfish from a water body, but may not reflect reality at a specific water body. The agency thus reserves the right to examine risks associated with ingestion of individual species of fish or shellfish from separate collection sites or at higher concentrations (e.g., the upper 95 percent confidence limit on the mean concentration. The SALG derives confidence intervals from Monte Carlo simulation techniques utilizing software developed by Dr. Richard Beauchamp of the DSHS).[33] DSHS SALG risk assessors evaluate contaminants in fish by comparing the mean, and – when appropriate – the 95% upper confidence limit on the mean concentration of a contaminant to its HAC values (measured in milligrams of contaminant per kilogram of edible tissue – mg/kg) derived for non-cancer or cancer endpoints. To derive HAC values for systemic (HAC_{nonca}) effects, the department assumes a standard adult weighs 70 kilograms and that adults consume 30 grams of edible tissue per day (about one 8-ounce meal per week). The DSHS uses EPA's oral reference doses (RfDs)[34] or the Agency for Toxic Substances and Disease Registry's (ATSDR) chronic oral minimal risk levels (MRLs)[35] to generate HAC values used in evaluating systemic (noncancerous) adverse health effects. The USEPA defines an RfD as

> *An estimate of a daily oral exposure for a given duration to the human population (including susceptible subgroups) that is likely to be without an appreciable risk of adverse health effects over a lifetime.*[36]

EPA also states that an RfD

> *… can be derived from a NOAEL* (no observed adverse effect level*), LOAEL* (lowest observed adverse effect level)*, or benchmark dose, with uncertainty factors generally applied to reflect limitations of the data used. Generally used in EPA's noncancer health assessments. [Durations include acute, short-term, subchronic, and chronic and are defined individually in this glossary]"* [36]

The ATSDR uses a similar technique to derive MRLs.[35] The DSHS compares the estimated daily dose (mg/kg/day) – derived from the mean of the measured concentrations of a contaminant – to the contaminant's RfD or MRL, using hazard quotient (HQ) methodology as suggested by the USEPA.

A HQ, defined by the EPA, is

> *...the ratio of the estimated exposure dose of a contaminant (mg/kg/day) to the contaminant's RfD or MRL (mg/kg/day).*[37]

Note that a linear increase in the hazard quotients for a site or species usually does not represent a linear increase in the likelihood or severity of systemic adverse effects (i.e., a substance having an HQ of 2 is not twice as toxic as if the substance had an HQ of 1.0. Similarly, a substance with a HQ of 4 does not imply that adverse events will be four times more likely than a HQ of 1.0). As stated by the EPA, a HQ (or an HI) of less than 1.0 "is no cause for concern, whereas an HQ (or HI) greater than 1.0 should indicate some cause for concern." Risk managers at the DSHS recognize a HQ of 1.0 as a point of departure for making management decisions assuming, in a manner similar to EPA's decision process, that fish or shellfish with a hazard quotient of less than 1.0 are an unlikely cause for concern while those with HQs greater than 1.0 may be of concern for human health. Since the chronic oral RfD derived by the USEPA represents chronic consumption, eating fish with a toxicant-to-RfD ratio (the HQ) of less than 1.0 is not likely to result in adverse health effects, whereas routine consumption of fish where the HQ for a specific chemical exceeds 1.0 represents a qualitatively unacceptable increase in the likelihood of systemic adverse health outcomes.

Although DSHS preferentially utilizes an RfD derived by federal scientists for each contaminant, should no RfD be available for a specific contaminant, the USEPA advises risk assessors to consider using a reference dose determined for a contaminant of similar molecular structure, or mode or mechanism of action. For instance, DSHS – as specifically directed by the USEPA – uses the published reference dose for Aroclor 1254 to assess noncarcinogenic effects of Aroclor 1260, for which no reference dose is available – the USEPA has derived one other reference dose for Aroclors® – that of Aroclor 1016. However, Aroclor 1016 is not so clearly like Aroclor 1260 as is Aroclor 1254. In the past, when DSHS had access only to the relatively crude measurement of Aroclors®, the agency did not attempt to determine the dioxin equivalent toxicity of coplanar PCBs found in fish. The SALG recently adopted PCB congener analysis, as is suggested by the USEPA. This change in methodology allows the agency to identify coplanar or dioxin-like PCBs and to apply toxicity equivalency factors (TEFs) to PCBs in fish should SALG staff consider this a priority.

Federal scientists derive from the peer-reviewed literature (which the federal agencies routinely re-examine for changes in the science of risk assessment or toxicity) the constants (RfDs, MRLs) employed by the DSHS to calculate HAC_{nonca} values. These values incorporate built-in margins of safety called "uncertainty factors" or "safety factors" as mentioned in EPA reference materials.[36] In developing an oral RfD or MRL, federal scientists review the extant literature on the toxicant to determine an experimentally-derived no observed adverse effect level (NOAEL), a lowest observed adverse effect level (LOAEL), or, in some cases, a benchmark dose (BMD).

Once the NOAEL, LOAEL, or BMD is determined, the scientist then utilizes uncertainty factors to minimize potential systemic adverse health effects in people exposed through consumption of contaminated materials. The uncertainty factors account for certain conditions that are undetermined by the experimental data. The classic four uncertainty factors are (1) extrapolation from animals to humans (interspecies variability), (2) intra-human variability, (3) using a subchronic study rather than a chronic study to determine the NOAEL, LOAEL, or BMD, (4) using a LOAEL instead of a NOAEL to determine the RfD. Recently, a fifth uncertainty factor, (5) database insufficiencies for the toxicant, was added.[34] Vulnerable groups – women who are pregnant or lactating, women who may become pregnant, the elderly, infants, children, people with chronic illnesses, those with compromised immune systems, or those who consume exceptionally large servings, called "sensitivities" by the EPA, also receive special consideration in calculations of the RfD.[36, 38]

The SALG calculates cancer-risk comparison values (HAC_{ca}) from the EPA's chemical-specific cancer potency factors (CPFs) – also known as slope factors (SFs) – derived through mathematical modeling of carcinogenicity studies. For carcinogenic outcomes, the DSHS calculates a theoretical lifetime excess risk of cancer for specific exposure scenarios for carcinogens, using a standard 70-kg body weight and assuming an adult consumes 30 grams of edible tissue per day. The SALG risk assessors incorporate two additional factors into determinations of theoretical lifetime excess cancer risk: (1) an acceptable lifetime risk level (ARL) [36] of one excess cancer case in 10,000 persons whose average daily exposure is equal and (2) daily exposure for 30 years. Comparison values used to assess the probability of cancer, thus, do not contain "uncertainty" factors as such. However, conclusions drawn from those probability determinations infer substantial safety margins for all people by virtue of the models utilized to derive the slope factors (cancer potency factors). For instance, the USEPA suggests using a tiered approach to determine the potency of PCB mixtures to cause cancer in exposed individuals. This approach depends on information available from the IRIS database.[27] Risk assessors have three tiers of carcinogen slope factors (SFs) from which to choose in assessing the carcinogenic impact of environmental PCBs. Risk assessors utilize Tier 1, with an upper bound slope factor of 2.0 and a central tendency slope factor of 1.0 for PCBs with "high risk and persistence." Criteria for using this most restrictive slope factor include (1) exposure via food, (2) ingestion of sediment or soil, (3) inhalation of dust or aerosols (4) dermal exposure – if an absorption factor was applied – (5) the presence of dioxin-like, tumor-promoting, or persistent PCB congeners, and, perhaps most importantly, (6) the possibility of early-life exposure. Because the potential implications of early-life exposures include factors such as possibly greater perinatal sensitivity, or the likelihood of interactions between PCBs and normal functions (such as PCB-mediated depletion of thyroid hormones, an effect that can result in irreparable damage to the developing brain) of development, the USEPA concludes that early-life exposures may be associated with increased risks.[27] The DSHS, in agreement with the federal agency, utilizes the upper bound slope factor of the "high risk" tier for all exposures to PCBs in fish.

The calculated comparison values (HAC_{nonca} and HAC_{ca}) are quite conservative, so adverse systemic or carcinogenic health effects are unlikely to occur, even if exposures are consistently greater or last longer than those used to calculate comparison values. Moreover, comparison values for adverse health effects (systemic or carcinogenic) do not represent sharp dividing lines (bright-line divisions) between safe and unsafe exposures. The perceived strict demarcation between acceptable and unacceptable exposures or risks is primarily a tool to assist risk managers to make decisions that ensure protection of the public's health. For instance, the DSHS considers it unacceptable when consumption of four or fewer meals per month of contaminated fish or shellfish would result in exposure to contaminant(s) in excess of a HAC value or other measure of risk even though most such exposures are unlikely to result in adverse health effects. The department further advises people who wish to minimize exposure to contaminants in fish or shellfish to eat a variety of fish and/or shellfish and to limit consumption of those species most likely to contain toxic contaminants. DSHS aims to protect vulnerable subpopulations with its consumption advice. The DSHS assumes that advice protective of vulnerable subgroups will also minimize the impact to the general population of consuming contaminated fish or shellfish.

Determination of the Toxicological Significance of Cumulative Adverse Noncarcinogenic Health Effects from Consuming Fish Contaminated with Multiple Systemic Contaminants using Hazard Index (HI) Methodology

To assist risk assessors in surveying the toxicity of chemical mixtures, in 1986 the USEPA published its *Guidelines for the Health Risk Assessment of Chemical Mixtures.*[39] The 1986 document described broad principles and concepts that remain the lynchpins of assessment of the toxicity of chemical mixtures. Adding to the principles and concepts of the 1986 document, the USEPA published a *Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures in 2000.* [40] That document provided more-complete instructions for application of the principles of assessment of chemical mixtures.

To determine whether structurally dissimilar compounds have the same target organ or cause similar systemic effects, DSHS SALG risk assessors rely upon information available in the IRIS database (a chemical may have carcinogenic, systemic, CNS, reproductive, and/or developmental effects – to name but a few) to evaluate possible cumulative noncancerous health effects of component mixtures that contain structurally dissimilar compounds. The SALG utilizes the simplest of methods for assessing the likelihood of cumulative noncarcinogenic effects of chemical mixtures – the hazard index (HI). A HI is created for a mixture of structurally dissimilar chemicals only after it is determined that each of those chemicals acts upon the same target organ and after the concentration of each component is compared to its RfD or MRL via an HQ.. The HI is the sum of the hazard quotients of those chemicals in the mixture that have identical target organs. The HI is a specific type of dose-addition, according to the USEPA.[40] HI methodology is usually utilized when the mixture is simple (has only a few components); it assumes effects are additive – the component chemicals do not interact to produce antagonistic or synergistic effects on the target organ.

With hazard index methodology, toxicologists and risk assessors generally interpret an index of less than 1.0 as meaning the additive effects of the components are toxicologically unimportant. On the other hand, while a HI greater than 1.0 may indicate some level of hazard, such a finding does not imply that exposure to the contaminants at doses that generating an HI >1.0 will result in adverse health effects. This seeming contradiction results from the fact that the hazard quotients used to generate the hazard index for observed concentrations have, by virtue of the use of the RfD or MRL, built-in safety factors that cause even HIs that are above 1.0 to be toxicologically unimportant. These uncertainty factors, mentioned in earlier paragraphs, are likely to reduce the RfD or MRL for chronic oral exposure to levels hundreds of times below the level at which no adverse effect is observed (the NOAEL) or below the lowest level at which an adverse effect (the LOAEL) was observer. Nonetheless, finding an HI for chemicals that act upon the same target organ and that exceeds 1.0 may prompt the agency to consider some public health intervention strategy.

Cumulative Carcinogenic Effects

To estimate the potential additive effects of multiple carcinogens on excess lifetime cancer risk, the DSHS sums the risks calculated for each observed carcinogenic contaminant, just as one might sum the noncarcinogenic effects of similar chemicals. This method is acceptable because the USEPA makes no assumptions about the mechanism of carcinogenesis, the mode of carcinogenesis, the target organ, or whether or not the observed tumors are malignant tumors or benign. The DSHS 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 excess cancer in 10,000 exposed persons (the same as the acceptable risk level for cancers caused by a single agent).

Children's Health Considerations

The DSHS recognizes that fetuses, infants, and children may be uniquely susceptible to the effects of toxic chemicals and suggests that exceptional susceptibilities demand special attention.[41, 42] Windows of special vulnerability; known as "critical developmental periods," exist during development. Critical periods occur particularly during early gestation (weeks 0 through 8), but can occur at any time during pregnancy, infancy, childhood, or adolescence – indeed, at any time during development – times when toxicants can impair or alter the structure or function of susceptible systems.[43] Unique early sensitivities may exist because organs and body systems are structurally or functionally immature – even at birth – continuing to develop throughout infancy, childhood, and adolescence. Developmental variables may influence the mechanisms or rates of absorption, metabolism, storage, or excretion of toxicants, any of which factors could alter the concentration of biologically effective toxicant at the target organ(s) or that could modulate target organ response to the toxicant. Children's exposures to toxicants may be more extensive than adults' exposures because, in proportion to their body weights, children consume more food and liquids than do adults do, another factor that might alter the concentration of toxicant at the target. Infants can ingest toxicants through breast milk – an exposure pathway that often goes unrecognized (nonetheless, the advantages of breastfeeding outweigh the probability of significant exposure to infants through breast milk. Women are encouraged to continue breastfeeding and to limit exposure of their infants by limiting intake of the contaminated foodstuff). Children's behaviors (i.e., hand to mouth behaviors) might expose them to more toxicants or higher concentrations of a toxicant than adults.[44] Children may experience effects at a lower exposure dose than might adults because children's organs may be more sensitive to the effects of toxicants. Stated differently, children's systems could respond more extensively or with greater severity to a given dose than would an adult organ exposed to an equivalent dose of a toxicant. Children could be more prone to developing certain cancers from chemical exposures than are adults.[45] In any case, if a chemical – or a class of chemicals – is observed to be – or is thought to be – more toxic to the fetus, infants, or children than to adults, the constants (e.g., RfD, MRL, or CPF) are usually further modified to assure protection of the immature system's potentially greater susceptibility.[34] Additionally, in accordance with the ATSDR's *Child Health Initiative*[46] and the EPA's *National Agenda to Protect Children's Health from Environmental Threats,*[47] *- (*in recognition of the possibly greater vulnerability of children to harmful substances, the USEPA has established the Office of Children's Health Protection (OCHP). The OCHP ensures that all standards set by the USEPA will protect children from heightened risks and that any newly developed policies address children's health concerns).[48] In its document, *A Framework for Assessing Health Risks of Environmental Exposure to Children* the USEPA detailed methodology by which that agency addresses children's health issues from environmental exposure.[49] The SALG follows that methodology so far as is possible within the agency. DSHS further seeks to protect children from the possible negative effects of toxicants in fish by suggesting that this potentially sensitive subgroup consume smaller quantities of contaminated fish or shellfish than adults consume. To illustrate: DSHS SALG recommends that children weighing 35 kg or less and/or who are 11 years of age or younger limit exposure to contaminants in fish or shellfish by eating no more than four ounces per meal of the contaminated species. The DSHS also recommends that consumers spread these meals over time. For instance, if the DSHS suggests that children consume no more than two meals per month of a contaminated species, those children should eat no more than 24 meals of the contaminated fish or shellfish per year and, ideally, should not eat such fish or shellfish more than twice per month.

RESULTS

Laboratory Analytical Results

In January 2007, the GERG laboratory electronically transmitted the results of the chemical analyses of the Arroyo Colorado fish samples collected by the DSHS in 2006. The GERG laboratory reported the analytical results for metals, pesticides, PCBS, SVOCs, and VOCs.

Table 2a through 2d present summary data for metalloids in fish collected in January 2006 from the Arroyo Colorado, with mercury results shown in Table 2d. Tables 3c and 3d present summary statistics for various minor pesticides while Table 3a contains the results of measurements of 4,4'-DDT and its metabolites and abiotic degradation products, 4,4'-DDD and 4,4'-DDE in each species at each sampling site. Table 3b shows the distribution of 4,4'-DDE in fish from each collection site along the Arroyo Colorado. Table 4 contains summary data for PCBs by site and species. The summarized data consist minimally of the contaminant, the species tested, the number of samples in which a contaminant was detected/the the total number of samples tested, the mean concentration ± 1 standard deviation and the minimum and maximum concentrations (in parentheses beneath the mean and standard deviation) unless stated otherwise.

Inorganic Contaminants

Arsenic, Cadmium, Copper, Lead, Mercury, Selenium, and Zinc

All species from the Arroyo Colorado contained unspeciated (total) arsenic (Table 2a). Six of 30 fish – each a channel catfish – contained traces of total arsenic (designated as J-values). Twenty-four fish contained measurable total arsenic. The average concentration of arsenic in all fish from the Arroyo Colorado, including the six estimated values (each of which was substituted with ½ the detection limit for arsenic for the calculations), was 0.293±0.645 mg/kg, using ½ the detection limit in place of the estimated concentrations for those six samples containing estimated arsenic concentrations (Table 2a). The average concentration of *inorganic* arsenic, calculated as 10% of the mean unspeciated (total) arsenic was 0.029 mg /kg tissue (all fish). Longnose gar, of which two samples were collected, contained the highest average concentration of total arsenic (1.752±2.359 mg/kg) while channel catfish – half of which (6/12) – contained only estimated concentrations, were reported as having the lowest concentration of unspeciated arsenic (0.110±0.143 mg/kg total arsenic. Calculated concentrations of inorganic arsenic of course mirrored the data for total arsenic (Table 2a, column 4). Table 2a also contains the HAC_{nonca} and the HAC_{ca} for inorganic arsenic and the basis upon which the HAC values are predicated (column 6, Table 2a).

Tables 2b, 2c, and 2d contain summary concentrations, HAC values, and predicates of the HAC values for metallic components other than arsenic. Cadmium (Table 2b) was present in measurable quantities in two of twelve channel catfish from the Arroyo Colorado. Both channel catfish with measurable cadmium came from the Llano Grande Lake (mean cadmium in catfish from Llano Grande Lake = 0.055 mg/kg; mean cadmium concentration in all 12 channel catfish = 0.019±0.019 mg/kg). The concentration of cadmium calculated for all fish from the Arroyo Colorado was 0.014±0.012 mg/kg, a concentration that approximated ½ the detection limit for cadmium. This phenomenon likely occurred because so few fish contained measurable concentrations of cadmium (Table 2b). One smallmouth buffalo contained an estimated cadmium level while other smallmouth buffalo contained no detectable cadmium. Other fish from the Arroyo Colorado contained no detectable cadmium (all were below the laboratory's reporting limit for cadmium, designated "ND").

All 30 fish from the Arroyo Colorado contained some concentration of copper (Table 2b). Twenty-eight fish contained measurable copper, an essential nutrient for many animal species. Two channel catfish contained only estimable concentrations (J-values) of copper, both from the Llano Grande Lake). The average concentration of copper in channel catfish was 0.295±0.220 mg/kg (Table 2b). Common carp contained the highest average concentration of copper at 0.543±0.322 mg/kg. Longnose gar (n=2) contained the lowest average concentration (0.120±0.031 mg/kg). The average copper concentration across all sites and species was 0.302±0.197 mg/kg (30 samples).

One channel catfish (ARC9) from the Llano Grande Lake contained measurable lead (0.116 mg/kg). Three smallmouth buffalo and three channel catfish contained estimated lead (BDL – J-values). Remaining fish of any species contained no lead at observable concentrations (ND; Table 2c).

Selenium measurements, also shown in Table 2c, occurred in 29/30 fish; one channel catfish from the Llano Grande Lake contained only estimated selenium. One channel catfish contained no observable selenium. The lowest average concentration of selenium occurred in channel catfish. Smallmouth buffalo, all eight of which contained measurable selenium, contained the highest average concentration of this element. The average concentration of selenium in fish from all sites along the Arroyo Colorado was 0.423±0.225 mg/kg.

Measurable concentrations of zinc (Table 2d) were present in all 30 samples. The average zinc concentration in common carp was three to four times the average concentration in other fish species (16.036±10.686 mg/kg). Longnose gar contained the lowest average concentration of zinc (3.087±0.712 mg/kg). The average concentration of zinc across all 30 samples was 6.522±5.088 mg/kg.

All species from the Arroyo Colorado contained mercury (Table 2d). Longnose gar, collected from the Arroyo Colorado at FM 506 (Site 2), contained the highest mercury concentration (averaging 2.362±2.419 mg/kg). Of the longnose gar (N=2), one contained 4.073 mg/kg mercury, the second, 0.651 mg/kg. Blue tilapia (N=3) collected from the Arroyo only at FM 493, contained estimated concentrations of mercury (J-values). Average mercury concentrations in other species were as follows: largemouth bass - 0.308 mg/kg (N=1); smallmouth buffalo: 0.301 mg/kg (N=8), red drum - 0.187 mg/kg (N=1); common carp 0.172 mg/kg (N=3), and channel catfish - 0.160 mg/kg (N=12). The average mercury concentration across all sites and species was 0.337±0.719 mg/kg (Table 2d).

Organic Contaminants

DDT, DDE, and DDD

The laboratory assessed 4,4'-DDT, its metabolites and degradation products, 4,4'-DDE and 4,4'-DDD. 2, 4'-DDT, 2, 4'-DDD, and 2, 4'-DDE were also reported, but were not addressed in this commentary because the USEPA has not published RfDs or CPFs for these compounds.[36] 4,4'-DDT. DDT (trade names include Anofex, Dedelo, Dinoside,Gyron, Neosid), like 4,4'-DDE, is an organochlorine pesticide that, like others of this class, alters sodium and potassium in neurons, disrupting neuronal transmission.[50] 4,4'-DDT, is the parent compound for 4,4'-DDE, which has substantially the same actions as 4,4'-DDT. Concentrations of 4,4'-DDE were high in some fish from the Arroyo Colorado. Acute toxicity from 4,4'-DDE is not expected in people who eat fish from the Arroyo Colorado. High doses of DDE may cause acute toxicity in humans, however. Signs and symptoms of acute toxicity of DDT-like compounds include nausea, diarrhea, mucous membrane irritation, disturbed gait, general malaise, and excitability. Liver enzymes may be elevated after ingestion of high doses. Very high doses may cause tremors and convulsions. In mammalian systems, 4,4'-DDT transforms slowly to 1,1-dichloro-2,2-bis(p-dichlorodiphenyl)ethylene (4,4'-DDE; and 1,1-dichloro-2,2-bis(p-chlorophenyl)ethane (4,4'-DDD), compounds that in turn are transformed into bis(dichlorodiphenyl) acetic acid. The kidneys of mammalians readily excrete DDA and DDA conjugates. DDT, DDD, and DDE persist in the environment. DDT is unavailable for use in the United States and, barring an outbreak of malaria or other national emergency, the pesticide will remain unavailable to US residents. In the Arroyo Colorado samples (Table 3a) 22 fish contained 4,4'-DDT (15 samples contained measurable 4,4'-DDT; the compound was estimated in seven fish (BDL) and was measurable in eight fish (ND). Channel catfish (7 of 12) averaged 0.005 mg/kg of 4,4'-DDT. Longnose gar averaged 0.005±0.006 mg/kg (only one of two longnose gar contained measurable 4,4'-DDT; for calculations, ½ the MDL was used for the other longnose gar). Smallmouth buffalo (8 of 8 fish) averaged 0.014 mg/kg of 4,4'-DDT. The lone largemouth bass collected from the Arroyo Colorado in 2006 contained 4,4'-DDT at an estimated 0.003 mg/kg (concentration was estimated as below the diction limit [BDL] or as a J-value). . Blue tilapia, common carp, and the only red drum collected, did not contain 4,4'-DDT concentrations at or above the MDL (ND). The average concentration of 4,4'-DDT in all fish from the Arroyo Colorado was 0.007±0.009 mg/kg. The MDL for 4,4'-DDT was 0.001 mg/kg.

All fish collected from the Arroyo Colorado in 2006 contained 4,4'-DDE, the distribution of which in each species of fish from each site along the Arroyo Colorado is shown in Table 3b. The average concentration of 4,4'-DDE in all fish from the Arroyo was 1.301±2.140 mg/kg. Fish from Site 1 (Port of Harlingen) – four smallmouth buffalo (0.846 mg/kg), two common carp (0.205 mg/kg), one red drum (0.073 mg/kg), and three channel catfish (0.707 mg/kg) – had a mean concentration of 0.599±0.368 mg/kg 4,4'-DDE. At site 2 (FM 506), the concentration of 4,4'-DDE in the single channel catfish collected was 0.407 mg/kg. Longnose gar from Site 2 (FM 506), in contrast, contained 3.829±1.068 mg/kg of 4,4'-DDE. Smallmouth buffalo from site 2 contained the highest average concentration of 4,4'-DDE observed - 4.860±4.036 mg/kg. One smallmouth buffalo from Site 2 contained 10.225 mg/kg of 4,4'-DDE. The mean concentration of 4,4'-DDE at Site 2 was 3.929±3.314 mg/kg. The seven fish from Site 3 (Llano Grande Lake) contained an average of 0.679 mg/kg 4,4'-DDE. One fish from the Llano Grande, a channel catfish, contained 1.582 mg/kg DDE. Site 4 (FM 493) fish contained an average 0.137 mg/kg of 4,4'-DDE, with blue tilapia having the lowest concentration (0.028±0.007 mg/kg) and the highest in the single channel catfish collected (0.327 mg/kg). At Site 5 (FM 907), where only one sample – a channel catfish – was collected, the channel catfish contained 0.087 mg/kg of 4,4'-DDE.

Twenty-four of 30 fish had measurable concentrations of 4,4'-DDD while five fish had estimated 4,4'-DDD concentrations and one blue tilapia contained no detectable 4,4'-DDD. Concentrations of 4,4'-DDD ranged from 0.001 mg/kg in the Arroyo at FM 907 to 0.043 mg/kg at FM 506. The average concentration across all sites and species was 0.016±.012 mg/kg)

The average concentration of all 4,4'-DDT-like compounds (4, 4'-DDT+4, 4'-DDE+4, 4'-DDD) was 1.323±2.154 mg/kg across all sites and species.

Chlordane

The laboratory reported measured or estimated technical chlordane (Table 3c) in all but three fish from the Arroyo Colorado (mean ± std dev across all species=0.018±0.017 mg/kg). One blue tilapia contained estimated chlordane; two did not contain chlordane at levels above the reporting limit. One of three common carp from the Llano Grande Lake contained estimated chlordane. The single red drum among the samples did not contain detectable chlordane. All other fish contained measurable, although low, levels of chlordane.

Dacthal

Dacthal occurred in all samples at an average concentration of 0.103±0.104 mg/kg (Table 3c). Channel catfish contained the highest average concentration (0.150 ±0.137 mg/kg), followed by smallmouth buffalo, at 0.107±0.069 mg/kg.

Diazinon

Diazinon (Table 3d) was present at measurable or estimated levels in 19 of 30 samples from the Arroyo Colorado. Diazinon averaged 0.004±0.003 mg/kg across all sites and species of fish. The highest average concentration of diazinon was in smallmouth buffalo from the Port of Harlingen (0.008±0.002 mg/kg.

Methoxychlor

The laboratory also reported eight fish to contain methoxychlor. One of eight fish – a common carp collected from the Port of Harlingen – contained measurable methoxychlor (0.028 mg/kg). Seven fish (five channel catfish, one common carp, and one blue tilapia) contained estimated levels (J-values). Three channel catfish containing estimated concentrations of methoxychlor were from the Port of Harlingen and two from the Llano Grande Lake; the team collected the common carp ultimately shown to contain estimated concentrations of methoxychlor from the Llano Grande Lake. One blue tilapia from FM 493 contained methoxychlor at an estimated concentration. The remaining 22 samples did not contain methoxychlor at concentrations above the laboratory's reporting limit. Methoxychlor, an organochlorine pesticide with a chemical structure similar to DDT (brand names Higalmetox, Marlate, Methoxy-DDT, and Prentox), does not persist in biological systems and is unlikely to build up in the food chain. Methoxychlor is practically nontoxic to humans. It is a general use pesticide (GUP) available to the public. Fish reportedly rapidly break down methoxychlor, insuring the pesticide to have little tendency to accumulate in fish. Methoxychlor is unlikely to be a carcinogen.[51]

PCBs

All samples collected from the Arroyo Colorado in 2006 contained PCBs. (Table 4). However, as discussed in the methods, the SALG used 43 congeners selected for specific characteristics to determine the total concentration of PCBs in each sample. Risk assessors from the DSHS SALG judged the congeners present in fish from the Arroyo Colorado in 2006 as consistent with the original presence of Aroclor 1254 and/or Aroclor 1260.[52] Additionally, the data showed several samples to contain congener patterns suggestive of the original presence of Aroclor 1248.[52]

The average concentration of PCBs in all species collected from all sites (30 fish) was 0.050±0.048 mg/kg. The highest average concentration of PCBs occurred in smallmouth buffalo (0.104±0.059 mg/kg), followed by that in longnose gar (0.0827±0.0363 mg/kg) – only two of which were collected, both from the Arroyo Colorado at FM 506. PCB concentrations in smallmouth buffalo and longnose gar were followed distantly by PCB concentrations in all other species. Channel catfish contained an average of, 0.0338±0.0165 mg/kg while the single largemouth bass collected from the Arroyo at FM 493 contained 0.0189 mg/kg PCBs. The single common carp sample – collected from the Llano Grande Lake (Site 3) – contained 0.0207 mg/kg PCBs. Common carp from the Port of Harlingen (Site 1) contained an average of 0.016±0.002 mg/kg PCBs. The single red drum contained 0.011 mg/kg, while blue tilapia averaged0.0105±0.0004 mg/kg PCBs.

Site 2 (Arroyo at FM 506) had the highest concentrations of PCBs of any site sampled during the 2006 trip (Table 4). The average concentration of PCBs at Site 2 was 0.0973±0.068 mg/kg. PCBs in fish from the Port of Harlingen (Site 1), which included four smallmouth buffalo, averaged 0.0515±0.0373 mg/kg. The Llano Grande Lake (Site 3) contained an average of 0.0349±0.0157 mg/kg. Samples from other sites contained much lower concentrations of PCBs. Fish collected from Site 4, the Arroyo Colorado at FM 493 – had an average of 0.0138±0.0044 mg/kg. The single channel catfish collected from Site 5 (the Arroyo Colorado at FM 907) contained 0.009 mg/kg of PCBs). The four smallmouth buffalo from Site 2 (FM 506), being the most heavily contaminated species collected, averaged 0.124±0.077 mg/kg. Longnose gar from Site 2 contained the 2nd highest average concentration of PCBs (0.083±0.036 mg/kg). The average PCB concentration in the four smallmouth buffalo (0.084±0.036 mg/kg) from Site 1 (Port of Harlingen) was similar to the average PCB concentration in longnose gar from Site 2 – FM 506, at 0.083±0.036 mg/kg.

The data on PCBs in fish collected in 2006 from the Arroyo Colorado suggest that the primary determinant of PCB concentration was “species,” with ‘collection site’ a secondary variable. Smallmouth buffalo (from all sites) contained the highest mean concentration of PCBs, followed by the longnose gar collected only from Site 2.

VOCs and SVOCs

Several volatile organic compounds (VOCs) occurred in one or more of five fish examined (data not shown). The laboratory reported the presence of acetone in the five tested fish. One sample contained a measured concentration; the other four samples contained estimated concentrations (J-values). Carbon disulfide and methylene chloride occurred at measurable levels in all five samples. Three samples contained estimated concentrations of benzene; one contained an estimated concentration of 1,2-dichloroethane. Toluene was also present at estimated concentrations in all five samples. The laboratory estimated naphthalene concentrations in two of the five tested samples. Although it is not possible to determine the source of these volatile organic compounds, acetone, carbon disulfide, and methylene chloride are often laboratory or field contaminants. Both procedural blanks from the QA/QC data sent along with the sample data contained acetone and methylene chloride. One blank also contained benzene. Both procedural blanks contained toluene. The sample run alongside the QA/QC procedure contained most of these compounds at levels relatively similar to those in the procedural blanks. No carbon disulfide was present in the procedural blank but this contaminant was present in the sample from the QA/QC run. Methylene chloride in the sample was just under three times the detection limit for this compound. Naphthalene was not present in the procedural blanks or in the QA/QC sample. The matrix spiked sample and its duplicate showed similar recoveries and were acceptable within the QA/QC parameters. Thus, it is probable that most, but not all, of the VOCs observed in these samples were of laboratory origin. Other plausible explanations exist. Living systems make very small quantities of many of these compounds, including benzene. Some could have been the result of necrotic processes in the samples. Finally, these contaminants may be valid environmental contaminants observed only at very low concentrations.

Two of five fish analyzed contained phenol, an SVOC. Phenol was not present in the procedural blank. One or more of three phthalate esters (semivolatile plasticizers) were present in one or more of the five fish, but were present only at estimated concentrations (not all phthalate esters were present in all samples). The same three phthalate esters, diethyl phthalate, di-n-butyl phthalate, and bis(2-ethylhexyl) phthalate were present in the procedural blank. The two samples (CAN 1 and CAN 2) from the QA/QC report also contained phthalates. 4,4'-DDE was present in samples run in this assay, as expected, and, as expected, measured at lower concentrations than the quantitative measurement in the pesticide scan. 4,4'-DDE was not present in the procedural blank or in the sample run during the QA/QC procedure.

DISCUSSION

Risk Characterization

The actual risk of adverse health outcomes from exposure to toxicants based on experimental or epidemiological data is subject to the known variability of individual and population responses. Thus, calculated risks can be orders of magnitude above or below the actual risks of systemic or local effects of toxicants. The variability depends upon many factors: the target organ; the species of animal used in the study; different exposure periods; different doses; or other variations in conditions.[34] Nevertheless, the DSHS calculated a number of risk parameters for potential toxicity to humans who consume contaminated fish from the Arroyo Colorado. Conclusions and recommendations predicated upon the stated goal of the DSHS to protect human health follow this discussion of findings.

Characterization of Possible Systemic (Noncancerous) Health Effects Related to Consumption of Fish from the Arroyo Colorado

Methylmercury, PCBs and 4,4'-DDE were the compounds of greatest concern in fish from the Arroyo Colorado.

Methylmercury ("Mercury" in Table 2d), a CNS toxicant in the developing fetus, exceeded the HAC_{nonca} in longnose gar. Table 5 shows the hazard quotient for methylmercury in longnose gar to be 3.37. Table 5 also shows that adults weighing 70+ kg could eat only approximately 0.3 eight-ounce meals per week – about one meal per month – of longnose gar containing mercury at similar concentrations. If, however, all people followed consumption advice given for longnose gar, sensitive subgroups such as women who might become pregnant, those who are pregnant, and those who are breastfeeding an infant should suffer no adverse health effects of methylmercury.

All fish sampled in 2006 from the Arroyo Colorado contained 4,4'-DDE. In longnose gar and in smallmouth buffalo, 4,4'-DDE exceeded the HAC_{nonca} (Table 3a). Table 6 gives HQs for 4,4'-DDE – derived from the RfD for 4,4'-DDT, a surrogate for DDE used because 4,4'-DDE does not have an RfD in the IRIS database. Table 6 also shows the composite HQ for all fish containing 4,4'-DDE to be 1.12, only slightly greater than 1.0 – suggesting the composite HQ for 4,4'-DDE is largely the result of including the concentrations of this substance in smallmouth buffalo and longnose gar. It is unlikely that consumption of any species other than longnose gar or smallmouth buffalo or any combination of species that does not include longnose gar or smallmouth buffalo from the Arroyo Colorado (Table 6) would increase the likelihood of adverse health effects from 4,4'-DDE. In fact, channel catfish, common carp, largemouth bass, or red drum concentrations of 4,4'-DDE did not exceed the HAC_{nonca} for this substance, nor was the HQ for any of these species greater than 1.0. The composite hazard quotient for species excluding longnose gar and smallmouth buffalo was 0.20. The allowable consumption rate for a combination of these fish would be almost 13 meals per week, interpreted as "unlimited" consumption as any calculated consumption rate greater than 1 meal per week would be considered unlimited.. These calculations again implicate the large quantities of 4,4'-DDE in longnose gar and/or smallmouth buffalo the primary sources of this toxicant.

The RfD for PCBs is 2E-05 mg/kg –day, having come from a dose of Aroclor 1254 that caused ocular exudates, inflamed and prominent Meibomian glands, distorted finger and toenail growth, and decreased antibody (IgG and IgM) responses to sheep erythrocytes in Rhesus monkeys.[53]

Serving as an example of the USEPA's methodology for determining most RfDs, the following paragraphs describe the derivation of the RfD for Aroclor 1254. The Aroclor 1254 RfD is based on a LOAEL of 0.005 mg/kg-day. Researchers applied several uncertainty factors to the LOAEL while developing the RfD for this mixture: a full factor of 10 for intra-human variability (sensitive subgroups), a partial factor of 3 to account for extrapolation to humans from monkeys, and, to account for use of a subchronic study (approximately 25% of the animal's life) - another factor of 3. To account for use of a LOAEL to develop the RfD, federal risk assessors applied another partial uncertainty factor of 3. Multiplying the uncertainty factors (10*3*3*3), as is standard practice yielded a composite uncertainty factor of 270, subsequently rounded to 300. The modifying factor was 1.0. To calculate the RfD for Aroclor 1254, the USEPA used the following formulae:[34]

$$RfD = LOAEL \div UFs * MF$$

Therefore, the RfD for Aroclor 1254 is

$$0.005 \div 300 * 1.0 = 0.00002 \text{ mg/kg-day (2E-05 mg/kg-day).}$$

The SALG, using its assumptions for consumption and adult weight, calculated a HAC_{nonca} for systemic effects for Aroclor 1254 as 0.047 mg/kg (mg PCBs as Aroclor 1254 per kg of edible tissue). Two species of fish from the Arroyo Colorado taken in 2006 contained PCBs at concentrations exceeding the HAC_{nonca} for PCBs (0.047 mg/kg): smallmouth buffalo and longnose gar (Table 4). Table 7 gives the HQs for PCBs in fish from the Arroyo Colorado, showing these values for smallmouth buffalo, longenose gar, and other species from the 2006 survey of the Arroyo Colorado. Table 7 also outlines suggested consumption rates for fish containing PCBs. The data from Table 7 show the majority of the toxicity of PCBs in fish from the Arroyo Colorado to be attributable to PCBs in smallmouth buffalo and longnose gar. Conclusions given for fish containing 4,4'-DDE (Table 6) also appear appropriate for smallmouth buffalo and longnose gar containing PCBs (Table 7), as do conclusions for species other than longnose gar and smallmouth buffalo. HIs for PCBs in blue tilapia, channel catfish, common carp, largemouth bass, and red drum are all less than 1.0. Thus, theoretically, each species could be eaten without concern.

Characterization of Possible Carcinogenic Effects Related to Consumption of Fish from the Arroyo Colorado

Methylmercury is classified by the USEPA as a possible carcinogen. The EPA however, has not published a carcinogen potency factor for methylmercury. Therefore, the DSHS SALG risk assessors did not assess methylmercury in fish from the Arroyo Colorado for carcinogenicity.[27]

4,4'-DDE is classified as a probable human carcinogen based on animal data (Class 2b).[27] Examination of concentrations of 4,4'-DDE in fish collected in 2006 from the Arroyo Colorado (Table 3a) showed that smallmouth buffalo and longnose gar each exceeded the HAC_{ca} for 4,4'-DDE. The calculated theoretical lifetime excess risk for cancer from 4,4'-DDE in longnose gar was 1 excess cancer in approximately 4000 equally-exposed persons; the calculated theoretical lifetime excess risk of cancer from 4,4'-DDE in smallmouth bass was 1 excess cancer in approximately 5600 people equally exposed to 4,4'-DDE through consumption of this species of fish.

PCBs in fish from the Arroyo Colorado did not exceed the HAC_{ca} for these chemicals in any species of fish. Thus, PCBs alone in fish from the Arroyo Colorado would not likely increase the risk of cancer if PCBs were the only chemicals of concern in these fish.

Characterization of Cumulative Systemic Health Effects and Cumulative Excess Lifetime Cancer Risk from Consumption of Fish from the Arroyo Colorado

Cumulative systemic adverse health effects may be of concern when exposure media contain mixtures of contaminants. Characteristics of the mixtures, mixture components, and methods for assessing responses or effects might assist risk assessors to determine whether cumulative effects are likely or not when chemical mixtures occur. In the current report on fish from the Arroyo Colorado, concentrations of most compounds are so low as to render unnecessary the combined effects. However, three components were of individual concern in this study. The combined effects of methylmercury, PCBs and DDE were of clear interest (Tables 2d, 3a, 4, 5, 6, 7, and 8). Mechanisms or – more often – modes of action – or identical target organs make more likely the probability of cumulative effects. SALG risk assessors utilize hazard index (HI) methodology to assess the likelihood of cumulative systemic adverse effects. This methodology requires that the contaminants in question have a common target organ or a similar mode of action. In the case of methylmercury, 4,4'-DDE and PCBs, neither assumption is true. The target organ for methylmercury is the fetal CNS. 4,4'-DDE – based on 4,4'-DDT because of the lack of an RfD for DDE likely first affects the liver, while the target organ identified with PCBs is usually the immune system (based in this case on Aroclor 1254), as shown by suppression of the immune response in Rhesus monkeys to sheep red blood cell challenge during treatment with Aroclor 1254.[52] Thus, cumulative systemic effects from consumption of fish collected in 2006 from the Arroyo Colorado for this simple mixture of three dissimilar contaminants are not likely to occur.[39]

Most researchers in risk assessment, on the other hand, consider carcinogenic effects as cumulative and additive, no matter the mechanism of action or the target organ, since most studies of carcinogenicity screening count all neoplasms in each dose group, whether benign or malignant. Table 3b reveals that smallmouth buffalo and longnose gar from Site 2 (FM 506 near the pump station) exceeded the HAC_{ca} for 4,4'-DDE (1.578 mg/kg) In fish containing PCBs, the HAC_{ca} was not exceeded (0.272 m/kg).

Nonetheless, Table 8 shows the calculated theoretical lifetime excess cancer risk from consuming fish from the Arroyo Colorado that contain PCBs and 4,4'-DDE. This table indicates that when one adds PCBs and 4,4'-DDE, smallmouth buffalo and longnose gar contain enough of the two toxicants to cause consumption of either of these two species to exceed the acceptable risk level used by the DSHS to protect the public from carcinogenic effects of environmental contaminants (1 excess cancer in 10,000 equally exposed people). This finding is an important example of the additive effects of carcinogens, showing that one can have an increase in the calculated theoretical risk of cancer from multiple chemicals in a source even when one or more carcinogenic chemicals are not present at concentrations high enough to elevate risk.

CONCLUSIONS

SALG risk assessors prepare risk characterizations to determine public health hazards from consumption of fish and shellfish harvested from Texas water bodies by recreational or subsistence fishers, and – if indicated – may suggest strategies for reducing risk to the health of those who eat contaminated fish or seafood to risk managers at DSHS, including the Texas Commissioner of Health.

This study addressed the public health implications of consuming fish from the Arroyo Colorado. Risk assessors from the DSHS SALG conclude from the present characterization of potential adverse health effects from consuming fish from the Arroyo Colorado.

1. That longnose gar collected in 2006 from the Arroyo Colorado at FM 506 contained mercury at an average concentration that exceeded, by a factor of approximately 3 times the DSHS HAC_{nonca} for methylmercury. Consumption of longnose gar containing mercury **poses an apparent hazard to human health**.

2. That all fish from the Arroyo Colorado contained PCBs, but that only some species contained these contaminants at concentrations that exceeded the HAC_{nonca} value for PCBs. The species of principal concern are smallmouth buffalo and longnose gar. Thus, consumption of longnose gar and/or smallmouth buffalo **pose(s) an apparent hazard to human health**.

3. That species other than smallmouth buffalo and longnose gar are unlikely to increase the likelihood of or systemic effects of PCBs and therefore **pose no apparent risk to human health from systemic effects**.

4. That longnose gar and smallmouth buffalo contained 4,4'-DDE at levels that exceeded the HAC_{ca} value for 4,4'-DDE. The DSHS concludes from this risk characterization that consumption of longnose gar and/or smallmouth buffalo **poses an apparent hazard to human health** because of the carcinogenic effects of 4,4'-DDE.

5. That no species contained PCBs or 4,4'-DDE at concentrations that, in isolation, would predict an increase in the theoretical lifetime risk of cancer. However, the carcinogenic effects of PCBs and 4,4'-DDE (calculated by adding the increase in risk from individual chemicals – a form of response addition – in smallmouth buffalo and longnose gar suggested that consumption of these species of fish **poses an apparent hazard to human health** because of the probability of additive carcinogenic effects.

6. That other contaminants present in fish from the Arroyo Colorado likely **pose no hazard to human health** either alone or in combination because concentrations of these compounds do not exceed the risk values used to protect human health, concentrations are low, and are often seen only at estimated values (J-values).

RECOMMENDATIONS

Risk managers at the DSHS have established criteria for issuing fish consumption advisories based on approaches suggested by the USEPA.[16, 24] If a risk characterization confirms that people can consume less than one meal per week (adults: eight ounces per meal; children: four ounces per meal) of fish or shellfish from the water body under investigation, such a finding could lead risk managers at DSHS to recommend consumption advice for fish or shellfish from that water body. Alternatively, the department may ban possession of fish from the affected water body. Consumption advice or possession bans may be general or may be species specific. Fish or shellfish possession bans are enforceable under subchapter D of the Texas Health and Safety Code, part 436.061(a).[54] Declarations of prohibited harvesting areas are enforceable under the Texas Health and Safety Code, Subchapter D, parts 436.091 and 436.101.[54] DSHS consumption advice carries no penalty for noncompliance. Consumption advisories, instead, inform the public of potential health hazards from consuming contaminated fish or shellfish from Texas waters. With this information, members of the public can make informed decisions about whether – and how much – contaminated fish or shellfish they wish to consume. Risk assessors from the SALG conclude from this risk characterization that consuming one or more species of fish from the Arroyo Colorado continues to **pose an apparent public health hazard**.

Therefore, the SALG recommends

1. That the DSHS advises people to refrain from consuming smallmouth buffalo or longnose gar from the Arroyo Colorado because these species are likely to contain 4,4'-DDE and/or PCBs at concentrations that could individually increase the likelihood of adverse systemic human health effects.

2. That the DSHS advises people to refrain from consuming longnose gar from the Arroyo Colorado because, in addition to the organic compounds listed in recommendation #1, the longnose gar collected in 2006 from the Arroyo Colorado contained mercury at a level that exceeded the concentration (0.7 mg/kg) considered protective of sensitive subpopulations who might consume this pisciverous species.

3. That the DSHS advises people that consumption of smallmouth buffalo and longnose gar from the Arroyo Colorado that contain both PCBs and 4,4'-DDE increases the calculated

theoretical lifetime risk of cancer and, thus, may increase the risk of cancer in those who eat these species from the Arroyo Colorado.

4. That the DSHS continues to monitor fish and/or shellfish from the Arroyo Colorado until consumption of fish containing contaminants such as PCBs, 4, 4'-DDE or mercury can reliably be determined as of no concern to public health.

PUBLIC HEALTH ACTION PLAN

Communication to the public of new or continuing possession bans and consumption advisories or the rescission of either condition is essential to effective management of human health risks from consumption of contaminated fish. In fulfillment of this responsibility, the Department of State Health Services (DSHS), state of Texas takes several steps, alone or in concert with federal government agencies or other state agencies. For instance, the DSHS irregularly publishes a booklet outlining fish consumption advisories and bans. The booklet is available to the public through the Seafood and Aquatic Life Group (SALG). To request a copy of the booklet and/or the data used to assess the risk of adverse health outcomes from consumption of environmentally contaminated fish or shellfish from state-controlled water bodies assessed by the DSHS, please contact the DSHS SALG at 1-512-834-6757.[55] The DSHS SALG also posts the most current information for advisories, bans – or the repeal of such – on the Internet at http://www.dshs.state.tx.us/seafood. The SALG regularly updates this Web site. The Department of State Health Services (Texas) also provides the U.S. Environmental Protection Agency (http://epa.gov/waterscience/fish/advisories/), the Texas Commission on Environmental Quality (TCEQ; http://www.tceq.state.tx.us), and the Texas Parks and Wildlife Department (TPWD; http://www.tpwd.state.tx.us) information on all consumption advisories and possession bans. Each year, the TPWD informs the fishing and hunting public of consumption advisories and fishing bans on its Web site. The TPWD also lists possession bans in an official hunting and fishing regulations booklet available at all establishments selling Texas fishing licenses and at many state parks.[56] Readers may direct questions about the scientific information or recommendations in risk characterizations to the SALG at 512-834-6757. The SALG also posts most such information on its Web site (http://www.dshs.state.tx.us/seafood). Secondarily, one may address inquiries to the Environmental and Injury Epidemiology and Toxicology Branch of the Department of State Health Services (512-458-7269). The EPA's IRIS Web site (http://www.epa.gov/iris/) contains information on environmental contaminants found in food and other environmental media. The Agency for Toxic Substances and Disease Registry (ATSDR), Division of Toxicology (888-42-ATSDR or 888-422-8737) or the ATSDR Web site (http://www.atsdr.cdc.gov) supplies brief information on environmental toxicants in that agency's ToxFAQs™, available on the ATSDR Web site in either English http://www.atsdr.cdc.gov/toxfaq.html) or Spanish (follow the link to TOXFAQS™ en Español). The ATSDR also publishes in-depth reviews of many toxic substances in its Toxicological Profiles. To request copies of Toxicological Profiles on CD-ROM, Public Health Statements (PHS), or ToxFAQs™ call 1-800-CDC-INFO (800-232-4636) or email cdcinfo@cdc.gov. People can also request copies of Toxicological Profiles at http://www.atsdr.cdc.gov/toxpro2.html. Many such documents can also be downloaded from the ATSDR's Web site.

TABLES

Table 1. Fish Samples Collected from the Arroyo Colorado. Sample Number, Species, Length, and Weight were Recorded for Each Sample.

Date	Sample Number	Species	Length (mm)	Weight (g)
Site 1 Arroyo Colorado (Port of Harlingen)				
1/23-26/06	ARC13	Smallmouth Buffalo	627	5037
	ARC14	Smallmouth Buffalo	633	4025
	ARC15	Smallmouth Buffalo	682	5268
	ARC16	Smallmouth Buffalo	630	4321
	ARC17	Common Carp	572	2784
	ARC18	Common Carp	505	2030
	ARC19	Red Drum	590	2182
	ARC20	Channel Catfish	560	2428
	ARC21	Channel Catfish	557	2255
	ARC23	Channel Catfish	560	2084
Site 2 Arroyo Colorado (FM 506)				
2/13-16/06	ARC36	Smallmouth Buffalo	585	4314
	ARC39	Smallmouth Buffalo	649	3862
	ARC41	Smallmouth Buffalo	623	3014
	ARC43	Smallmouth Buffalo	591	3311
	ARC44	Channel Catfish	440	784
	ARC45	Longnose Gar	763	1220
	ARC46	Longnose Gar	1033	3985
Site 3 Arroyo Colorado (Llano Grande Lake)				
1/23-26/06	ARC6	Channel Catfish	477	1106
	ARC7	Channel Catfish	580	2467
	ARC8	Common Carp	605	3789
	ARC9	Channel Catfish	473	1248
	ARC10	Channel Catfish	592	2741
	ARC11	Channel Catfish	531	1921
	ARC12	Channel Catfish	481	1283
Site 4 Arroyo Colorado (FM 493)				
1/23-26/06	ARC1	Channel Catfish	455	792
	ARC2	Largemouth Bass	367	812
	ARC3	Blue Tilapia	307	554
	ARC4	Blue Tilapia	292	404
	ARC5	Blue Tilapia	271	345
Site 5 Arroyo Colorado (FM 907)				
2/13-16/06	ARC35	Channel Catfish	517	1495

Table 2a. Arsenic (mg/kg) in Fish from Arroyo Colorado, 2006.

Species	# Detected/ # Sampled	Total Arsenic Mean Concentration ± S.D.	Inorganic Arsenic Mean Concentration[a]	Health Assessment Comparison Value (mg/kg)[2]	Basis for Comparison Value
Blue tilapia	3/3	0.055± 0.001 (0.054-0.055)	0.006	0.7 0.362	EPA chronic oral RfD for Inorganic arsenic: 0.0003 mg/kg–day EPA oral slope factor for inorganic arsenic: 1.5 per mg/kg–day
Channel catfish	12/12	0.110± 0.143 (BDL[3]-0.362)	0.011		
Common carp	3/3	0.180± 0.128 (0.032-0.256)	0.018		
Largemouth bass	1/1	0.094	0.009		
Longnose gar	2/2	1.752± 2.359 (0.084, 3.420)	0.175		
Red drum	1/1	1.402	0.140		
Smallmouth buffalo	8/8	0.221± 0.091 (0.108-0.368)	0.022		
All Sampled Fish	30/30	0.293± 0.645 (BDL-3.420)	0.029		

[a] Most arsenic in fish and shellfish occurs as organic arsenic and virtually nontoxic to humans. For risk assessment calculations, DSHS assumes that total arsenic is composed of 10% inorganic arsenic in fish and shellfish tissues.
[2] Derived from the 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 assumes a 30-year exposure period for carcinogens and an excess lifetime cancer risk of $1x10^{-4}$.
[3] BDL: "Below Detection Limit" – Concentrations were reported as less than the laboratory's method detection limit ("J" values). In some instances, a "J" value was used to denote the discernable presence in a sample of a contaminant at concentrations estimated as different from the sample blank, while at other times, a "<" followed by the laboratory's MDL was utilized to note that a contaminant was detected below the detection limit, but was not quantified.

Table 2b. Inorganic Contaminants (mg/kg) in Fish from Arroyo Colorado, 2006.

Contaminant	# Detected/ # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
Cadmium				
Blue Tilapia	0/3	ND[4]	0.47	ATSDR chronic oral MRL: 0.0002 mg/kg–day
Channel Catfish	2/12	0.019± 0.019 (0.009-0.060)		
Common Carp	0/3	ND		
Largemouth Bass	0/1	ND		
Longnose Gar	0/2	ND		
Red Drum	0/1	ND		
Smallmouth Buffalo	1/8	BDL		
All Sampled Fish	3/30	0.014±0.012 (DL-0.060)		
Copper				
Blue tilapia	3/3	0.158± 0.014 (0.142-0.167)	333	National Academy of Science Upper Limit: 0.143 mg/kg–day
Channel catfish	12/12	0.295± 0.220 (BDL-0.873)		
Common carp	3/3	0.543± 0.322 (0.298-0.908)		
Largemouth bass	1/1	0.191		
Longnose gar	2/2	0.120± 0.031 (0.098-0.142)		
Red drum	1/1	0.202		
Smallmouth buffalo	8/8	0.349± 0.081 (0.255-0.498)		
All Sampled Fish	30/30	0.302± 0.197 (BDL-0.908)		

[4] ND: "Not Detected" was used to indicate that a compound was not present in a sample at a level greater than the MDL.

Table 2c. Inorganic Contaminants (mg/kg) in Fish from Arroyo Colorado, 2006.

Contaminant	# Detected/ # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
Lead				
Blue tilapia	0/3	ND	0.6	EPA IEUBKwin[c]
Channel catfish	4/12	0.050± 0.021 (BDL-0.116)		
Common carp	0/3	ND		
Largemouth bass	0/1	ND		
Longnose gar	0/2	ND		
Red drum	0/1	ND		
Smallmouth buffalo	3/8	BDL		
All Sampled Fish	7/30	0.047± 0.014 (ND-0.116)		
Selenium				
Blue tilapia	3/3	0.392± 0.025 (0.369-0.419)	6	EPA chronic oral RfD: 0 .005 mg/kg–day ATSDR chronic oral MRL: 0.005 mg/kg–day NAS NAS UL: 0.400 mg/day (0.005 mg/kg–day) RfD or MRL/2: (0.005 mg/kg –day/2= 0.0025 mg/kg–day) to account for other sources of selenium in the diet
Channel catfish	11/12	0.221± 0.125 (BDL-0.409)		
Common carp	3/3	0.530± 0.010 (0.519-0.536)		
Largemouth bass	1/1	0.399		
Longnose gar	2/2	0.409± 0.056 (0.369, 0.448)		
Red drum	1/1	0.523		
Smallmouth buffalo	8/8	0.690± 0.162 0.541-0.999)		
All Sampled Fish	29/30	0.423± 0.225 (BDL-0.999)		

Table 2d. Inorganic Contaminants (mg/kg) in Fish from Arroyo Colorado, 2006.

Contaminant	# Detected/ # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
Zinc				
Blue tilapia	3/3	4.619± 0.751 (4.042-5.468)	700	EPA chronic oral RfD: 0.3 mg/kg–day
Channel catfish	12/12	6.650± 3.958 (0.406-16.760		
Common carp	3/3	16.036± 10.686 (4.211-25.002)		
Largemouth bass	1/1	4.502		
Longnose gar	2/2	3.087± 0.712 (2.583, 3.590)		
Red drum	1/1	3.209		
Smallmouth buffalo	8/8	5.003± 1.114 (3.622-6.914)		
All Sampled Fish	30/30	6.522± 5.088 (0.406-25.002)		
Mercury				
Blue tilapia	3/3	BDL	0.7	ATSDR chronic oral MRL: 0.0003 mg/kg–day
Channel catfish	12/12	0.160± 0.074 (0.084-0.367)		
Common carp	3/3	0.172± 0.090 (0.069-0.235)		
Largemouth bass	1/1	0.308		
Longnose gar	2/2	**2.362**± 2.419 (0.651, **4.073**)		
Red drum	1/1	0.187		
Smallmouth buffalo	8/8	0.301± 0.090 (0.193-0.441)		
All Sampled Fish	30/30	0.337± 0.719 (BDL-**4.073**)		

Table 3a. 4,4'-DDE, 4,4'-DDD, and 4,4'-DDT(mg/kg) in Fish from Arroyo Colorado, 2006

Contaminant	# Detected / # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
4,4'-DDE				
Blue Tilapia	3/3	0.028± 0.007 (0.020-0.034)	1.167 1.578	EPA chronic oral RfD for 4,4'DDT: 0.0005 mg//kg–day EPA slope factor 0.34 per mg/kg–day
Channel Catfish	12/12	0.628± 0.400 (0.087-**1.582)**		
Common Carp	3/3	0.191± 0.049 (0.161-0.248)		
Largemouth Bass	1/1	0.276		
Longnose Gar	2/2	**3.829**± 1.068 (**3.074, 4.584**)		
Red Drum	1/1	0.073		
Smallmouth Buffalo	8/8	**2.853**± 3.407 (0.510-**10.225**)		
All Sampled Fish	30/30	**1.301**± 2.140 (0.020-**10.225**)		
4,4'-DDD				
Blue Tilapia	2/3	BDL	1.167 2.27	EPA chronic oral RfD for 4,4'-DDT: 0.0005 mg//kg–day EPA slope factor 0.24 per mg/kg–day
Channel Catfish	12/12	0.019± 0.012 (BDL-0.039)		
Common Carp	3/3	0.005± 0.003 (BDL-0.007)		
Largemouth Bass	1/1	0.009		
Longnose Gar	2/2	0.020± 0.013 (0.010, 0.029)		
Red Drum	1/1	BDL		
Smallmouth Buffalo	8/8	0.023± 0.012 (0.008-0.043)		
All Sampled Fish	29/30	0.016± 0.012 (ND-0.043)		
4,4'-DDT				
Blue Tilapia	0/3	ND	1.167 1.578	EPA chronic oral RfD: 0.0005 mg/kg–day EPA slope factor 0.34 per mg/kg–day
Channel Catfish	11/12	0.005± 0.003 (BDL-0.008)		
Common Carp	0/3	ND		
Largemouth Bass	1/1	BDL		
Longnose Gar	2/2	0.005± 0.006 (BDL, 0.009)		
Red Drum	0/1	ND		
Smallmouth Buffalo	8/8	0.014± 0.014 (BDL-0.045)		
All Sampled Fish	22/30	0.007± 0.009 (BDL-0.045)		

Table 3b. 4,4'-DDE (mg/kg) in Fish from the Arroyo Colorado by Species and Site, 2006				
Contaminant	**# Detected / # Sampled**	**Mean Concentration ± S.D. (Min-Max)**	**Health Assessment Comparison Value (mg/kg)**	**Basis for Comparison Value**
Site 1 (Port of Harlingen)				
Channel catfish	3/3	0.707± 0.297 (0.514-1.050)	1.167 1.578	EPA chronic oral RfD for 4,4'-DDT: 0.0005 mg//kg–day EPA slope factor 0.34 per mg//kg–day
Common carp	2/2	0.205± 0.061 (0.16, 0.248)		
Red drum	1/1	0.073		
Smallmouth buffalo	4/4	0.846± 0.239 (0.510, 1.051)		
All Sampled Fish, Site 1	10/10	0.599± 0.368 (0.073-1.051)		
Site 2 (FM 506)				
Channel catfish	1/1	0.407	1.167 1.578	EPA chronic oral RfD for 4,4'-DDT: 0.0005 mg//kg–day EPA slope factor 0.34 per mg//kg–day
Longnose gar	2/2	**3.829**± 1.068 **(3.074, 4.584)**		
Smallmouth buffalo	4/4	**4.860**± 4.036 (0.785-**10.225**)		
All Sampled Fish, Site 2	7/7	**3.929**± 3.314 (0.407-**10.225**)		
Site 3 (Llano Grande Lake)				
Channel catfish	6/6	0.765± 0.451 (0.332-**1.582**)	1.167 1.578	EPA chronic oral RfD for 4,4'-DDT: 0.0005 mg//kg–day EPA slope factor 0.34 per mg/kg–day
Common carp	1/1	0.164		
All Sampled Fish, Site 3	7/7	0.679± 0.471 (0.164-**1.582**)		
Site 4 (FM 493)				
Blue tilapia	3/3	0.028± 0.007 (0.020-0.034)	1.167 1.578	EPA chronic oral RfD for 4,4'-DDT: 0.0005 mg//kg–day EPA slope factor 0.34 per mg/kg–day
Channel catfish	1/1	0.327		
Largemouth bass	1/1	0.276		
All Sampled Fish, Site 4	5/5	0.137± 0.151 (0.020-0.327)		
Site 5 (FM 907)				
Channel catfish	1/1	0.087	1.167 1.578	EPA chronic oral RfD for 4,4'-DDT: 0.0005 mg//kg–day EPA slope factor 0.34 per mg/kg–day
All Sites				
Blue tilapia	3/3	0.028± 0.007 (0.020-0.034)	1.167 1.578	EPA chronic oral RfD for 4,4'-DDT: 0.0005 mg//kg–day EPA slope factor 0.34 per mg/kg–day
Channel catfish	12/12	0.628± 0.400 (0.087-**1.582**)		
Common carp	3/3	0.191± 0.049 (0.161-0.248)		
Largemouth bass	1/1	0.276		
Longnose gar	2/2	**3.829**± 1.068 **(3.074, 4.584)**		
Red drum	1/1	0.073		
Smallmouth buffalo	8/8	**2.853**± 3.407 (0.510-**10.225**)		
All Sampled Fish	30/30	**1.301**± 2.140 (0.020-**10.225**)		

Table 3c. Chlordane and Dacthal (mg/kg) in Fish from the Arroyo Colorado by Species and Site, 2006

Contaminant	# Detected / # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
Chlordane				
Blue Tilapia	1/3	BDL	1.167 1.578	EPA chronic oral RfD: 0.0005 mg//kg–day EPA slope factor 0.35 per mg//kg–day
Channel Catfish	12/12	0.025± 0.020 (0.004-0.068)		
Common Carp	3/3	0.005± 0.002 (BDL-0.007)		
Largemouth Bass	1/1	0.009		
Longnose Gar	2/2	0.015± 0.010 (0.007, 0.021)		
Red drum	0/1	ND		
Smallmouth Buffalo	8/8	0.024± 0.016 (0.007-0.052)		
All Sampled Fish	27/30	0.018± 0.017 (ND-0.068)		
Dacthal				
Blue Tilapia	3/3	0.014± 0.008 (0.008-0.022)	23.3	EPA chronic oral RfD: 0.01 mg//kg–day
Channel Catfish	12/12	0.150± 0.137 (0.001-0.465)		
Common Carp	3/3	0.048± 0.015 (0.038-0.065)		
Largemouth Bass	1/1	0.098		
Longnose Gar	2/2	0.071± 0.056 (0.031, 0.111)		
Red Drum	1/1	0.008		
Smallmouth Buffalo	8/8	0.107± 0.069 (0.017-0.227)		
All Fish Sampled	30/30	0.103± 0.104 (0.001-0.465)		

Table 3d. Diazinon (mg/kg) in Fish from the Arroyo Colorado, 2006.				
Contaminant	**# Detected / # Sampled**	**Mean Concentration ± S.D. (Min-Max)**	**Health Assessment Comparison Value (mg/kg)**	**Basis for Comparison Value**
Diazinon				
Blue Tilapia	1/3	BDL	1.633	ATSDR chronic oral MRL: 0.0007 mg/kg–day
Channel Catfish	9/12	0.005± 0.003 (ND-0.013)		
Common Carp	3/3	0.006± 0.003 (BDL-0.007)		
Largemouth Bass	1/1	0.008		
Longnose Gar	0/2	ND		
Red Drum	1/1	BDL		
Smallmouth Buffalo	4/8	0.008± 0.002 (ND-0.010)		
All Sampled Fish	17/30	0.004± 0.003 (ND-0.013)		

Table 4. Polychlorinated Biphenyls (PCBs) (mg/kg) in Fish from the Arroyo Colorado, 2006, by Species and Site

Species by Site	# Detected / # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
Site 1 (Port of Harlingen)				
Channel Catfish	3/3	0.0450±0.0112 (0.0350-0.0572)	0.047 0.272	EPA chronic oral RfD for Aroclor 1254: 0.00002 mg/kg–day EPA slope factor :for PCBs 2.0 per mg/kg–day
Common Carp	2/2	0.0164±0.0029 (0.0144, 0.0185)		
Red Drum	1/1	0.0111		
Smallmouth Buffalo	4/4	**0.0840±0.0358 (0.0385-0.1177)**		
All Species within Site 1	10/10	**0.0515**±0.0373 (0.0111-**0.1177**)		
Site 2 (FM 506)				
Channel Catfish	1/1	0.0193	0.047 0.272	EPA chronic oral RfD for Aroclor 1254: 0.00002 mg/kg–day EPA slope factor for PCBs: 2.0 per mg/kg–day
Longnose Gar	2/2	**0.0827**±0.0363 **(0.0570, 0.1084)**		
Smallmouth Buffalo	4/4	**0.1241±0.0767** (0.0412-**0.2093**)		
All Species within Site 2	7/7	**0.0973±0.0687** **(**0.0193-**0.2093**)		
Site 3 (Llano Grande Lake)				
Channel Catfish	6/6	0.0372±0.0158 (0.0204-0.**0625**)	0.047 0.272	EPA chronic oral RfD for Aroclor 1254: 0.00002 mg/kg–day EPA slope factor for PCBs: 2.0 per mg/kg–day
Common Carp	1/1	0.0207		
All Species within Site 3	7/7	0.0349±0.0157 (0.0204-**0.0625**)		
Site 4 (FM 493)				
Blue Tilapia	3/3	0.0105±0.0004 (0.0101-0.0108)	0.047 0.272	EPA chronic oral RfD for Aroclor 1254: 0.00002 mg/kg–day EPA slope factor for PCBs: 2.0 per mg/kg–day
Channel Catfish	1/1	0.0184		
Largemouth Bass	1/1	0.0189		
All Species within Site 4	5/5	0.0138±0.0044 (0.0101-0.0189)		
Site 5 (FM 907)				
Channel Catfish	1/1	0.0091	0.047 0.272	EPA chronic oral RfD for Aroclor 1254: 0.00002 mg/kg–day EPA slope factor for PCBs: 2.0 per mg/kg–day
All Sites				
Blue Tilapia	3/3	0.0105±0.0004 (0.0101-0.0108)	0.047 0.272	EPA chronic oral RfD for Aroclor 1254: 0.00002 mg/kg–day EPA slope factor for PCBs: 2.0 per mg/kg–day
Channel Catfish	12/12	0.0338±0.0165 (0.0091-0.0625)		
Common Carp	3/3	0.0179±0.0032 (0.0144-0.0207)		
Largemouth Bass	1/1	0.0189		
Longnose Gar	2/2	**0.0827**±0.0363 **(0.0571, 0.1084)**		
Red Drum	1/1	0.0111		
Smallmouth Buffalo	8/8	**0.1040±0.0594 (0.0385-0.2093)**		

Table 4. Polychlorinated Biphenyls (PCBs) (mg/kg) in Fish from the Arroyo Colorado, 2006, by Species and Site

Species by Site	# Detected / # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
All Species and All Sites	30/30	**0.0506±0.0484** (0.0091-**0.2093)**	0.047	EPA chronic oral RfD for Aroclor 1254: 0.00002 mg/kg–day
			0.272	EPA slope factor for PCBs: 2.0 per mg/kg–day

Table 5. Hazard quotients (HQ) for Mercury in fish Collected from the Arroyo Colorado in 2006 along with suggested consumption rates for adults consuming an 8-oz meal of fish containing Mercury at concentrations near those found in tissue samples from the Arroyo Colorado in 2006.[b]

Species	Hazard Quotient	Meals per Week
Blue tilapia	NA[c]	NA
Channel catfish	0.23	4.0
Common carp	0.25	3.8
Largemouth bass	0.44	2.1
Longnose gar	**3.37**	**0.3**
Red drum	0.27	3.5
Smallmouth buffalo	0.43	2.2
All Fish Combined	0.48	1.9

[b] DSHS assumes that children under the age of 12 years and/or those who weigh less than 35 kg eat 4-ounce meals.
[c] NA: Not Applicable. Mercury concentration in blue tilapia was below the laboratory's detection limit. The hazard quotient for mercury in blue tilapia could not be calculated.

Table 6. Hazard quotients (HQ) for DDE in fish collected from the Arroyo Colorado in 2006 along with suggested consumption for 70+ kg adults consuming 8-oz of fish containing DDE at concentrations near those in the 2006 samples from the Arroyo Colorado.

Species	Hazard Quotient	Meals per Week
Blue tilapia	0.02	38.6
Channel catfish	0.54	1.7
Common carp	0.16	5.7
Largemouth bass	0.24	3.9
Longnose gar	**3.28**	**0.3**
Red drum	0.06	14.8
Smallmouth buffalo	**2.45**	**0.4**
Arithmetic mean HQ and meals/week for all fish calculated from HQs and meals/week of all sampled fish	**1.12**	**0.8**
Arithmetic mean HQ and meals/week for fish other than longnose gar & smallmouth buffalo	0.20	12.9

Table 7. Hazard quotients (HQ) for PCBs in fish Collected from the Arroyo Colorado in 2006 along with suggested consumption rates for adults consuming a 8-oz meal of fish containing PCBs at concentrations near those found in tissue samples from the Arroyo Colorado in 2006.[d]

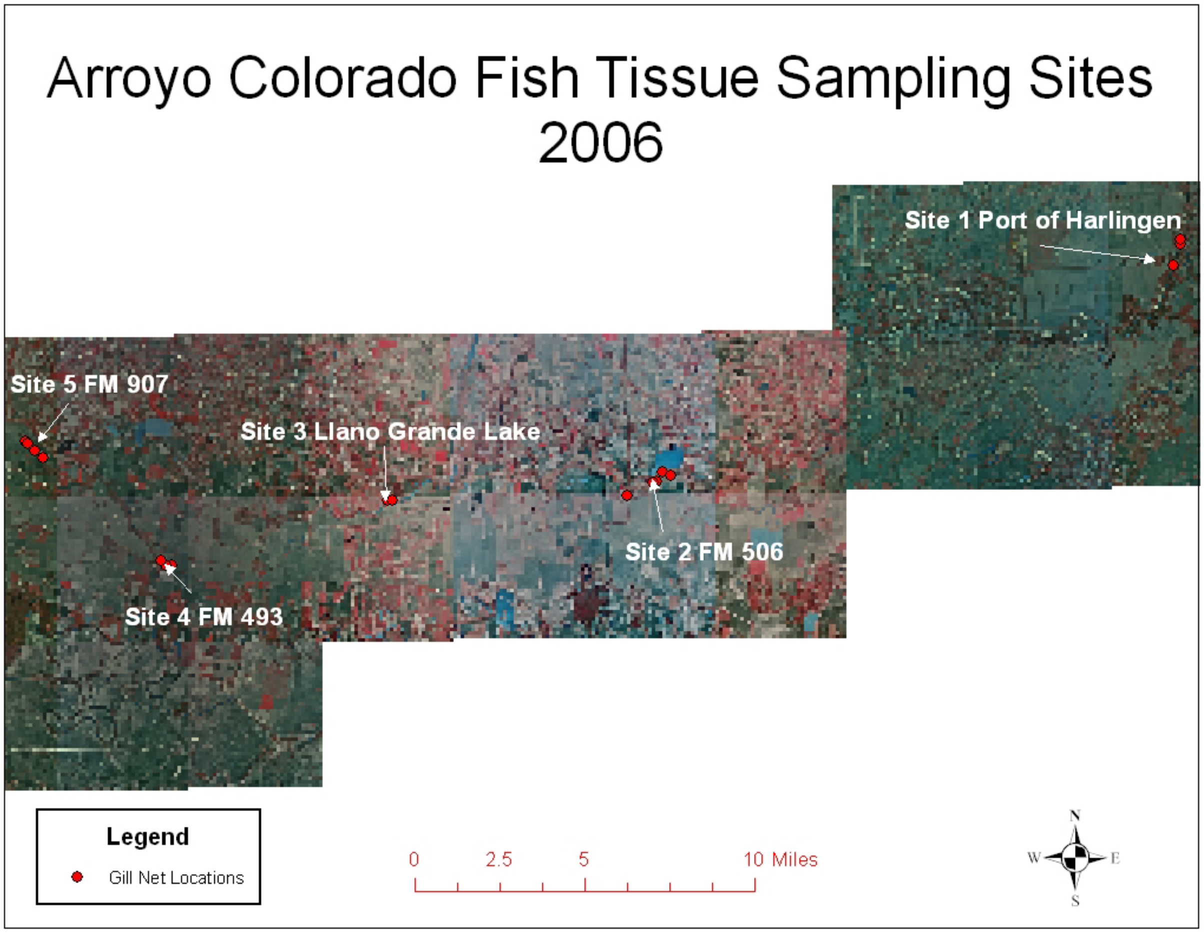
Species	Hazard Quotient	Meals per Week
Blue tilapia	0.23	4.1
Channel catfish	0.72	1.3
Common carp	0.38	2.4
Largemouth bass	0.41	2.3
Longnose gar	**1.77**	**0.5**
Red drum	0.23	4.0
Smallmouth buffalo	**2.23**	**0.4**
Average HI for all fish, assuming equal consumption (≈14% of each species at each meal).	**1.08**	**0.9**

[d] DSHS assumes that children under the age of 12 years and/or those who weigh less than 35 kg eat 4-ounce meals.

Table 8. Calculated Theoretical Lifetime Excess Cancer Risk from Consuming Fish containing Both PCBs and 4,4'-DDE taken in 2006 from the Arroyo Colorado and Suggested Consumption (8-ounce meals/week) for 70+kg adults who regularly eat fish from the Arroyo Colorado over a 30-Year Period. [d]

Species	Theoretical Lifetime Excess Cancer Risk		Meals per Week
	Risk	1 excess cancer per number of people exposed	
Blue tilapia,	5.6E-06	178,389	16.5
Channel catfish	5.2E-05	19,367	1.8
Common Carp	1.9E-05	54,045	5.0
Largemouth Bass	2.4E-05	41,3595	3.8
Longnose Gar	**2.7E-04**	**3711**	**0.3**
Red Drum	8.6E-06	115,790	10.7
Smallmouth buffalo	**2.2E-04**	**4622**	**0.4**
Average of all fish, assuming equal consumption (≈14% each species/meal)	8.56E-05	112788	5.5
Average of all fish other than smallmouth buffalo and longnose gar, assuming equal consumption (≈14% each species/meal)	2.18E-05	156,237	7.6
Smallmouth buffalo and longnose gar, only, assuming equal consumption (≈ 14% each species/meal)	**2.45E-04**	**4167**	**0.35**

Figure 1. Arroyo Colorado Sample Site Map



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