# Evaluation of Dioxin Soil Direct Contact Cleanup Levels for Home-Raised Chicken Egg Consumption

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## Abbreviations and Acronyms

| | |
|---|---|
| AhR | Aryl hydrocarbon receptor |
| ATSDR | Agency for Toxic Substances and Disease Registry (U.S.) |
| bw | Body weight |
| CALUX | Chemical activated luciferase gene expression bioassay |
| cPCB | Coplanar polychlorinated biphenyl |
| Dioxin | Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans with toxicity similar to 2,3,7,8-tetrachlorodibenzo-p-dioxin |
| DF | Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans |
| DLC | Dioxin-like compound |
| DL | Detection Limit |
| dl-PCB | Dioxin-like polychlorinated biphenyl |
| DNA | Deoxyribonucleic acid |
| Dow | The Dow Chemical Company |
| EC | European Commission |
| EFH | Exposure Factors Handbook (EPA, 2011) |
| EPA | United States Environmental Protection Agency |
| FAO | Food and Agriculture Organization of the UN |
| FDA | United States Food and Drug Administration |
| g | gram |
| GLM | Generalized linear model – regression model |
| HQ | Hazard quotient |
| IARC | International Agency for Research on Cancer |
| I-TEFs | International toxic equivalency factors (EPA, 1989) |
| I-TEQ | Total toxic equivalence of dioxin based on I-TEFs |
| JECFA | Joint FAO/WHO Expert Committee on Food Additives |
| kg | kilogram |
| LCL | 95% lower confidence level on the mean predicted egg concentration |
| LOD | Level of detection |
| MDEQ | Michigan Department of Environmental Quality |
| mRNA | Messenger ribonucleic acid |
| nd | nondetect |
| NHANES | National Health and Nutrition Examination Survey |
| Non-TDS | Non-Total Diet Study (FDA, 2007) |
| NTP | United States National Toxicology Program |
| PCB | Polychlorinated biphenyl |
| PCDD | Polychlorinated dibenzo-p-dioxins |
| PCDF | Polychlorinated dibenzofurans |
| PCDD/F | Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans |

**Abbreviations and Acronyms (continued)**

| | |
|---|---|
| pg | picogram |
| ppt | Parts per trillion, picograms per gram, or micrograms per kilogram |
| RfD | Reference dose |
| SCF | European Commission, Scientific Committee on Food |
| Std. | Standard |
| TCDD | 2,3,7,8-tetrachlorodibenzo-p-dioxin |
| TDS | Total Diet Study (FDA, 2006) |
| TEF | Toxic equivalency factor |
| TEQ | Total toxic equivalence of dioxin |
| UCL | 95% upper confidence level on the mean predicted egg concentration |
| U.S. | United States |
| USDA | United States Department of Agriculture |
| WHO | World Health Organization |
| WHO 1998 TEFs | Toxic equivalency factors updated by the World Health Organization in 1998 (Van den Berg *et al.*, 1998) |
| WHO 2005 TEFs | Toxic equivalency factors updated by the World Health Organization in 2005 (Van den Berg *et al.*, 2006) |
| WHO 1998 TEQ | Total toxic equivalence of dioxin based on WHO 1998 TEFs |
| WHO 2005 TEQ | Total toxic equivalence of dioxin based on WHO 2005 TEFs |

**Evaluation of Dioxin Soil Direct Contact Cleanup Levels for Home-Raised Chicken Egg Consumption**

## Executive Summary


### Purpose

Site-specific dioxin cleanup levels that have been developed for direct contact with soil are evaluated to determine their adequacy to protect for food-chain exposures due to consuming eggs from home-raised chickens. While not evaluated here, livestock, other than chickens, that have been raised on contaminated soil are also a food-chain exposure concern. Focus on chicken eggs is warranted due to the more common practice of home-raising these animals, especially with the recent increases in the number of urban areas that allow backyard chickens to be kept for home egg consumption.

### Basis: Dioxin Soil Contamination; Midland, Michigan and the Tittabawassee River Floodplain Areas

Dioxins, furans, and other dioxin-like compounds are found as mixtures with varying amounts of the individual congeners (i.e., related chemicals). The mixture type (congener distribution) depends upon the source of contamination. Dioxins and furans are the predominant contaminants with this type of toxicity for the soils in the Midland area and along the Tittabawassee River floodplain. Dioxins and furans are the focus of this evaluation and will collectively be referred to as “dioxin”.

In Midland, dioxin contamination is the result of airborne emissions from historic waste management practices at The Dow Chemical Company, Michigan Operations Midland Plant (Dow). Emissions released into the air from incinerators and Dow’s manufacturing operations contained dioxin which deposited on the downwind soil. Dioxin emissions from Dow have decreased dramatically over the years as processes were modernized to meet regulatory requirements. Dow’s rotary kiln incinerator system now destroys and removes 99.999 percent of dioxin emissions.

Elevated dioxin levels are also found in and along the Tittabawassee and Saginaw Rivers and in Saginaw Bay from releases to the Tittabawassee River as a result of Dow’s former waste management practices. In the past, dioxin was transported in Dow’s waste water, storm water, groundwater, and from fill material adjacent to the river. These discharges into the Tittabawassee River caused the dioxin to mix with the sediment and build up in some riverbanks. Frequent flooding over decades moved contaminated sediment into the floodplain. Current waste management practices and controls help prevent new releases of dioxins and furans into the river from Dow’s facility. Contaminated material in river banks and sediments, as well as soil movement in the floodplain continues to cause the deposition of dioxins and furans on the floodplain

For residential properties in Midland a site-specific cleanup level of 250 parts per trillion (ppt) dioxin total toxic equivalence (TEQ) has been approved by the Michigan Department of Environmental Quality (MDEQ) based on the risk of human direct contact exposures to dioxin in surface soils. Currently, a local ordinance restricts residents from raising livestock within the city, except in certain agricultural areas. This ordinance requires modification to ensure that it can be reliably enforced to prevent human consumption of impacted livestock products related to the dioxin soil contamination.

Two site-specific soil cleanup levels have been approved to protect for human direct contact for the Tittabawassee River floodplain: 250 ppt for maintained areas of residential properties and 2,000 ppt for all other areas/properties. Exposure pathways other than human direct contact with soil were not considered in the development of the site-specific cleanup levels. Currently, there are no known ordinances to prevent the raising of livestock within the Tittabawassee River floodplain. Two of the five townships in the impacted area allow the raising of livestock in special zoning areas along the river. Livestock for human consumption have previously been raised in the floodplain, including chicken eggs and beef cattle (Dykema and Groetsch, 2009; Franzblau *et al.,* 2008). People who consumed these livestock products in the past had elevated blood furan levels as compared to the general population.

To address this exposure concern, Dow is working on long-term land use controls with floodplain property owners. These controls will eventually be included as part of the Institutional Control portion of Dow's response proposal. Where Dow cannot come to agreement with a property owner, a survey, education, and outreach are planned as part of an interim remedial risk management approach. Dow will retain the obligation to monitor property use for all properties and to address this exposure pathway for any properties that do not adopt the institutional control.

**Evaluation: Dioxin Intake from Consumption of Eggs Raised on Dioxin Contaminated Soil**

To evaluate dioxin uptake from soil into chicken eggs, the MDEQ used data from studies that reported dioxin concentration in chicken eggs together with the soil from where the chickens foraged. A generalized linear regression model based on this data was used to predict chicken egg concentrations at soil concentrations of interest (generic and site-specific dioxin cleanup levels).

The most sensitive adverse noncancer effects from dioxin based on human data are prenatal exposure effecting thyroid function in newborns and exposure of young boys resulting in decreased male reproductive function. Impacts to the fetus/newborn are a result of the mother's exposure, predominantly prior to pregnancy due to the bioaccumulative nature of dioxin. Therefore, young children and women of childbearing age are the critical receptors for this evaluation.

The critical receptors' average egg consumption rates were used with the predicted chicken egg dioxin concentrations to determine if the dioxin intake from egg consumption alone would exceed the United States (U.S.) Environmental Protection Agency (EPA) reference dose (RfD) for dioxin. An RfD is an estimate of the daily exposure to a chemical below which negative effects are not expected over a lifetime. The ratio of the dioxin intake rate over the RfD is the hazard quotient (HQ). Typically, the risk management goal for any chemical is to have an HQ of less than one (EPA, 1991; EPA, 2000).

Only average exposures to dioxin in chicken eggs were considered. Other pathways, including other dietary or soil contact exposures, are not accounted for in this evaluation. Since the reasonable maximum exposure was not considered, this evaluation does not identify specific soil concentration(s) for this exposure pathway for cleanup decisions. This evaluation determines whether this exposure pathway is a priority concern for properties where soil concentrations will remain above background, but below generic and site-specific cleanup levels for human direct contact exposure.

**Results: Hazard Quotients Associated with Cleanup Levels**

For each sensitive receptor, average daily intake rates of dioxins from egg consumption were divided by the EPA RfD to calculate a HQ for each of the soil levels of interest and egg consumption rates. Comparison values were also included for U.S. Food and Drug Administration (FDA) raw and cooked egg concentrations and the European Commission egg standard. The HQs for consumption of home-produced chicken eggs are shown in bold in Table 1.

**Conclusions**

This evaluation was based on average concentrations and average rates of egg consumption. High end values are likely to be at least three times higher. The following are based on the HQs in Table 1 that were calculated from estimated dioxin intakes from egg consumption from chickens raised on dioxin contaminated soils:

1. Chickens that forage on soils with elevated dioxin TEQ produce eggs with elevated dioxin levels. Eating these eggs can result in harmful effects.
2. The Tittabawassee River and Saginaw River floodplain site-specific soil criteria of 250 ppt and 2,000 ppt and Midland area soil site-specific soil criterion of 250 ppt were developed to protect for human direct contact hazards with soil. These criteria do not protect for human consumption of eggs produced from chickens raised on soils at those concentrations.
3. Neither the EPA residential soil screening level of 50 ppt nor the MDEQ generic residential soil direct contact criterion of 90 ppt are adequately protective for raising chickens for human egg consumption.
4. The calculated HQs are sufficiently high that they represent a high priority concern for consumption of chicken eggs in areas with dioxin contaminated soil.

**Table 1. Predicted Average Hazard Quotients (HQs) for Free-Range Chicken Egg Consumption - Soil Cleanup Levels, Background Soil Levels plus Comparison Egg Concentrations**

| | | Average Child HQs | | | Average Woman of Childbearing Age HQs | | |
|---|---|---|---|---|---|---|---|
| Soil Dioxin Concentration of Interest | Soil TEQ (ppt) | Home-Produced | Consumers Only | Per Capita | Home-Produced | Consumers Only | Per Capita |
| Site-Specific Residential Direct Contact Cleanup Level | 250 | **30** | 14 | 11 | **8.0** | 4.2 | 2.7 |
| Site-Specific Other Direct Contact Cleanup Level | 2,000 | **104** | 49 | 38 | **27** | 14 | 9 |
| EPA Residential Soil Screening Level | 50 | **12** | 5.5 | 4.2 | **3.1** | 1.6 | 1.0 |
| MDEQ Generic Residential Direct Contact Criterion | 90 | **16** | 7.7 | 5.9 | **4.3** | 2.2 | 1.4 |
| Average TEQ Outside 8-year Floodplain of Tittabawassee River | 20 | **6.7** | 3.2 | 2.4 | **1.8** | 0.93 | 0.59 |
| Michigan Mean + 1 Standard Deviation TEQ | 12 | **5.0** | 2.4 | 1.8 | **1.3** | 0.69 | 0.44 |
| Average Michigan Background TEQ | 5.8 | **3.2** | 1.5 | 1.2 | **0.84** | 0.44 | 0.28 |
| European Commission TEQ Egg Std. 2011 (2.5 pg TEQ/g fat) | NA | **0.85** | 0.40 | 0.31 | **0.22** | 0.12 | 0.075 |
| FDA cooked eggs | NA | **0.11** | 0.051 | 0.040 | **0.029** | 0.015 | 0.0095 |
| FDA raw eggs | NA | **0.17** | 0.078 | 0.060 | **0.043** | 0.023 | 0.014 |

**Home-Produced** – average consumption rate for population that eats home-produced eggs (typically from free-range, backyard chickens)

**Consumers Only** – average consumption rate for population that eats eggs

**Per Capita** – average consumption rate for total population including people who do not eat eggs

**Bold** values are predicted HQs based on average consumption rates for population that eats home-produced eggs.

Recommendations for Midland and the Tittabawassee River Floodplain:

1. Evaluate whether production and consumption of chicken eggs is occurring at this time in areas of soil dioxin concentrations above background levels.
2. Provide educational materials and outreach relative to the raising of livestock for areas where there are elevated levels of dioxin.
3. Develop and implement institutional controls/reliable land use restrictions to manage these exposure pathways for current and future land use where elevated levels of dioxin in soil exist.
4. Evaluate additional food-chain pathways for these areas.

General Recommendations:

1. Evaluate additional food-chain pathways and other bioaccumulative chemicals where appropriate.
2. Develop or modify institutional controls/reliable land use restrictions for any additional food-chain exposure pathways of concern. These institutional controls/reliable land use restrictions could be presumptively implemented.
3. Include footnotes to the generic soil cleanup criteria (e.g., Part 201 generic criteria and EPA RSLs tables) for dioxin to identify that the cleanup criteria are not adequately protective for the human consumption of chicken eggs raised on soils at these levels (and possibly other food-chain livestock product consumption).
4. Formally establish updated statewide background level for dioxin.

**Evaluation of Dioxin Soil Direct Contact Cleanup Levels for Home-Raised Chicken Egg Consumption**

## Background on Dioxins and Furans

Dioxins, furans, and other dioxin-like compounds (DLCs), including polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and coplanar polychlorinated biphenyls (cPCBs), are a group of toxic chemicals that is known to have toxicity through a common mechanism resulting in additive effects (Van den Berg, *et al.*, 2006; WHO, 2010). Dioxins and furans (DF) are found as mixtures with varying amounts of the individual congeners (i.e., chemicals within a category of similar structure or activity). The mixture type (congener distribution) depends upon the source of contamination. Dioxins and furans are the predominant contaminants with this type of toxicity for the soils in the Midland, Michigan area and along the Tittabawassee River floodplain. Therefore, this evaluation will focus on dioxins and furans, and these compounds will collectively be referred to as “dioxin”.

Dioxins are unintentional byproducts created during the production of chlorine-containing chemicals (e.g., chlor-alkali processes, herbicides, pesticides). Dioxins are not manufactured intentionally, except in small amounts for research purposes (ATSDR, 1998). Metal processing, chlorine bleaching used by pulp and paper mills, combustion, and incineration of wastes have also produced dioxins. Over time, trace amounts of dioxins have been released into the air and deposited onto soil, water bodies, buildings, pavement, plants, etc. Once released, dioxins can remain in the environment for decades (EPA, 2011b). Historic industrial releases of dioxins exceed present day industrial releases (Weber, *et al.*, 2008; EPA, 2012). Due to their persistent nature, widespread distribution, and tendency to bioaccumulate, dioxins remain a concern for environmental and human health risks.

Among the congeners of dioxins, 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) is the most toxic form to humans (Bertrazzi *et al.*, 1993; Huff, 1992; Johnson *et al.*, 1992; Huff *et al.*, 1994; Van den Berg *et al.*, 1998; Van den Berg *et al.*, 2006). TCDD has been extensively studied (IARC, 1997; ATSDR, 1998; WHO, 2010; NTP, 2011; ATSDR, 2012).

Toxic equivalency factors (TEFs) have been established for the individual dioxins as compared to TCDD. TEFs are used with individual congener concentrations and adding these toxic equivalent concentrations determines the total toxicity quotient or TEQ concentrations of a mixture of dioxins. The first internationally recognized TEFs were published in 1989 (I-TEFs) (EPA, 1989), and were subsequently updated in 1998 and 2005 by expert panels organized by the World Health Organization (WHO). The most current version, the WHO 2005 TEFs (Van den Berg *et al.*, 2006), are used by the EPA (EPA, 2010;

EPA, 2013) and for the TEQ values in this evaluation (see Appendix A, Table 7 for TEFs). TEQs are reported based on the TEF values used.

Both noncancer and cancer endpoints following dioxin exposure have been reported. These endpoints depend on exposure concentration and duration. Short-term exposure to high levels of dioxin typically results in abnormalities in the human skin. Chloracne, lesions and patchy darkening of the skin have all been reported following brief, high-level dioxin exposure (Geusau *et al.*, 2001; Tang *et al.*, 2008; WHO, 2010). Liver impairments, including fibrosis in animal models, have also been observed following short-term dioxin exposure (Pierre *et al.*, 2014). Long-term exposure to low levels of dioxin is associated with multiple site cancers in animal models. Human occupational exposures have also been associated with increased incidence of multiple site cancers. Lymphatic and hematopoietic cancers, certain digestive system cancers, and other site cancers were documented to be increased in a population of several thousand people in Seveso, Italy following a major dioxin exposure in 1976 (Bertazzi *et al.*, 1997; Bertazzi *et al.*, 1998; Bertazzi *et al.*, 2001; Consonni *et al.*, 2008; Pesatori *et al.*, 2009). Serious noncancer ailments have also been reported in the human epidemiology literature, including deficits and/or dysfunction to neural development, reproductive function, dental formation, and cardiac, endocrine and immune systems (Porterfield, 1994; Steenland *et al.*, 1999; Baccarelli *et al.*, 2008; Mocarelli *et al.*, 2008; EPA, 2012,).

The developing fetus and newborns are the most sensitive groups to dioxin toxicity (WHO, 2010; EPA, 2012; ATSDR, 2012). Dioxins can pass through the placenta impacting the developing fetus and inadvertent exposure can continue after birth during breastfeeding (Marinković *et al.*, 2010). Infants of mothers with elevated blood TCDD levels had increased thyroid stimulating hormone, a hallmark indicator for low thyroid hormone function (Baccarelli *et al.*, 2008). This adverse outcome in humans is concordant with animal studies that have also demonstrated decreased thyroid hormone function after TCDD exposure (Sewall *et al*., 1995; Seo *et al.*, 1995; Van Birgelen *et al.*, 1995, Crofton *et al.,* 2005; and NTP, 2006). Stringent regulation of endocrine function is imperative for normal fetal neural development. Studies show that mothers with low thyroid hormone during early pregnancy had children with reduced intelligence (Pop *et al.*, 1999; Vulsma, 2000). Neurobehavioral effects and altered brain structure and function after prenatal TCDD exposure have also been demonstrated in animal studies (Markowski *et al.*, 2001; Hojo *et al.*, 2002; Kuchiiwa *et al.*, 2002; Zareba *et al.*, 2002).

The weight of evidence shows that the developing male reproductive system is also very sensitive to adverse effects from TCDD exposure both in humans and animal models. Latent reproductive dysfunction has been observed in adults exposed to dioxin during early development. Mocarelli *et al.* (2008) reported decreased male fertility indices among men exposed to a TCDD release as young boys. Another study also found decreased male fertility endpoints in the sons of mothers who were exposed to dioxins before birth and through breast feeding after birth as compared to controls (Mocarelli *et al*., 2011). Animal studies have also shown that the male reproductive system is very sensitive to adverse effects after maternal exposure to TCDD, for similar male reproductive function and structure (Gray *et al.*, 1997; Faqi *et al*., 1998; Hurst *et al.*, 2000; Simanainen *et al.*, 2004; Takeda *et al.*, 2009). Alteration of normal copulatory behaviors in offspring when they reach sexual maturity was also observed in animal models (Faqi *et al*., 1998).

TCDD was classified as a human carcinogen based on epidemiologic and animal studies by the International Agency for Research on Cancer (IARC) in 1997, and the United States National Toxicology Program (NTP) in 2001. In addition, 2,3,4,7,8-pentachlorodibenzofuran and polychlorinated biphenyl (PCB) 126 were classified as human carcinogens by IARC in 2009 (IARC, 2012) and shown to have additive carcinogenicity with TCDD by the NTP (Walker *et al.*, 2005).

The precise mechanism(s) of dioxin carcinogenesis is still not fully understood; however, dioxins are known to bind to the aryl hydrocarbon receptor (AhR) in human (Landi *et al.*, 2003) and animal models (Bradfield *et al.*, 1991). The AhR is a critical ligand-activated regulatory transcription factor that is involved in gene expression and toxicity in response to dioxins (Poland and Knutson, 1982). A simplified likely mechanism for dioxin-induced carcinogenesis involves dioxin binding to the AhR in tissues following an exposure. The dioxin-bound AhR complex then binds to deoxyribonucleic acid (DNA), disrupting normal gene regulation and subsequent messenger ribonucleic acid (mRNA) regulation and protein synthesis. Disturbance to this cascade of events by the dioxin-AhR complex can then result in biochemical alterations, inappropriate cellular responses (e.g., uninhibited cell growth) and tissue response (e.g., cancer) (Mandal, 2005).

Dioxins are lipophilic, bioaccumulative, and persistent in the environment, because of their chemical structure. TCDD can remain stored in fatty tissues in humans with a half-life of 5 to 11 years depending upon exposure levels, duration of exposure, body fat and age (Pirkle *et al.*, 1989; Olson, 1994; Marinković *et al.*, 2010). Other dioxins also have long half-lives. Bioaccumulation in prey species or lower-level trophic organisms allows dioxin concentrations to increase (biomagnify) as they move up in the food web, affecting numerous species. As animals age and grow, continued exposure to contamination results in meat, fish, eggs, and dairy products with increasing dioxin levels due to bioaccumulation that ends up in the next level of consumer. The main human exposure route is through ingestion of dioxin-contaminated foods. Human exposure can also occur through inadvertent soil ingestion, dermal absorption, and inhalation (WHO, 2010; EPA, 2012). Dioxins build up in the body over time with low level exposures. Once an elevated exposure is stopped, it would take at least 5-10 years for half of the dioxin in an adult to be eliminated.

Even shorter-term, higher exposures will result in elevated blood and tissue levels for a fairly long time.

Dioxins are persistent and toxic environmental contaminants and represent a human health concern. They have a widespread distribution in environmental media, food sources, and human body tissues in the U.S. and overseas due to historical releases. In the U.S., measured dioxin levels have declined since the 1970s; however, most people have detectable levels in body tissues (typically measured in blood/serum) from lifetime exposure to low dioxin levels (WHO, 2010; EPA, 2011b). The most recent background levels measured for humans are typically in the low ppt (picogram/gram [pg/g] or nanogram/kilogram [ng/kg]) range in blood or serum, but can increase readily with additional exposures, which are most likely to occur from ingestion of contaminated foods (DeVries *et al.*, 2006; Lorber, 2010).

Dioxins in Chickens Eggs

This evaluation has been conducted to determine if regular consumption of eggs from free-range, backyard chickens raised in areas with elevated dioxin soil concentrations is a human health concern. The U.S. Department of Agriculture (USDA) reports that per capita egg consumption is approximately 250 eggs per year or 4.8 eggs per week (USDA, 2012). The EPA reports egg consumption rates from various data sources including per capita (total population including people who do not eat eggs), consumers only, and home-producers (typically from free-range, backyard chickens) in the Exposure Factors Handbook (EFH; EPA, 2011a).

A number of studies have evaluated the relative uptake of dioxins into chicken eggs from different potential sources including feed, bedding, and soil. Chickens continuously forage and peck at soil for food and ultimately ingest soil and insects with associated dioxins (Pussemier *et al.*, 2004; Pirard and De Pauw, 2005; DeVries *et al.*, 2006; Van Overmeire *et al.*, 2006; Van Overmeire, 2009b). Yolk from the eggs of foraging chickens has been reported to have elevated concentrations of dioxins when compared to commercially raised chickens (Schuler *et al.*, 1997; Harnly, 2000). As compared to other U.S. urban and rural populations, blood levels were elevated among chicken egg and meat consumers in areas with greater soil dioxin levels (Goldman *et al.*, 2000).

A 1995 uptake study in chickens reported that between 5-30% of ingested dioxin is deposited in eggs (Stephens, 1995). This same study also estimated the half-life of dioxins in chicken to be anywhere from 25-60 days based on fat and egg concentrations. Laying hens accumulate lower body burdens of dioxins than males because dioxins are preferentially deposited into lipid-rich egg yolk and eliminated, in part, from the hen when eggs are laid (Petreas *et al.*, 1996). Tragg *et al.* (2006) demonstrated uptake of dioxin into egg yolk following a 7-day exposure to dioxin-contaminated feed (61 pg TEQ/g). The egg yolk concentrations peaked at day nine (approximately 200 pg TEQ/g egg fat), two days after contaminated feed was changed to clean feed.

Dioxin-related food safety issues have been reported in the U.S. and Europe for decades. Chick edema (a typically fatal condition in chickens characterized by excess fluid in the pericardial sac and abdominal cavity) was observed in chickens consuming contaminated feed in the 1950s. The feed was later found to be contaminated with dioxins (Firestone, 1973). Adverse effects from dioxins in chickens and other avian species has since been demonstrated (Gilbertson *et al.*, 1991; Ludwig *et al.*, 1993; Giesy *et al.*, 1994; Cohen-Barnhouse *et al.*, 2011; Farmahin *et al.*, 2012). Ball clay used in chicken feed was identified as the source of increased dioxin levels in chicken samples in 1996 in the U.S. (Hayward *et al.*, 1999; Ferrario and Bryne, 2000; Ferrario *et al.*, 2000) causing concern for human consumption. Ball clay has since been prohibited for use in animal feed. Poultry was again affected by dioxin and other DLCs through feed in an incident in Belgium in 1999 (van Larebeke *et al.*, 2001). Following these and other incidents, thousands of chickens and their eggs were destroyed.

In response to the food safety events, the WHO recommended a standard for tolerable daily dioxin intake of 1-4 pg TEQ/kg body weight (bw) per day (WHO, 1998). The WHO (in collaboration with the Food and Agriculture Organization [FAO] as part of the Joint FAO/WHO Expert Committee on Food Additives or JECFA) revised the dioxin advisory to a provisional tolerable monthly intake (PTMI) of 70 pg/kg bw per month (WHO, 2001) and the European Commission (EC), Scientific Committee on Food (SCF) set a tolerable weekly intake for dioxins of 14 pg TEQ/kg bw per week (SCF, 2000). In 2006, the EC established a maximum dioxin level in egg fat of 3 pg TEQ/g fat. Since these tolerable intake rates were set by the WHO and the European Commission, additional human studies have been published evaluating more sensitive developmental effects (Baccarelli *et al.*, 2008; Mocarelli *et al.*, 2008; Mocarelli *et al.*, 2011). The EC updated the maximum dioxin level in egg fat to 2.5 pg TEQ/g fat in 2011 (EC, 2011). The newer human studies also resulted in the EPA developing an oral reference dose of 0.7 pg/kg bw per day to protect for these more sensitive human developmental effects (EPA, 2012).

Food contamination monitoring systems are overseen by government organizations to protect the commercial food supply and public health. The U.S. Food and Drug Administration (FDA) worked with the U. S. Department of Agriculture (USDA) to collect data on dioxin levels in commercially available food in the U.S. However, foods raised by individuals for personal or family consumption, including chicken eggs, are not subject to FDA monitoring. This may put individuals living in areas with soil contamination at risk for inadvertent ingestion of contaminants such as dioxins from home raised foods. In many instances, dioxin levels in eggs from chickens raised on soils with elevated concentrations exceed the standards set for human health protection for eggs in Europe (similar standards are not available in the U.S). Consumption of these eggs can pose a substantial health concern for consumers, including developmental (thyroid and reproductive) effects.

**Evaluation of Chicken Egg Uptake and Exposure**

Literature Review

A literature search was conducted to identify published studies with paired chicken egg, chicken meat, and soil dioxin concentrations (i.e., the soil samples were collected where the chickens foraged). Limited information was found with paired chicken meat and soil concentrations; however, sufficient paired information was obtained for chicken egg and soil dioxin concentrations to identify and evaluate that relationship.

The various studies reported TEQs that were calculated with different TEFs (1989, 1998, and 2005). Therefore, the studies used for this evaluation were those that had sufficient congener-specific data to use reported, calculated, or estimated 2005 WHO DF TEQs (Dykema and Groetsch, 2009; Hsu *et al.*, 2010; Schuler *et al.*, 1997; Van Overmeire *et al.*, 2009b). The primary evaluation using 2005 WHO TEQs was also compared to an additional analysis with TEQs calculated by setting nondetect analytical results (nondetects) equal to zero for those studies with congener-specific data. Also, a regression analysis was done with WHO 1998 TEQs to include additional studies that only reported WHO 1998 TEQs (Harnly *et al.*, 2001; Fernandes *et al.*, 2011). Studies that only reported 1989 Interim TEQs (I-TEQs) were not included in the analysis as there were insufficient paired samples with only 1989 I-TEQs (Harnley *et al.*, 2000).

Studies Included in the Analysis:

Hsu *et al.*, 2010 - Caged and free-range chicken egg samples (10 eggs in each sample) were collected from different areas within Taiwan for this study. Collocated soil samples (each a composite from nine locations) were collected from two of the farms where free-range chicken eggs were collected. All samples had congener-specific results and the calculated values for both WHO 1998 TEQ and WHO 2005 TEQs reported. In total, 12 caged egg samples and 6 free-range egg samples underwent congener-specific analysis, with the free-range samples having a mean level of dioxins that was 5.7 times greater than that of caged egg samples. Lipid levels in free-range eggs ranged from 9.22 to 11.0% with a mean value of 10.8% ± 1.04%. The mean lipid level from caged eggs was 9.16% ± 0.81%.

Schuler *et al.*, 1997 - The correlation between dioxins in soil and eggs was examined across several contaminated locations within Switzerland, ranging from 1.3-11 ppt WHO 2005 TEQ. Each foraging area had a soil sample that was a composite from 36 locations from the top 10 centimeters within the area. Data reported included congener-specific concentrations and calculated 1989 I-TEQs for eggs and soils. The goal was to provide baseline information to help with the ability to predict dioxin levels in eggs based on the level of soil contamination. Foraging chickens were studied and those with access to soil had elevated dioxin levels within their eggs as compared to those without soil contact. A model was then created based on specific congener values to describe the pattern of transfer from soil into the eggs through the act of foraging. Limitations and uncertainties of this model were discussed alongside the predicted dioxin levels and applications of these values. The congener specific data was used to calculate WHO 2005 DF TEQs for this evaluation.

Van Overmeire *et al.*, 2009a and 2009b - This Belgian study focused upon both dioxin and PCB levels in soil, eggs, feces, and kitchen waste within two seasons (autumn and spring) as well as an assessment of TEQ intake of the consumers of free-range eggs compared to commercial eggs. Egg samples comprised 10 to 15 eggs per location and season. Soil samples comprised 15 sub samples from the top 10 centimeters at various locations in the outdoor foraging area. Gas chromatography/mass spectrometry results were reported for DF TEQ, dl-PCBs TEQ, and total TEQ values (WHO 1998 TEFs) of all the samples collected. Median concentrations (n=20) were reported for specific congeners for both soil and eggs. These congener-specific medians were used to calculate both WHO 1998 DF TEQs and WHO 2005 DF TEQs to develop a ratio to use as a correction factor for the reported individual location WHO 1998 TEQs. This ratio was used to convert the WHO 1998 DF TEQs to WHO 2005 DF TEQs for this evaluation. An AhR chemical activated luciferase gene expression assay (CALUX) was also used to estimate DLC concentrations in egg samples. Eggs sampled in the autumn tended to show higher CALUX values within the eggs than those obtained in the spring, with TEQ values in both the eggs and the soil demonstrating a similar pattern. Egg and soil DF TEQ values were shown to be correlated through this study.

Dykema and Groetsch, 2009 - Four chicken eggs were collected from home-raised, free-range chickens on the Tittabawassee River floodplain. Two soil samples were collected in the area the chickens foraged. Congener specific data and calculated WHO 2005 TEQs were reported for soil, eggs, walleye, and serum (blood) from human consumers. The soil and egg samples TEQs were predominantly from furan congeners. Serum levels from four youths and one adult that consumed chicken eggs for two years had higher than median serum TEQs with higher percentage contributions from furan congeners. The youths (14-17 years old) had roughly twice the median furan proportion for serum TEQ as compared to Michigan control populations (aged 18-29 was the closest age group to serve as a youth comparison group). The serum was collected from the adult three years after the family had stopped consuming the home-raised eggs and four years after consumption ceased for the youths.

Studies That Only Reported WHO 1998 TEQs:

Fernandes *et al.*, 2011 - The goal of this study was to investigate the transfer and uptake abilities of PCDD/Fs and PCBs into sheep, pigs, and chickens in Norfolk and

Northumberland, United Kingdom. One hundred and five samples including muscle (meat), kidneys, liver, eggs, feed, milk, grass, and soil were collected and analyzed with the results reported in WHO 1998 TEQ. The soil TEQ concentrations are in the range of typical rural background. This is important as even low concentrations of dioxin contamination in soil have been seen to accumulate in eggs and meat tissues. Greater TEQs were noted in eggs from chickens raised in free-range conditions as compared to those raised indoors. This increase may be due to additional intake of contaminants from the soil through ingestion. Biotransfer factors were also analyzed, with contaminant transfer tending to be higher in chickens as compared to sheep or pigs. No congener-specific data were available for conversion to WHO 2005 TEQs. Free-range eggs were reported to have 6.6-10.2% fat and indoor eggs were reported to have 7.9-12.3% fat.

Pirard *et al.*, 2005 - This study looked at chicken egg uptake of PCDDs/Fs and dl-PCBs from soils located near a municipal solid waste incinerator (MSWI) and a comparison area near Maincy, France. Data was reported only as WHO 1998 TEQs, with no congener-specific data reported, although PCDD/F TEQs and dl-PCB TEQ were reported. There were higher soil and egg concentrations for those samples near the MSWI versus the comparison samples. PCDD/F levels in eggs correlated fairly well with the soil concentrations, with the exception of three eggs with higher than expected results. One sample came from a farm that did not use commercial feed, so all of the hens' food was from foraging, which may account for the higher uptake into the eggs.

Other Studies Considered:
Other studies (e.g., Chang *et al*., 1989; Harnly *et al.*, 2000; Petreas *et al.*, 1991) saw a similar relationship between soil concentrations and egg concentrations, but the data could not be converted to WHO 1998 or 2005 TEQs. Piskorska-Pliszczyńska *et al*., 2015 also evaluated chicken egg uptake using four different production methods, two that include cage-free conditions. Soil concentrations were collected only for a few locations with elevated egg concentrations. High concentrations of the same dioxin congeners found in the eggs were also found in the soils. The five paired soil and egg concentrations provided from this study were not included in the evaluation since only a few high egg samples had paired soil concentration. However, these paired samples were consistent with the regression relationship modeled in this evaluation.

Statistical Methods
Inspection of data plots indicated that the logarithm of soil TEQs was approximately linearly related to the logarithm of egg TEQs. Linearity of this log-log relationship suggests fitting a nonlinear model to summarize the relationship. Traditionally, nonlinear regressions have been fit to data by transforming the dependent variable in hopes of achieving normality in the transformed scale followed by fitting a line by least squares to the transformed data. This traditional approach is problematic because: 1) regression relationships must be back-

transformed to the original scale, which is a mathematically biased procedure; and 2) the data are implicitly assumed to be lognormally distributed. In practice, data are frequently more skewed than a normal distribution and less skewed than a lognormal distribution, indicating that an alternative distributional assumption would be more appropriate.

Generalized linear models provide a modern solution to the mathematical bias in traditional methods (McCullagh and Nelder, 1989), providing a framework for fitting more flexible distributions, such as the gamma. This approach avoids bias of back transformation and also relaxes the relatively strict assumption of a lognormal distribution. The biasing effects of data transformation are avoided by fitting a model wherein the logarithm of the expected value (not the data) is modeled as a linear function of the independent variables directly. Also, the gamma distribution provides an alternative that is particularly useful in this context as it is more flexible than either the normal or lognormal distributions. It provides a model that is robust across a range of distributional shapes ranging from nearly symmetric, like the normal distribution, to highly skewed, like the lognormal.

Soil and Egg Dioxin Data Evaluation

The data used in this evaluation are provided in Appendix A, Tables 8-13.

A generalized linear model (McCullagh and Nelder, 1989) with gamma distributed errors was fit to model egg TEQ as a function of the natural logarithm of soil TEQ (conducted by John Kern, MDEQ Statistical Contractor, Figure 1 and SAS statistical software output files in Appendix D).

An evaluation with the generalized linear model was done using 1998 TEQs to include the additional studies (Fernandes *et al.*, 2011; Pirard *et al.*, 2005), see Appendix C, Figures 16 and 19. This evaluation showed an increase in variability as well as an increase in estimated TEQ values (predominantly from higher TEFs for the pentachlorinated furans). The addition of this data did not appear to result in better predictions of egg concentrations.

Most of the soil concentrations from the paired data are well below the site-specific soil cleanup criteria. The reported soil concentrations that are higher (1,300-2,200 ppt, average 1,750 ppt) had paired chicken egg concentrations (Dykema and Groetsch, 2009) from soil and home-raised eggs collected from the Tittabawassee River floodplain. Since there was a big gap in soil concentrations, the model was run without the high end Tittabawassee River floodplain sample data, to determine if the relationship is robust (Appendix C, Figures 17-19). The influence of nondetect data was also tested using a dataset with the Tittabawassee River floodplain nondetects set to the detection limit (Appendix C, Figures 15 and 18).

Egg concentrations associated with soil concentrations set at the various cleanup levels as identified in Table 2 were estimated including confidence intervals for soil concentrations based on the generalized linear model regression analysis described above.

**Figure 1. Generalized Linear Model for All Paired Soil and Egg WHO 2005 TEQ Data with Nondetects Equal to Zero and 95% Confidence Intervals**

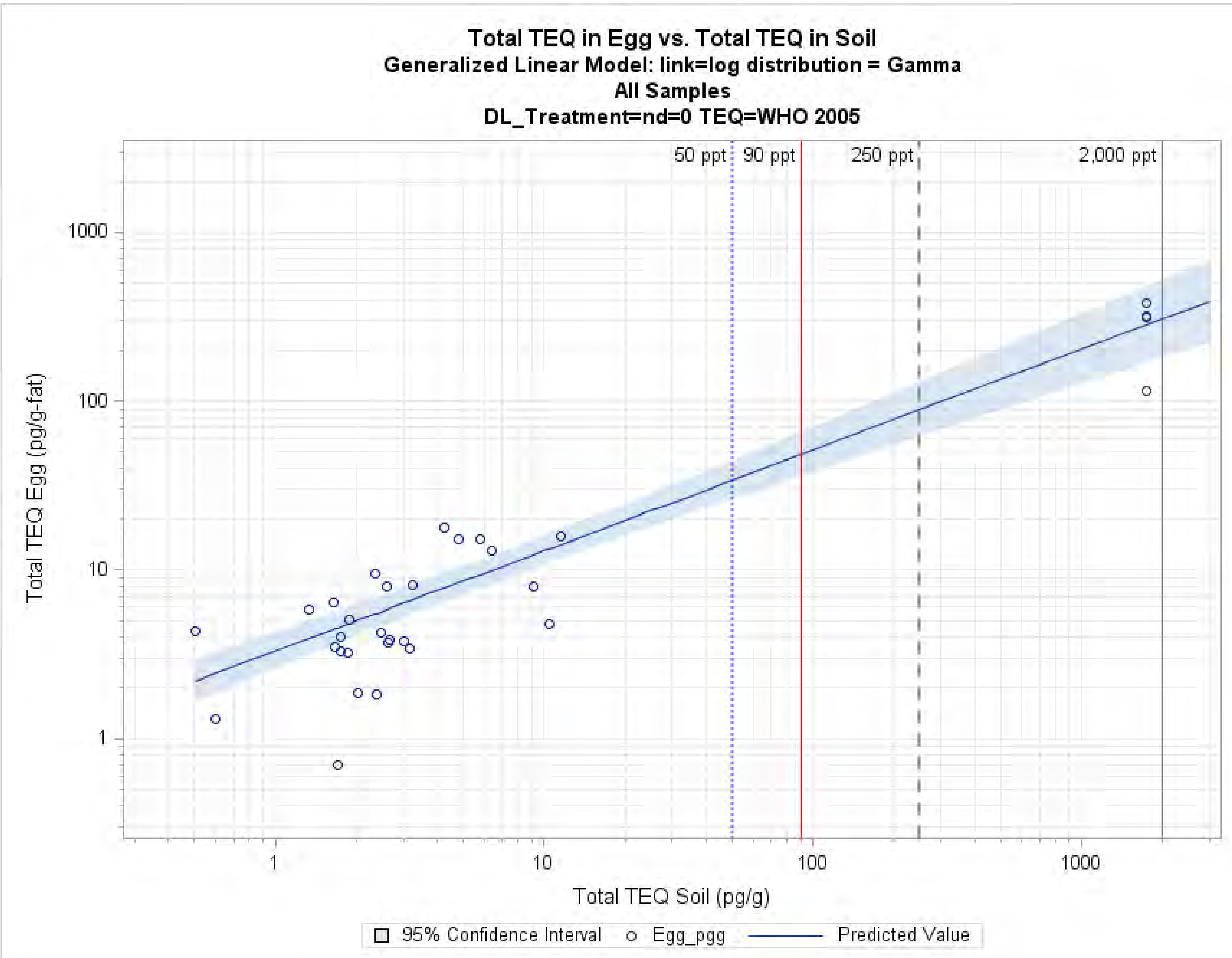


**Table 2. Predicted Egg Dioxin Concentrations from Generalized Linear Model (GLM)**

| Soil Dioxin Concentration of Interest | Soil Concentration (pg/g or ppt) | Average Predicted Egg Concentration (pg/g fat) | 95% Confidence Interval for Predicted Egg Concentration (pg/g fat) |
|---|---|---|---|
| Average Michigan Background TEQ | 5.8 | 9.4 | 7.7-11 |
| Michigan Mean + 1 Standard Deviation TEQ | 12 | 15 | 12-18 |
| Average TEQ Outside 8-year Floodplain of Tittabawassee River | 20 | 20 | 16-25 |
| EPA Residential Soil Regional Screening Level | 50 | 34 | 26-44 |
| MDEQ Generic Residential Direct Contact Criterion* | 90 | 48 | 36-65 |
| Site-Specific Residential Direct Contact Cleanup Level | 250 | 89 | 61-129 |
| Site-Specific Other Direct Contact Cleanup Level | 2000 | 306 | 180-522 |

*From Part 201, Environmental Remediation, of the Michigan Natural Resources and Environmental Protection Act, 1994 PA 451, as amended.

## Risk Assessment

This assessment will use the estimated egg dioxin concentrations from Table 2 and average egg consumption rates from the EFH to calculate dioxin intake levels for consuming these eggs on a picogram of TEQ per kilogram of body weight per day (pg/kg-bw day) basis. The calculated dioxin intake levels from the eggs will then be compared to the EPA noncancer reference dose (RfD) of 0.7 pg/kg-bw day for dioxin to determine if home raised egg consumption is a potential concern for soils with concentrations similar to the site-specific and generic dioxin soil direct contact cleanup levels referenced in this document. The ratio of the dioxin intake rate over the RfD is the hazard quotient (HQ). The risk management goal is to have HQs that are less than one (EPA, 1991; EPA, 2000).

The EPA RfD for dioxin is based on human data for male reproductive effects in exposed boys and thyroid function effects in newborns of exposed mothers. These critical noncancer effects of dioxins for humans make the young child (5 and under) and a woman of childbearing age the appropriate focus of this risk assessment. Since dioxins are bioaccumulative, the woman's body burden prior to pregnancy contributes more of an impact to the developing fetus than her exposure during pregnancy.

The EPA reports egg consumption rates from various data sources for per capita, egg consumers only, and egg home-producers in the EFH (EPA, 2011a). Although the consumption rates for eggs in this document are based on older data (1980s-1990s), the

EFH consumption rates are used in this analysis as they include home-produced egg consumption rates that best represent the receptors of concern for this assessment (young children and women of childbearing age that consume home-raised free-range, backyard chicken eggs), and not just per capita data. A comparison of the per capita data from the EFH to more recent per capita data (2003-2008) is included in the uncertainty analysis.

The receptors of interest for this risk assessment are young children and women of childbearing age that eat home-produced eggs, the available egg consumption rates from the EFH (EPA, 2011a) that represented or were closest to being representative of these receptors were included. The average daily egg ingestion rates from the EFH (EPA, 2011a) were used for these calculations as follows (see Table 3 below for summary egg consumption rates and Appendix B, Table 14 with detailed source information):

1. Home-produced eggs consumption rates.
   a. Available for adults 20-39 years old.
   b. The EFH indicated there was insufficient data for children less than 5 years old, so the average of the adult/child ratios for the per capita and consumers only consumption rates were used to estimate a consumption rate for children less than 5 years old (Appendix B, Table 15).
2. Consumers only (includes only people who eat eggs) consumption rates.
   a. Available for children less than 5 years old.
   b. Available for adults 20-49 years old.
3. Per capita (includes egg eaters and people who do not eat eggs) consumption rates.
   a. Available for children less than 5 years old.
   b. Available for women over 20 years of age.

Appendix B, Table 16 provides the number of eggs per week with the different USDA egg weight classes for these average daily egg consumption rates.

Body weights for a child less than 5 years old and for a woman of childbearing age were obtained from the EFH (Tables 8-1 and 8-5, respectively; EPA, 2011a).

Estimated egg fat dioxin concentrations (WHO 2005 TEQ) were converted to wet weight concentrations using the egg fat content of 9.94% recommended in Table 11-38 of the EFH. These wet weight WHO 2005 TEQs were used to calculate daily intake rates of dioxins from eggs for young children and women of childbearing age by multiplying the wet weight TEQ (pg/g egg) by the egg consumption rates (g egg/kg bw-day).

**Table 3. Egg Consumption Rates Used in Evaluation (from EPA Exposure Factors Handbook [EPA, 2011a] or *Estimated*)**

| | Child 5 and under | | | Woman of Childbearing Age | | |
|---|---|---|---|---|---|---|
| **Average Exposure Assumptions** | ***Home-Produced (ESTIMATED)*** | **Consumers Only** (EPA, 2011a; Table 11-20) | **Per Capita** (EPA, 2011a; Table 11-13) | **Home Produced** Adults 20-39 (EPA, 2011a; Table 13-40) | **Consumers Only** Adults 20-49 (EPA, 2011a; Table 11-20) | **Per Capita** Adult Females over 20 (EPA, 2011a; Table 11-12) |
| Daily egg consumption (g egg/kg bw-day) | ***2.4*** | 1.1 | 0.87 | 0.63 | 0.33 | 0.21 |
| # of Medium Eggs Consumed per Week (44 g egg) | ***5.8*** | 2.7 | 2.1 | 7.6 | 4.0 | 2.5 |
| Body Weight (kg) | 15 | 15 | 15 | 73 | 73 | 73 |

## Results

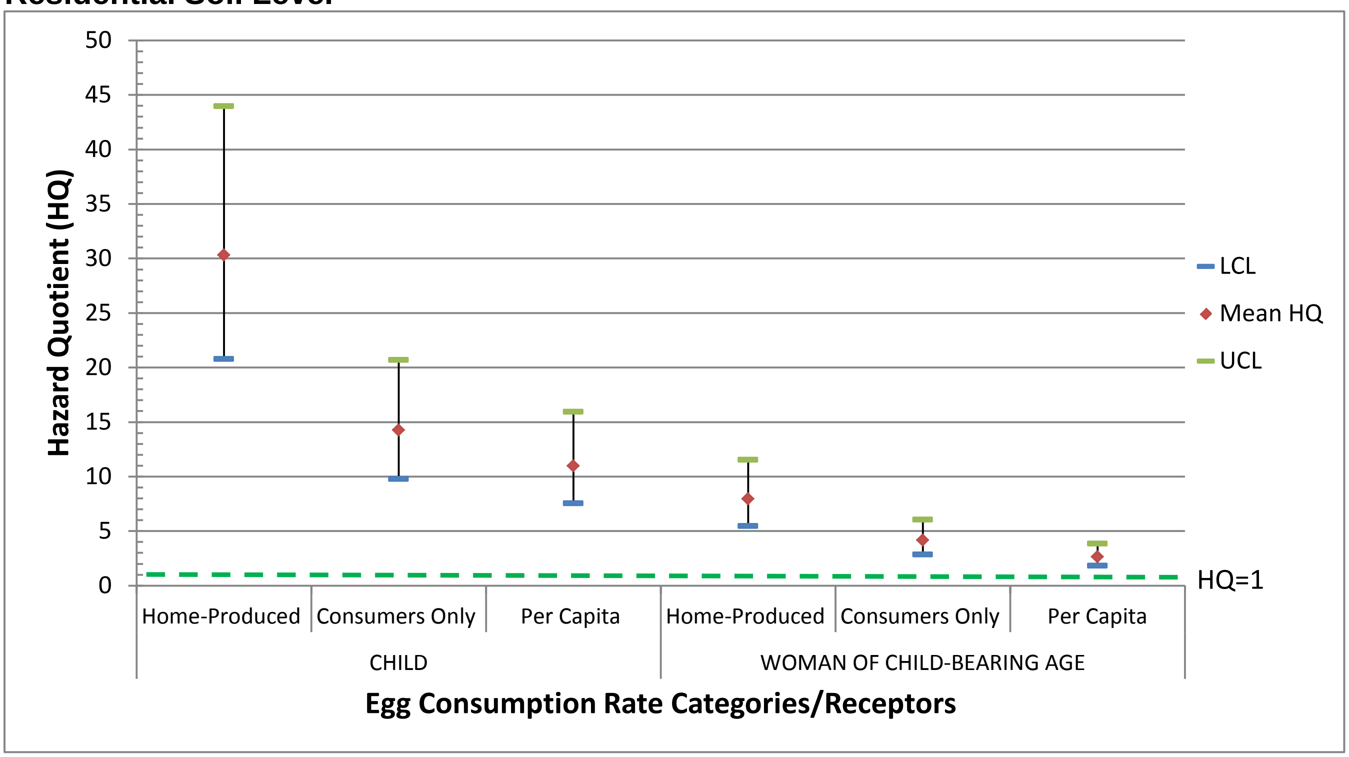
For each sensitive receptor, average daily intake rates of dioxins from egg consumption were divided by the EPA RfD to calculate a hazard quotient (HQ) for each of the soil levels of interest identified in Table 2 and each of the consumption rates identified in Table 3. Table 4 shows the calculated HQs for soil concentrations of interest and Table 20 (Appendix B) includes the 95% upper and lower confidence limits. Figure 2 shows the HQs for the site-specific residential (250 ppt) dioxin cleanup level for each receptor and egg consumption rate with confidence limits on the estimated egg concentrations, with Figure 3 representing the same information for the site-specific other (2,000 ppt) dioxin cleanup level. Figures 4 and 5 show the child and adult receptors with average egg consumption rates for home-produced eggs and all soil concentrations of interest. See also Appendix B, Table 17 for detailed calculations and Figures 6-13 in Appendix B for additional soil concentrations and consumer only and per capita average egg consumption rates.

### Table 4. Hazard Quotients for Egg Consumption Dioxin Intake at Soil Cleanup Levels

| | | Average Child HQs | | | Average Woman of Childbearing Age HQs | | |
|---|---|---|---|---|---|---|---|
| **Soil Dioxin Concentration of Interest** | **Soil (pg/g)** | **Home-Produced*** | **Consumers Only** | **Per Capita** | **Home-Produced** | **Consumers Only** | **Per Capita** |
| Site-Specific Residential Direct Contact Cleanup Level | **250** | 30 | 14 | 11 | 8.0 | 4.2 | 2.7 |
| Site-Specific Other Direct Contact Cleanup Level | **2,000** | 104 | 49 | 38 | 27 | 14 | 9 |
| EPA Residential Soil Regional Screening Level | **50** | 12 | 5.5 | 4.2 | 3.1 | 1.6 | 1.0 |
| MDEQ Generic Residential Direct Contact Criterion | **90** | 16 | 7.7 | 5.9 | 4.3 | 2.2 | 1.4 |
| Average TEQ Outside 8-year Floodplain of Tittabawassee River | **20** | 6.7 | 3.2 | 2.4 | 1.8 | 0.93 | 0.59 |
| Michigan Mean + 1 Standard Deviation TEQ | **12** | 5.1 | 2.4 | 1.9 | 1.3 | 0.70 | 0.45 |
| Average Michigan Background TEQ | **5.8** | 3.2 | 1.5 | 1.2 | 0.84 | 0.44 | 0.28 |

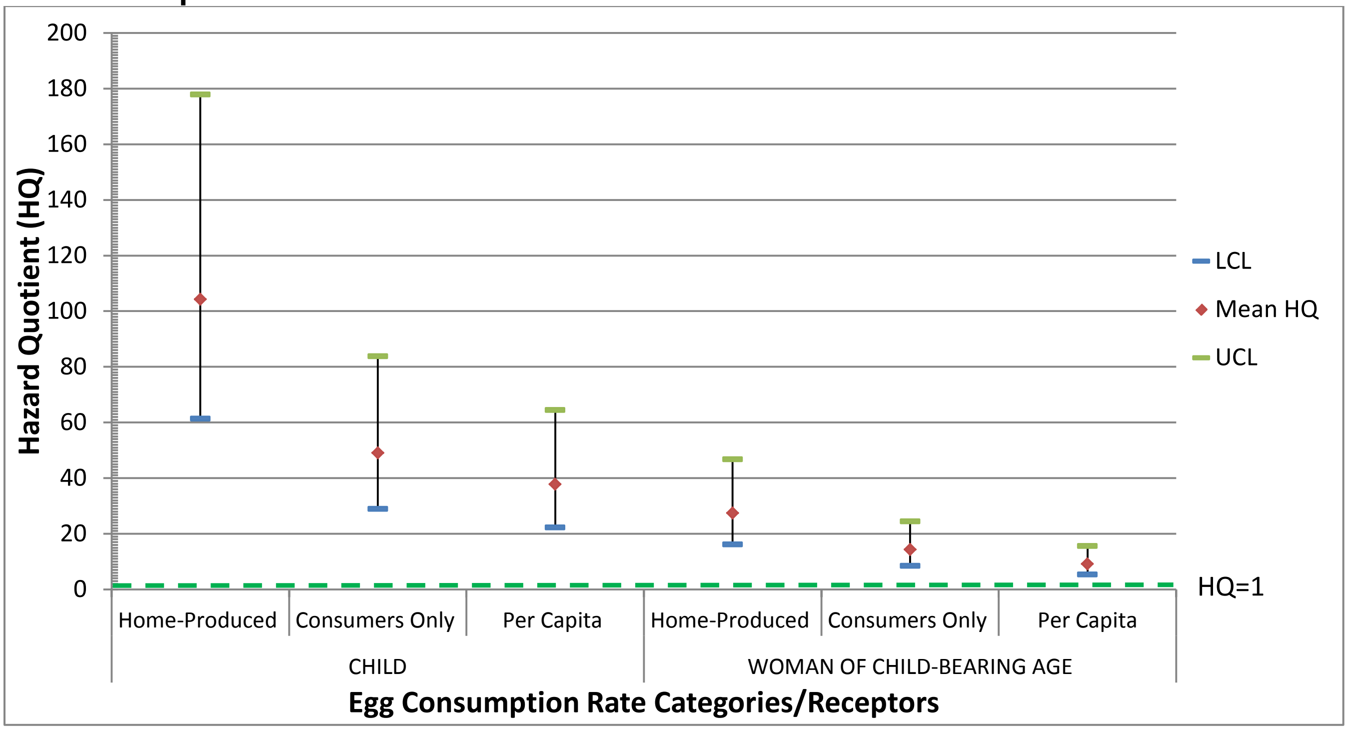
*Estimated Egg Consumption Rate

### Figure 2. HQs for Average Egg Consumption Rates for 250 ppt Site-Specific Residential Soil Level



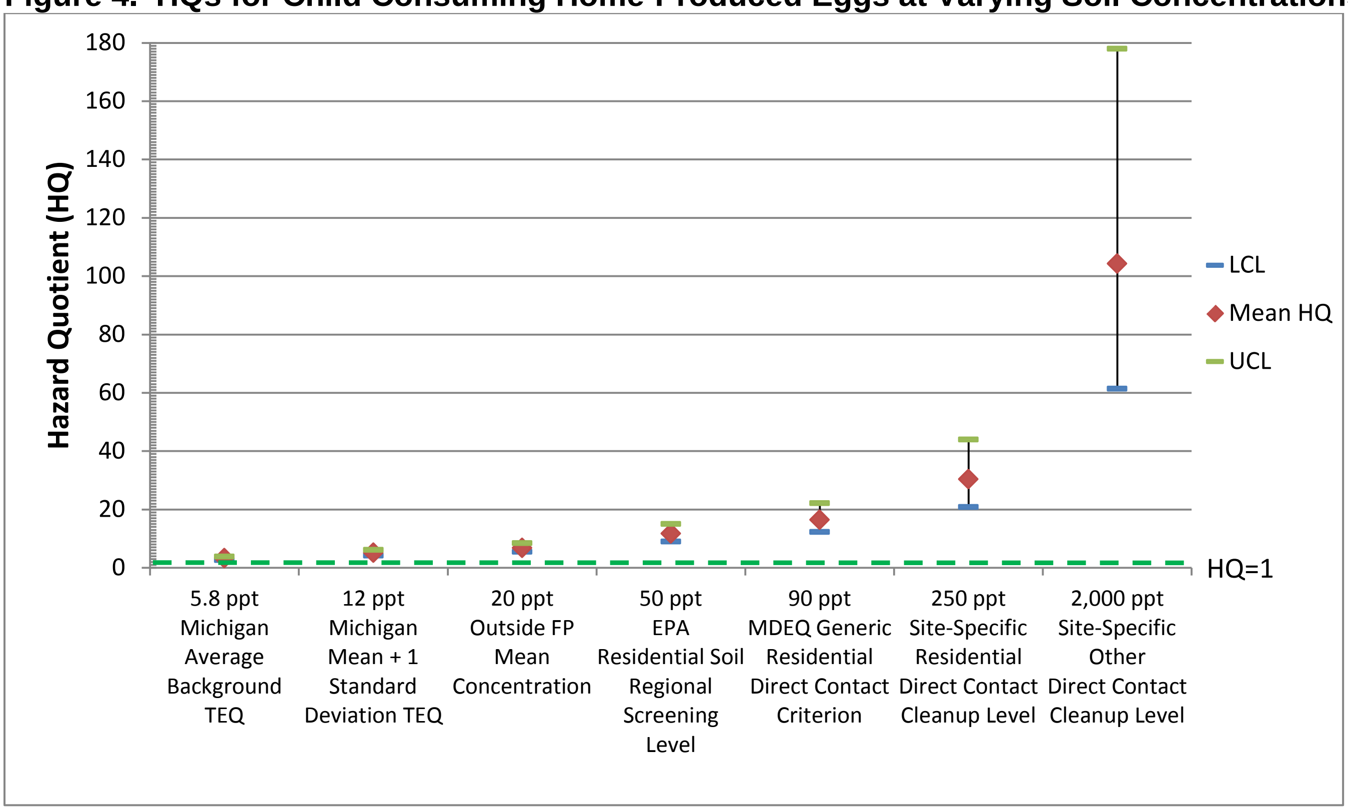

**(UCL and LCL - 95% Upper and Lower Confidence Levels for Predicted Egg Concentration)**

**Figure 3. HQs for Average Egg Consumption Rates for 2,000 ppt Site-Specific Other Soil Cleanup Level**



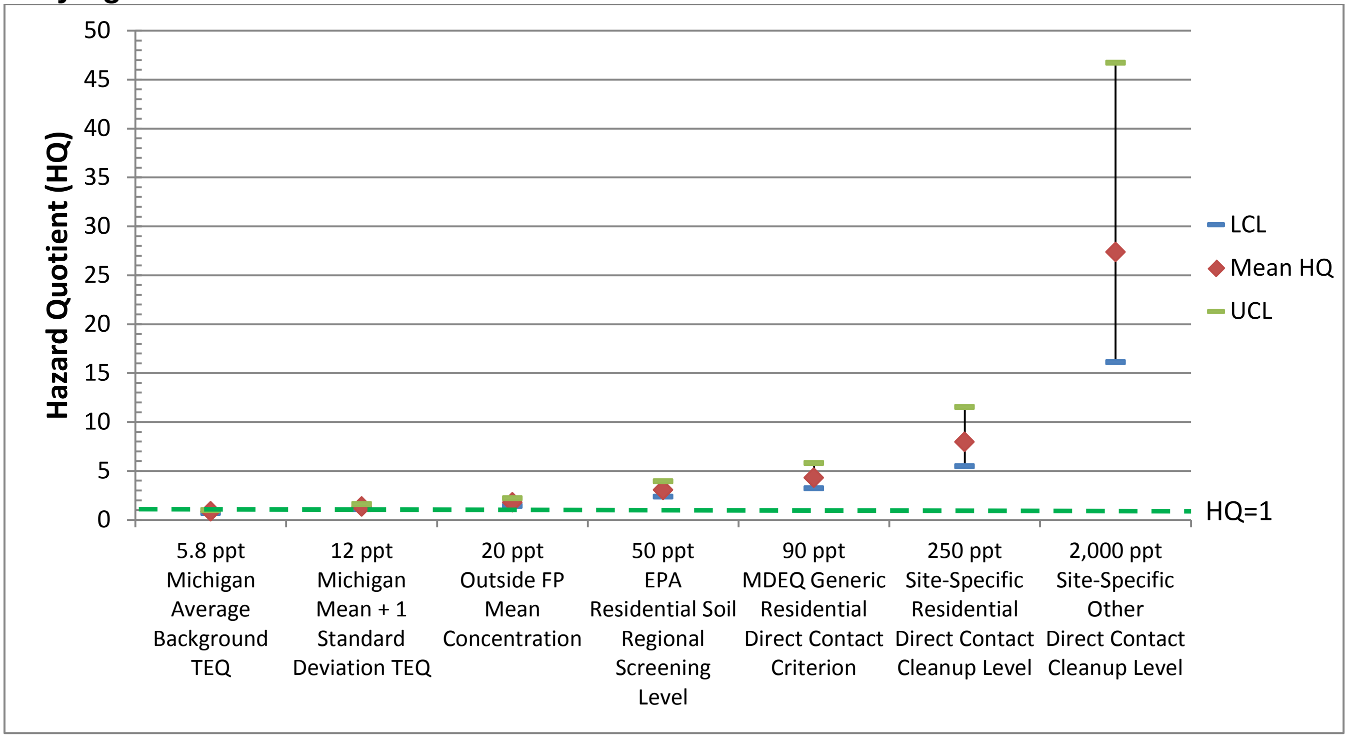

(UCL and LCL - 95% Upper and Lower Confidence Levels for Predicted Egg Concentration)

**Figure 4. HQs for Child Consuming Home-Produced Eggs at Varying Soil Concentrations**




(UCL and LCL - 95% Upper and Lower Confidence Levels for Predicted Egg Concentration)

**Figure 5. HQs for Woman of Childbearing Age Consuming Home-Produced Eggs at Varying Soil Concentrations**




(UCL and LCL - 95% Upper and Lower Confidence Levels for Predicted Egg Concentration)

<u>Analysis</u>

An HQ (unitless ratio) represents how much an exposure is above or below an acceptable reference dose that is protective for adverse health effects. An HQ below one represents a protective level. An HQ above one does not necessarily represent an unsafe level, but the higher the HQ, the more likely that there is a human health risk. The average HQs for average egg consumption rates for the 250 ppt site-specific residential cleanup level range from 11 to 30 for the child and 2.7 to 8 for the woman of childbearing age. The average HQs for the 2,000 ppt site-specific cleanup level range from 38 to 104 for the child and 9 to 27 for the woman of childbearing age based on average egg consumption rates.

Perspective on the HQs from this risk assessment:

1. These HQs are based on the average, not the high end, consumption rates. High end consumption (95$^{th}$ percentile) may be as much as three times these average consumption rates for home produced eggs (EPA, 2011a, Table 13-40).
2. This assessment assumes that the entire dioxin reference dose comes from egg consumption. Other dietary or exposure mechanisms (e.g., soil direct contact) are not directly taken into account.

3. The EPA RfD used for the HQ is based on adverse effects in humans with the following considerations:
   a. Impaired reproductive function in men who were exposed to elevated levels as boys;
   b. Altered thyroid hormone function in infants can be found when their mothers were exposed to elevated levels about 20 years before;
   c. Both studies identified the lowest adverse effects levels that serve as the basis of the RfD; and
   d. The combined uncertainty factors are 30.
4. Some of the calculated HQs are at or above 30 for the child receptor (all 2,000 ppt and the home-produced 250 ppt values).
5. The other uncertainties, variability, and data gaps described above are not likely to significantly influence the HQs calculated as part of this analysis to eliminate the concerns raised by the high HQs.

Another way to evaluate these estimated HQs is to have comparison values. Table 5 includes HQs comparison values for chicken egg consumption and the HQs for the 250 ppt site-specific dioxin cleanup level. The first comparison value provided is based on the EU initial standard for dioxins in chicken eggs of 3 pg/g fat (EC, 2006) and the revised standard of 2.5 pg/g fat (EC, 2011). The HQs for these standards are at or below one.

Comparison HQs were also developed for FDA market basket egg dioxin concentration datasets. Table 5 shows HQs for this market basket data with nondetects set at the detection limits to represent the highest possible egg concentrations. The Total Diet Study (TDS) data is based on cooked food concentrations collected in 2001-2004 (FDA, 2006). HQs from this dataset are also well below one (range 0.0042-0.10). There is another FDA data set (Non-TDS) collected in 2001-2003 (FDA, 2007) that is based on uncooked egg concentrations that also results in HQs less than one (range 0.008-0.15). Appendix B, Table 18 shows the detail for these calculations and additional values for different treatment of detection limits.

A comparison of estimated dioxin intake rates as reported by FDA (FDA, 2006) and those calculated by the MDEQ for this evaluation (converted back to WHO 1998 TEQ) using the same TDS egg concentration data demonstrates that the two different exposure estimates are very similar (see Table 6, next page, and Table 19 in Appendix B for details on calculations).

Although FDA also provides exposure estimates for the Non-TDS data, there are no comparable age ranges, only average per capita and egg eaters' (consumers only) for one age group (2+ years). These cross age group averages are within the child to adult female ranges estimated as part of this analysis.

The FDA market basket egg dioxin concentration data (2001-2004) used for comparison purposes is over 10 years old and current trends for more commercially available free-range chicken eggs may not be reflected.

**Table 5. Hazard Quotients for Comparison Values**

| Comparison Data | Average Child HQ | | | Average Adult HQ | | |
|---|---|---|---|---|---|---|
| | ***Home-Produced*** | **Consumers Only** | **Per Capita** | **Home-Produced** | **Consumers Only** | **Per Capita** |
| Site-Specific Residential Direct Contact Cleanup Level (250 ppt) | 30 | 14 | 11 | 8 | 4.2 | 2.7 |
| EC TEQ egg standard 2011 (2.5 pg TEQ/g fat) | 0.85 | 0.40 | 0.31 | 0.22 | 0.12 | 0.07 |
| EC TEQ egg standard 2006 (3 pg TEQ/g fat) | 1.0 | 0.48 | 0.37 | 0.27 | 0.14 | 0.09 |
| FDA TDS cooked eggs nd=dl | 0.11 | 0.051 | 0.040 | 0.029 | 0.015 | 0.0095 |
| FDA Non-TDS raw eggs nd=dl | 0.17 | 0.078 | 0.060 | 0.043 | 0.023 | 0.014 |

**Table 6. Comparison of Egg Consumption Exposure Estimates, FDA TDS and MDEQ Per Capita Average Daily Intake Rates**

| | FDA TDS Exposure Estimates Daily Intakes from Egg Consumption based on Reported Monthly Intakes (pg 1998 DF WHO-TEQ/kg bw-day) | | | MDEQ Per Capita Average Daily Egg Consumption Intake Estimates using 1998 WHO TEQs (pg 1998 DF WHO-TEQ/kg bw-day) | | |
|---|---|---|---|---|---|---|
| | ND=0 | ND=½LOD | ND=LOD | ND=0 | ND=½LOD | ND=LOD |
| **Child 5 and under** Estimate is age-adjusted | 0.009 | 0.020 | 0.028 | 0.013 | 0.022 | 0.030 |
| **Adult Female** Estimate is age-adjusted | 0.0033 | 0.0067 | 0.0083 | 0.0032 | 0.0052 | 0.0073 |

Variability and Uncertainty Discussion with a Data Gap Analysis

The following qualitative uncertainties are identified for this analysis.

Soil/Egg Concentration Related Uncertainty/Variability:

1. Soil concentration data from 20 ppt to 2,000 ppt was very limited in the studies available. Extrapolation from data sets with predominantly lower soil concentrations and a few data sets with concentrations near 2,000 ppt were used. No soil concentrations near the 250 ppt soil cleanup level were found.
   a. Additional data could be collected to better represent chicken egg uptake from Midland soil contamination.
   b. Expanded soil concentrations from Tittabawassee River floodplain could also be evaluated.
2. Some of the data sets used in this evaluation came from farm raised chickens. Differing chicken foraging conditions, including size of foraging area, flock size, and number of chickens per area, have been found to influence dioxin uptake (Schuler *et al.*, 1997; Pirard *et al.*, 2005; Kijlstra *et al.*, 2007). Although not specifically evaluated in these studies, ingestion of soil organisms by foraging chickens may also be an important route for uptake of dioxins from soil (Chang *et al.*, 1989; Schuler *et al.*, 1977). Other potential chicken related variability could include behavior differences between breeds and age related differences in bioaccumulation and egg laying (Fernandes *et al.*, 2011).
3. Many of the studies used in this analysis reported different sources of dioxin contamination. This difference was also evident from the congener distributions in the soil and egg data that was reported. Most of the egg congener distributions were similar to the paired soil congener data. The heavily dominant furan congener distribution for both the soil and eggs from the Tittabawassee River floodplain samples (Dykema and Groetsch, 2009) was striking in that it was very different from the other data sets. Different sources and congener distributions can be expected to affect dioxin bioavailability and uptake into eggs.
4. Although study-specific soil characteristics were not reported, it is likely that the soils varied in organic carbon and clay content. Different soil characteristics such as these could also affect dioxin bioavailability and uptake into eggs.
5. Each of the studies had different sample collection methods. Soil samples varied from individual grab samples from the foraging area to composite samples, with up to 36 samples from a 25 square meter foraging area. Most egg samples were composites of 10 or more eggs. The Tittabawassee River floodplain samples were individual eggs. It is unknown how these different sample collection methods would influence the evaluation. In addition, there were also different sample preparation methods and analytical methods, although all studies included high resolution gas chromatography/mass spectrometry.

6. One study had reported WHO 1998 TEQ concentrations for 20 sets of paired chicken egg and soil samples from 10 different farms (Van Overmeire *et al.*, 2009a and 2009b). Median congener-specific data were reported. The WHO 1998 TEQs were adjusted to WHO 2005 TEQs based on the ratio from the median congener-specific data. The regression analysis based on the calculated WHO 2005 TEQs may not be accurate if the congener distributions varied significantly between locations for the soil and the eggs.
7. Two studies had nondetect values used for the evaluation and set nondetects equal to zero (nd=0) for reported TEQ values. For this analysis, nondetects were treated as reported in the study results (set at nd=0). The two studies had six egg samples, and one soil sample with WHO 2005 TEQs based on one to five congeners that were reported below the detection limit. A comparison regression analysis used data with the non-detects set to the detection limit (nd=dl) as obtained from the study's author (Dykema, personal communication) to determine if the estimated egg concentrations were substantively influenced by the levels of detection. Resulting regression coefficients resulted in a difference of less than 2% between predictions based on nd=0 and nd=dl when all data were included in the regression.

This evaluation included upper and lower 95% confidence intervals on the mean predicted egg concentrations to address some of the soil and egg concentration variability described above.

<u>Dioxin Intake Rate Related Uncertainty/Variability:</u>

1. Egg consumption rates found in the EFH (EPA, 2011a) are based on older USDA data (1987-1998). Other per capita summaries of the National Health and Nutrition Examination Survey (NHANES) data from 2003 through 2008 indicate that the more recent per capita consumption rates for eggs (from the USDA Food Patterns Equivalent Database and the USDA Food Intakes Converted to Retail Commodities reported as eggs without shell) are higher:
   a. 13-18 g/day or 0.87-1.2 g/kg bw-day for 2-5 year olds; and
   b. 21-22 g/day or 0.34-0.35 g/kg bw day for females over 20.

   Per capita consumption rates may reflect the number of individuals consuming eggs, not just the amount consumed per individual. These increases in per capita may not be observed for the consumers only and home-produced consumption rates, so the older EFH values are used in this evaluation.
2. This evaluation used mean egg consumption rates. Some datasets show egg consumption rates that are more than three times the mean value (EPA, 2011a, Table 13-40). This evaluation does not reflect this variation in consumption rates and represents a central tendency HQ, not a reasonable maximum exposure.
3. There is no cooking loss assumed for dioxin intake from eggs. The USDA

(Bowman *et al.*, 2013b) assumes no cooking loss from eggs in the determination of fat intake from eggs.

4. The estimated chicken egg fat content was assumed to be 9.94% (EPA, 2011a). This value was used to convert concentrations reported in pg TEQ/g egg fat to wet weight for the intake estimates. Two of the studies (Hsu *et al*., 2010; Fernandez *et al.,* 2011) used in the evaluation reported free-range eggs had 6.6-11.0% fat. The EFH recommends the use of 9.94% for converting between percent lipid and wet weight for chicken eggs (Table 11-38 of EPA, 2011a). USDA reports a chicken egg fat content of 9.5%.
5. No adjustment was made for bioavailability since egg fat bioavailability is likely to be very similar to that used for intake in oil in the pharmacokinetic model for the EPA RfD.
6. Uncertainties associated with the EPA RfD are not included here as they are described in EPA 2012. Additional uncertainties in the average egg consumption rates are also described elsewhere (USDA and NHANES data evaluations).

Quantitative uncertainty or variability associated with egg consumption rates was not included in this evaluation except for the 95 percentile for home-produced eggs.

Data Gaps:

1. The data sets evaluated contained no paired soil/egg data for the range of soil concentrations from about 50 ppt up to the 250 ppt cleanup level for residential properties in Midland and maintained residential properties along the Tittabawassee River floodplain;
2. Minimal paired soil/egg data was available for higher soil concentrations, except for the four eggs raised on soil concentrations close to the 2,000 ppt cleanup level;
3. There is a lack of specific data to represent Midland soil uptake into chicken eggs in the range from 50 ppt to 250 ppt with similar soil congener distributions (predominantly PCDDs) or contamination source;
4. Minimal chicken egg data specific to the Tittabawassee River floodplain is available:
    a. Only soil concentrations from Tittabawassee River floodplain close to the 2,000 ppt cleanup level for other land uses were associated with the four egg samples from the floodplain; and
    b. Minimal paired soil/egg data with similar congener distributions (predominantly PCDFs) or contamination source.

Additional data could be collected to address these identified data gaps and for other livestock raised on dioxin contaminated soils or with feed grown on dioxin contaminated soils.

## Conclusions

The following conclusions are based on the HQs in Table 1 that were calculated using estimated dioxin intakes from egg consumption from chickens raised on dioxin contaminated soils:

1. Chickens that forage on soils with elevated dioxin TEQ produce chicken eggs with elevated dioxin levels. Human consumption of these eggs can result in harmful effects.
2. The Tittabawassee River and Saginaw River floodplain site-specific soil criteria of 250 ppt and 2,000 ppt and Midland area soil site-specific soil criterion of 250 ppt were developed to protect for human direct contact hazards with soil. **These criteria do not protect for human consumption of eggs produced from chickens raised on soils at those concentrations.** A child eating these eggs would have an exposure that is 10 to 100 times greater than the acceptable exposure level based on average consumption and uptake rates. For women of childbearing age, the exposure is 2.7 to 27 times greater than the acceptable exposure. If the reasonable maximum exposure consumption rate is three times higher than the average (EPA, 2011a; Table 13-40), these cleanup levels may represent exposures that are 8 to 300 times greater than acceptable exposures.
3. Neither the EPA residential soil screening level of 50 ppt nor the MDEQ generic residential soil direct contact criterion of 90 ppt are adequately protective for raising chickens for egg consumption. If the reasonable maximum exposure consumption rate is three times higher than the average (EPA, 2011a; Table 13-40), these cleanup levels may represent reasonable maximum exposure HQs of 3 to 50.

The calculated HQs are sufficiently high that they represent a high priority concern for consumption of chicken eggs in areas with dioxin contaminated soil.

Recommendations for Midland and the Tittabawassee River Floodplain:

1. Evaluate whether production and consumption of chicken eggs is occurring at this time in areas of soil dioxin concentrations above background levels.
2. Provide educational materials and outreach relative to the raising of livestock for areas where there are elevated levels of dioxin.
3. Develop and implement institutional controls/reliable land use restrictions to manage these exposure pathways for current and future land use where elevated levels of dioxin in soil exist.
4. Evaluate additional food-chain pathways for these areas.

General Recommendations:

1. Evaluate additional food-chain pathways and other bioaccumulative chemicals where appropriate.
2. Develop or modify institutional controls/reliable land use restrictions for any additional food-chain exposure pathways of concern. These institutional controls/reliable land use restrictions could be presumptively implemented.
3. Include footnotes to the generic soil cleanup criteria (e.g., Part 201 generic criteria and EPA RSLs tables) for dioxin to identify that the cleanup criteria are not adequately protective for the human consumption of chicken eggs raised on soils at these levels (and possibly other food-chain livestock product consumption).
4. Formally establish updated statewide background level for dioxin.

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# Appendix A – Data Used for Soil and Chicken Egg Concentration Relationship

**Table 7. Toxic Equivalency Factors (TEFs) Used for Various D/F TEQs Within the Available Studies**

| Chemical | CAS Number | 1989 I-TEF[a] | WHO 1998 Mammalian TEF[b] | WHO 2005 Mammalian TEF [c,d] |
|---|---|---|---|---|
| **Dioxins** | | | | |
| 2,3,7,8-TCDD | 1746-01-6 | 1 | 1 | 1 |
| **1,2,3,7,8-PeCDD** | 40321-76-4 | **0.5** | **1** | **1** |
| 1,2,3,4,7,8-HxCDD | 39227-28-6 | 0.1 | 0.1 | 0.1 |
| 1,2,3,6,7,8-HxCDD | 57653-85-7 | 0.1 | 0.1 | 0.1 |
| 1,2,3,7,8,9-HxCDD | 19408-74-3 | 0.1 | 0.1 | 0.1 |
| 1,2,3,4,6,7,8-HpCDD | 35822-46-9 | 0.01 | 0.01 | 0.01 |
| **1,2,3,4,6,7,8,9-OCDD** | 3268-87-9 | **0.001** | **0.0001** | **0.0003** |
| **Furans** | | | | |
| 2,3,7,8-TCDF | 51207-31-9 | 0.1 | 0.1 | 0.1 |
| **1,2,3,7,8-PeCDF** | 57117-41-6 | **0.05** | **0.05** | **0.03** |
| **2,3,4,7,8-PeCDF** | 57117-31-4 | **0.5** | **0.5** | **0.3** |
| 1,2,3,4,7,8-HxCDF | 70648-26-9 | 0.1 | 0.1 | 0.1 |
| 1,2,3,6,7,8-HxCDF | 57117-44-9 | 0.1 | 0.1 | 0.1 |
| 2,3,4,6,7,8-HxCDF | 72918-21-9 | 0.1 | 0.1 | 0.1 |
| 1,2,3,7,8,9-HxCDF | 60851-34-5 | 0.1 | 0.1 | 0.1 |
| 1,2,3,4,6,7,8-HpCDF | 67562-39-4 | 0.01 | 0.01 | 0.01 |
| 1,2,3,4,7,8,9-HpCDF | 55673-89-7 | 0.01 | 0.01 | 0.01 |
| **1,2,3,4,6,7,8,9-OCDF** | 39001-02-0 | **0.001** | **0.0001** | **0.0003** |

**Bold congeners have had TEF changes.**

[a]U.S. EPA (Environmental Protection Agency). (1989) Interim procedures for estimating risks associated with exposures to mixtures of chlorinated dibenzo-p-dioxins and dibenzofurans (CDDs and CDFs) and 1989 update. EPA/625/3-89/016. Risk Assessment Forum, Washington, DC.

[b]van den Berg, M; Birnbaum, L; Bosveld, AT; et al. (1998) Toxic equivalency factors (TEFs) for PCBs, PCDDs, PCDFs for humans and wildlife. Environ Health Perspect 106(12):775−792.

[c]van den Berg, M; Birnbaum, LS; Denison, M; et al. (2006) The 2005 World Health Organization re-evaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. Toxicol Sci 93(2):223−241.

[d]U.S. EPA (Environmental Protection Agency). (2010) Recommended Toxicity Equivalence Factors (TEFs) for Human Health Risk Assessments of 2,3,7,8-Tetrachlorodibenzo-p-dioxin and Dioxin-Like Compounds. Risk Assessment Forum, Washington, DC. EPA/600/R-10/005.

**Appendix A – Data Used for Soil and Chicken Egg Concentration Relationship**

**Table 8. Congener Specific Data from Studies Used in this Analysis**

| | Hsu *et al.*, 2010 | | | | | | Schuler *et al.*, 1997 | | | | | | | | | | | | | | Van Overmeire *et al.*, 2009a,b | | Dykema and Groetsch, 2009 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | soil F1 | free-range egg F1 | soil F2 | free-range egg F2 | avg. caged | avg. free-range | site A soil | site A egg 1 | site A egg 2 | site B soil | site B egg 1 | site B egg 2 | site C soil | site C egg 1 | site C egg 2 | site D soil | site D egg | site E soil | site E egg | Cage egg | Avg soil | Avg egg | soil 1 | soil 2 | egg 1 | egg 2 | egg 3 | egg 4 |
| | ppt | ppt fat | ppt | ppt fat | ppt fat | ppt fat | ppt | ppt fat | ppt fat | ppt | ppt fat | ppt fat | ppt | ppt fat | ppt fat | ppt | ppt fat | ppt | ppt fat | ppt fat | ppt | ppt fat | ppt | ppt | ppt fat | ppt fat | ppt fat | ppt fat |
| 2,3,7,8-TCDD | 0.047 | 0.288 | 0.027 | 0.124 | 0.048 | 0.114 | 0.21 | 1.0 | 0.94 | 1.4 | 2.5 | 1.9 | 0.13 | 1.5 | 0.69 | 0.17 | 1.2 | 0.04 | 0.86 | 0.44 | 0.2 | 0.53 | 2.0 | 4.0 | 0 | 0 | 3.3 | 0.91 |
| 1,2,3,7,8-PeCDD | 0.169 | 1.25 | 0.111 | 0.429 | 0.071 | 0.467 | 1.7 | 0.65 | 1.6 | 2.0 | 5.9 | 4.5 | 0.32 | 1.1 | 0.7 | 0.35 | 1.2 | 0.31 | 0.53 | 0.29 | 0.5 | 2.04 | 9.0 | 7.0 | 8.7 | 0 | 9.2 | 0 |
| 1,2,3,4,7,8-HxCDD | 0.086 | 0.71 | 0.104 | 0.184 | 0 | 0.242 | 1.9 | 0.61 | 1.2 | 2.3 | 4.4 | 2.7 | 0.39 | 0.63 | 0.39 | 0.21 | 0.84 | 0.3 | 0.48 | 0.2 | 0.5 | 1.27 | 7.0 | 5.0 | 7.8 | 9.9 | 7.3 | 5.0 |
| 1,2,3,6,7,8-HxCDD | 0.167 | 1.91 | 0.195 | 0.542 | 0.11 | 0.66 | 4.1 | 2.1 | 3.8 | 5.5 | 12 | 6.4 | 1.1 | 1.4 | 0.75 | 0.59 | 2.4 | 0.7 | 0.95 | 0.78 | 1.6 | 4.33 | 59 | 28 | 22 | 24 | 19 | 0 |
| 1,2,3,7,8,9-HxCDD | 0.181 | 0.814 | 0.173 | 0.23 | 0.057 | 0.27 | 3.5 | 0.64 | 1.5 | 3.7 | 4.1 | 2.6 | 0.78 | 0.66 | 0.28 | 0.4 | 0.94 | 0.44 | 0.55 | 0.25 | 0.9 | 1.26 | 14 | 10 | 12 | 14 | 11 | 7.0 |
| 1,2,3,4,6,7,8-HpCDD | 1.59 | 3.74 | 2.59 | 1.04 | 0.464 | 1.6 | 61 | 7.2 | 15 | 62 | 35 | 25 | 6.4 | 5.9 | 2.4 | 8.8 | 5.0 | 12 | 5.3 | 4.1 | 19.9 | 17 | 1167 | 465 | 48 | 68 | 46 | 29 |
| OCDD | 14.8 | 10.9 | 22.3 | 4 | 4.99 | 6.66 | 246 | 17 | 34 | 207 | 45 | 33 | 33 | 13 | 6.9 | 28 | 12 | 48 | 15 | 14 | 110.3 | 57.82 | 11431 | 4619 | 69 | 130 | 73 | 54 |
| 2,3,7,8-TCDF | 0.283 | 2.83 | 0.315 | 1.05 | 0.266 | 1.79 | 11 | 2.5 | 8.1 | 4.5 | 19 | 12 | 0.91 | 4.9 | 2.3 | 0.76 | 8.8 | 0.5 | 6.4 | 0.90 | 1.8 | 4.4 | 8368 | 3440 | 1298 | 1147 | 1117 | 435 |
| 1,2,3,7,8-PeCDF | 0.252 | 3.3 | 0.398 | 0.914 | 0.161 | 1.18 | 9.8 | 3.3 | 8.2 | 3.3 | 26 | 4.6 | 1.1 | 4.6 | 0.97 | 0.72 | 4.0 | 0.59 | 3.0 | 0.60 | 1.6 | 2.86 | 3691 | 2329 | 732 | 664 | 631 | 233 |
| 2,3,4,7,8-PeCDF | 0.31 | 4 | 0.502 | 0.993 | 0.192 | 1.23 | 6.6 | 1.2 | 2.9 | 11 | 11 | 7.1 | 1.1 | 2.1 | 1.2 | 0.69 | 3.7 | 1.0 | 1.9 | 0.61 | 1.8 | 3 | 2890 | 2285 | 543 | 460 | 458 | 174 |
| 1,2,3,4,7,8-HxCDF | 0.277 | 2.75 | 0.644 | 0.608 | 0.138 | 0.81 | 22 | 1.4 | 7.1 | 8.2 | 9.3 | 7.1 | 1.8 | 2.5 | 0.79 | 1.2 | 4.6 | 1.0 | 1.5 | 0.52 | 2.1 | 1.86 | 2296 | 971 | 264 | 257 | 238 | 79 |
| 1,2,3,6,7,8-HxCDF | 0.201 | 2.51 | 0.521 | 0.575 | 0.11 | 0.7 | 6.7 | 0.86 | 2.1 | 4.0 | 5.2 | 3.6 | 0.82 | 1.0 | 0.36 | 0.59 | 1.5 | 6.3 | 0.65 | 0.36 | 1.9 | 1.6 | 490 | 291 | 65 | 63 | 60 | 19 |
| 2,3,4,6,7,8-HxCDF | 0.257 | 2.12 | 0.494 | 0.468 | 0.092 | 0.61 | 2.8 | 0.6 | 1.7 | 7.8 | 5.3 | 4.0 | 1.2 | 1.0 | 0.37 | 0.73 | 2.0 | 0.79 | 0.74 | 0.19 | 2.1 | 1.39 | 187 | 191 | 211 | 22 | 21 | 7.2 |
| 1,2,3,7,8,9-HxCDF | 0.097 | 0.191 | 0.201 | 0.033 | 0 | 0.058 | 0.82 | 0.11 | 0.33 | 0.58 | 0.18 | 0 | 0.090 | 0.13 | 0 | 0 | 0.070 | 0.050 | 0.020 | 0.060 | 0.4 | 0.4 | 74 | 325 | 6.5 | 7.7 | 5.3 | 0 |
| 1,2,3,4,6,7,8-HpCDF | 0.851 | 2.36 | 2.12 | 0.517 | 0.24 | 0.655 | 22 | 1.1 | 3.9 | 29 | 7.0 | 6.9 | 5.7 | 1.4 | 0.40 | 3.7 | 2.4 | 4.4 | 1.3 | 0.81 | 12.8 | 3.04 | 2981 | 1666 | 46 | 49 | 39 | 19 |
| 1,2,3,4,7,8,9-HpCDF | 0.07 | 0.319 | 0.306 | 0.058 | 0 | 0.088 | 4.5 | 0.018 | 0.41 | 4.8 | 0.74 | 0.63 | 1.0 | 0.21 | 0 | 0.74 | 0.27 | 0.58 | 0.13 | 0.07 | 1 | 0.95 | 187 | 128 | 3.1 | 0 | 0 | 0 |
| OCDF | 1.43 | 1.31 | 2.56 | 0.352 | 0 | 0.409 | 58 | 1.4 | 3.8 | 25 | 3.7 | 2.6 | 6.5 | 2.0 | 0.43 | 3.2 | 1.6 | 4.4 | 1.1 | 1.3 | 16.5 | 3.26 | 3864 | 1766 | 0 | 0 | 0 | 0 |

(nondetect data highlighted)

## Appendix A – Data Used for Soil and Chicken Egg Concentration Relationship

### Table 9. Calculated Congener Specific 2005 WHO Toxic Equivalent Concentrations for 2005 WHO TEQ from Studies Used in this Analysis

| | Hsu *et al.* | | | | | | Schuler *et al.* | | | | | | | | | | | | | | Van Overmeire *et al.* | | Dykema and Groetsch | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | soil F1 | free-range egg F1 | soil F2 | free-range egg F2 | avg. caged egg | avg. free-range egg | site A soil | site A egg 1 | site A egg 2 | site B soil | site B egg 1 | site B egg 2 | site C soil | site C egg 1 | site C egg 2 | site D soil | site D egg | site E soil | site E egg | Cage egg | Avg soil | Avg egg | soil 1 | soil 2 | egg 1 | egg 2 | egg 3 | egg 4 |
| | 2005 WHO TEC ppt | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt | 2005 WHO TEC ppt | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt fat | 2005 WHO TEC ppt fat |
| 2,3,7,8-TCDD | 0.047 | 0.29 | 0.027 | 0.12 | 0.048 | 0.11 | 0.21 | 1.0 | 0.94 | 1.4 | 2.5 | 1.9 | 0.13 | 1.5 | 0.69 | 0.17 | 1.2 | 0.040 | 0.86 | 0.44 | 0.2 | 0.53 | 2.0 | 4.0 | 0 | 0 | 3.3 | 0.91 |
| 1,2,3,7,8-PeCDD | 0.17 | 1.3 | 0.11 | 0.43 | 0.071 | 0.47 | 1.7 | 0.65 | 1.6 | 2.0 | 5.9 | 4.5 | 0.32 | 1.1 | 0.70 | 0.35 | 1.2 | 0.31 | 0.53 | 0.29 | 0.5 | 2.04 | 9.0 | 7.0 | 8.7 | 0 | 9.2 | 0 |
| 1,2,3,4,7,8-HxCDD | 0.0086 | 0.071 | 0.010 | 0.018 | 0 | 0.02 | 0.19 | 0.061 | 0.12 | 0.23 | 0.44 | 0.27 | 0.039 | 0.063 | 0.039 | 0.021 | 0.084 | 0.030 | 0.048 | 0.020 | 0.05 | 0.127 | 0.70 | 0.50 | 0.78 | 1.0 | 0.73 | 0.50 |
| 1,2,3,6,7,8-HxCDD | 0.017 | 0.19 | 0.020 | 0.054 | 0.011 | 0.066 | 0.41 | 0.21 | 0.38 | 0.55 | 1.2 | 0.64 | 0.11 | 0.14 | 0.075 | 0.059 | 0.24 | 0.070 | 0.095 | 0.078 | 0.16 | 0.433 | 5.9 | 2.8 | 2.2 | 2.4 | 1.9 | 0 |
| 1,2,3,7,8,9-HxCDD | 0.018 | 0.081 | 0.017 | 0.023 | 0.0057 | 0.027 | 0.35 | 0.064 | 0.15 | 0.37 | 0.41 | 0.26 | 0.078 | 0.066 | 0.028 | 0.040 | 0.094 | 0.044 | 0.055 | 0.025 | 0.09 | 0.126 | 1.4 | 1.0 | 1.2 | 1.4 | 1.1 | 0.70 |
| 1,2,3,4,6,7,8-HpCDD | 0.016 | 0.037 | 0.026 | 0.010 | 0.0046 | 0.016 | 0.61 | 0.072 | 0.15 | 0.62 | 0.35 | 0.25 | 0.064 | 0.059 | 0.024 | 0.088 | 0.050 | 0.12 | 0.053 | 0.041 | 0.199 | 0.17 | 12 | 4.7 | 0.48 | 0.68 | 0.46 | 0.29 |
| OCDD | 0.0044 | 0.0033 | 0.0067 | 0.0012 | 0.0015 | 0.0020 | 0.074 | 0.0051 | 0.010 | 0.062 | 0.014 | 0.0099 | 0.0099 | 0.0039 | 0.0021 | 0.0084 | 0.0036 | 0.014 | 0.0045 | 0.0042 | 0.033 | 0.017 | 3.4 | 1.4 | 0.021 | 0.039 | 0.022 | 0.016 |
| 2,3,7,8-TCDF | 0.028 | 0.28 | 0.032 | 0.11 | 0.027 | 0.18 | 1.1 | 0.25 | 0.81 | 0.45 | 1.9 | 1.2 | 0.091 | 0.49 | 0.23 | 0.076 | 0.88 | 0.050 | 0.64 | 0.090 | 0.18 | 0.44 | 837 | 344 | 130 | 115 | 112 | 43 |
| 1,2,3,7,8-PeCDF | 0.0076 | 0.099 | 0.012 | 0.027 | 0.0048 | 0.035 | 0.29 | 0.099 | 0.25 | 0.099 | 0.78 | 0.14 | 0.033 | 0.14 | 0.0291 | 0.022 | 0.12 | 0.018 | 0.090 | 0.018 | 0.048 | 0.0858 | 111 | 70 | 22 | 20 | 19 | 7.0 |
| 2,3,4,7,8-PeCDF | 0.093 | 1.2 | 0.15 | 0.30 | 0.058 | 0.37 | 2.0 | 0.36 | 0.87 | 3.3 | 3.3 | 2.1 | 0.33 | 0.63 | 0.36 | 0.21 | 1.1 | 0.30 | 0.57 | 0.18 | 0.54 | 0.9 | 867 | 686 | 163 | 138 | 137 | 52 |
| 1,2,3,4,7,8-HxCDF | 0.028 | 0.28 | 0.064 | 0.061 | 0.014 | 0.081 | 2.2 | 0.14 | 0.71 | 0.82 | 0.93 | 0.71 | 0.18 | 0.25 | 0.079 | 0.12 | 0.46 | 0.10 | 0.15 | 0.052 | 0.21 | 0.186 | 230 | 97 | 26 | 26 | 24 | 7.9 |
| 1,2,3,6,7,8-HxCDF | 0.020 | 0.25 | 0.052 | 0.058 | 0.011 | 0.070 | 0.67 | 0.086 | 0.21 | 0.40 | 0.52 | 0.36 | 0.082 | 0.10 | 0.036 | 0.059 | 0.15 | 0.63 | 0.065 | 0.036 | 0.19 | 0.16 | 49 | 29 | 6.5 | 6.3 | 6.0 | 1.9 |
| 2,3,4,6,7,8-HxCDF | 0.026 | 0.21 | 0.049 | 0.047 | 0.0092 | 0.061 | 0.28 | 0.060 | 0.17 | 0.78 | 0.53 | 0.40 | 0.12 | 0.10 | 0.037 | 0.073 | 0.20 | 0.079 | 0.074 | 0.019 | 0.21 | 0.139 | 19 | 19 | 21 | 2.2 | 2.1 | 0.7 |
| 1,2,3,7,8,9-HxCDF | 0.0097 | 0.019 | 0.020 | 0.0033 | 0 | 0.0058 | 0.082 | 0.011 | 0.033 | 0.058 | 0.018 | 0 | 0.009 | 0.013 | 0 | na | 0.0070 | 0.0050 | 0.0020 | 0.0060 | 0.04 | 0.04 | 7.4 | 33 | 0.65 | 0.77 | 0.53 | 0 |
| 1,2,3,4,6,7,8-HpCDF | 0.0085 | 0.024 | 0.021 | 0.0052 | 0.0024 | 0.0066 | 0.22 | 0.011 | 0.039 | 0.29 | 0.070 | 0.069 | 0.057 | 0.014 | 0.0040 | 0.037 | 0.024 | 0.044 | 0.013 | 0.0081 | 0.128 | 0.0304 | 30 | 17 | 0.46 | 0.49 | 0.39 | 0.19 |
| 1,2,3,4,7,8,9-HpCDF | 0.00070 | 0.0032 | 0.0031 | 0.00058 | 0 | 0.00088 | 0.045 | 0.00018 | 0.0041 | 0.048 | 0.0074 | 0.0063 | 0.010 | 0.0021 | 0 | 0.0074 | 0.0027 | 0.0058 | 0.0013 | 0.00070 | 0.01 | 0.0095 | 1.9 | 1.28 | 0.031 | 0 | 0 | 0 |
| OCDF | 0.00043 | 0.00039 | 0.00077 | 0.00011 | 0 | 0.00012 | 0.017 | 0.00042 | 0.0011 | 0.0075 | 0.00111 | 0.00078 | 0.0020 | 0.00060 | 0.00013 | 0.00096 | 0.00048 | 0.00132 | 0.00033 | 0.00039 | 0.0049 | 0.00097 | 1.2 | 0.53 | 0 | 0 | 0 | 0 |
| **2005 WHO TEQ calc** | **0.5** | **4.3** | **0.6** | **1.3** | **0.3** | **1.5** | **10** | **3.1** | **6.4** | **11** | **19** | **13** | **1.7** | **4.7** | **2.3** | **1.3** | **5.8** | **1.9** | **3.3** | **1.3** | **2.8** | **5.4** | **2186** | **1317** | **383** | **314** | **318** | **116** |
| | | | | | | | | **Avg. = 4.8** | | | **Avg. = 16** | | | **Avg. = 3.5** | | | | | | | | | **Avg. = 1752** | | | | | |

## Appendix A – Data Used for Soil and Chicken Egg Concentration Relationship

### Table 10. Calculated Congener Specific 1998 WHO Toxic Equivalent Concentrations for 1998 WHO TEQ for Combining with Additional Studies Reporting WHO 1998 TEQ Data

| | Hsu *et al.* | | | | | | Schuler *et al.* | | | | | | | | | | | | | | Van Overmeire *et al.* | | Dykema and Groetsch | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | soil F1 | free-range egg F1 | soil F2 | free-range egg F2 | avg. caged egg | avg. free-range egg | site A soil | site A egg 1 | site A egg 2 | site B soil | site B egg 1 | site B egg 2 | site C soil | site C egg 1 | site C egg 2 | site D soil | site D egg | site E soil | site E egg | Cage egg | Avg soil | Avg egg | soil 1 | soil 2 | egg 1 | egg 2 | egg 3 | egg 4 |
| | 1998 WHO TEC ppt | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt | 1998 WHO TEC ppt | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt fat | 1998 WHO TEC ppt fat |
| 2,3,7,8-TCDD | 0.047 | 0.29 | 0.027 | 0.12 | 0.048 | 0.11 | 0.21 | 1 | 0.94 | 1.4 | 2.5 | 1.9 | 0.13 | 1.5 | 0.69 | 0.17 | 1.2 | 0.04 | 0.86 | 0.44 | 0.20 | 0.53 | 2.0 | 4.0 | 0 | 0 | 3.3 | 0.91 |
| 1,2,3,7,8-PeCDD | 0.17 | 1.3 | 0.11 | 0.43 | 0.071 | 0.47 | 1.7 | 0.65 | 1.6 | 2.0 | 5.9 | 4.5 | 0.32 | 1.1 | 0.70 | 0.35 | 1.2 | 0.31 | 0.53 | 0.29 | 0.50 | 2.04 | 9.0 | 7.0 | 8.7 | 0 | 9.2 | 0 |
| 1,2,3,4,7,8-HxCDD | 0.0086 | 0.071 | 0.010 | 0.018 | 0 | 0.024 | 0.19 | 0.061 | 0.12 | 0.23 | 0.44 | 0.27 | 0.039 | 0.063 | 0.039 | 0.021 | 0.084 | 0.03 | 0.048 | 0.020 | 0.050 | 0.127 | 0.70 | 0.50 | 0.78 | 1.0 | 0.73 | 0.50 |
| 1,2,3,6,7,8-HxCDD | 0.017 | 0.19 | 0.020 | 0.054 | 0.011 | 0.066 | 0.41 | 0.21 | 0.38 | 0.55 | 1.2 | 0.64 | 0.11 | 0.14 | 0.075 | 0.059 | 0.24 | 0.07 | 0.095 | 0.078 | 0.16 | 0.433 | 5.9 | 2.8 | 2.2 | 2.4 | 1.9 | 0 |
| 1,2,3,7,8,9-HxCDD | 0.018 | 0.081 | 0.017 | 0.023 | 0.0057 | 0.027 | 0.35 | 0.064 | 0.15 | 0.37 | 0.41 | 0.26 | 0.078 | 0.066 | 0.028 | 0.04 | 0.094 | 0.044 | 0.055 | 0.025 | 0.090 | 0.126 | 1.4 | 1.0 | 1.2 | 1.4 | 1.1 | 0.70 |
| 1,2,3,4,6,7,8-HpCDD | 0.016 | 0.037 | 0.026 | 0.010 | 0.0046 | 0.016 | 0.61 | 0.072 | 0.15 | 0.62 | 0.35 | 0.25 | 0.064 | 0.059 | 0.024 | 0.088 | 0.05 | 0.12 | 0.053 | 0.041 | 0.20 | 0.17 | 12 | 4.7 | 0.48 | 0.68 | 0.46 | 0.29 |
| OCDD | 0.0015 | 0.0011 | 0.0022 | 0.00040 | 0.00050 | 0.00067 | 0.025 | 0.0017 | 0.0034 | 0.021 | 0.0045 | 0.0033 | 0.0033 | 0.0013 | 0.00069 | 0.0028 | 0.0012 | 0.0048 | 0.0015 | 0.0014 | 0.011 | 0.0058 | 1.1 | 0.46 | 0.0069 | 0.013 | 0.0073 | 0.0054 |
| 2,3,7,8-TCDF | 0.028 | 0.28 | 0.032 | 0.11 | 0.027 | 0.18 | 1.1 | 0.25 | 0.81 | 0.45 | 1.9 | 1.2 | 0.091 | 0.49 | 0.23 | 0.076 | 0.88 | 0.050 | 0.64 | 0.090 | 0.18 | 0.44 | 837 | 344 | 130 | 115 | 112 | 43 |
| 1,2,3,7,8-PeCDF | 0.013 | 0.17 | 0.020 | 0.046 | 0.0081 | 0.059 | 0.49 | 0.17 | 0.41 | 0.17 | 1.3 | 0.23 | 0.055 | 0.23 | 0.049 | 0.036 | 0.20 | 0.030 | 0.15 | 0.030 | 0.080 | 0.14 | 185 | 116 | 37 | 33 | 32 | 12 |
| 2,3,4,7,8-PeCDF | 0.16 | 2.0 | 0.25 | 0.50 | 0.096 | 0.62 | 3.3 | 0.60 | 1.5 | 5.5 | 5.5 | 3.6 | 0.55 | 1.1 | 0.60 | 0.35 | 1.9 | 0.50 | 0.95 | 0.305 | 0.90 | 1.5 | 1445 | 1143 | 272 | 230 | 229 | 87 |
| 1,2,3,4,7,8-HxCDF | 0.028 | 0.28 | 0.064 | 0.061 | 0.014 | 0.081 | 2.2 | 0.14 | 0.71 | 0.82 | 0.93 | 0.71 | 0.18 | 0.25 | 0.079 | 0.12 | 0.46 | 0.10 | 0.15 | 0.052 | 0.21 | 0.19 | 230 | 97 | 26 | 26 | 24 | 7.9 |
| 1,2,3,6,7,8-HxCDF | 0.020 | 0.25 | 0.052 | 0.058 | 0.011 | 0.070 | 0.67 | 0.086 | 0.21 | 0.40 | 0.52 | 0.36 | 0.082 | 0.10 | 0.036 | 0.059 | 0.15 | 0.63 | 0.065 | 0.036 | 0.19 | 0.16 | 49 | 29 | 6.5 | 6.3 | 6.0 | 1.9 |
| 2,3,4,6,7,8-HxCDF | 0.026 | 0.21 | 0.049 | 0.047 | 0.0092 | 0.061 | 0.28 | 0.060 | 0.17 | 0.78 | 0.53 | 0.40 | 0.12 | 0.10 | 0.037 | 0.073 | 0.2 | 0.079 | 0.074 | 0.019 | 0.21 | 0.14 | 19 | 19 | 21.13 | 2.2 | 2.1 | 1 |
| 1,2,3,7,8,9-HxCDF | 0.0097 | 0.019 | 0.020 | 0.0033 | 0 | 0.0058 | 0.082 | 0.011 | 0.033 | 0.058 | 0.018 | 0 | 0.0090 | 0.013 | 0 | na | 0.0070 | 0.0050 | 0.0020 | 0.0060 | 0.040 | 0.040 | 7.4 | 33 | 0.65 | 0.77 | 0.53 | 0 |
| 1,2,3,4,6,7,8-HpCDF | 0.0085 | 0.024 | 0.021 | 0.0052 | 0.0024 | 0.0066 | 0.22 | 0.011 | 0.039 | 0.29 | 0.070 | 0.069 | 0.057 | 0.014 | 0.0040 | 0.037 | 0.024 | 0.044 | 0.013 | 0.0081 | 0.13 | 0.030 | 30 | 17 | 0.46 | 0.49 | 0.39 | 0.19 |
| 1,2,3,4,7,8,9-HpCDF | 0.00070 | 0.0032 | 0.0031 | 0.00058 | 0 | 0.00088 | 0.045 | 0.00018 | 0.0041 | 0.048 | 0.0074 | 0.0063 | 0.010 | 0.0021 | 0 | 0.0074 | 0.0027 | 0.0058 | 0.0013 | 0.00070 | 0.010 | 0.0095 | 1.9 | 1.3 | 0.031 | 0 | 0 | 0 |
| OCDF | 0.00014 | 0.00013 | 0.00026 | 0.000035 | 0 | 4.1E-05 | 0.0058 | 0.00014 | 0.00038 | 0.0025 | 0.00037 | 0.00026 | 0.00065 | 0.0002 | 0.000043 | 0.00032 | 0.00016 | 0.00044 | 0.00011 | 0.00013 | 0.0017 | 0.00033 | 0.39 | 0.18 | 0 | 0 | 0 | 0 |
| **1998 WHO TEQ calc** | **0.6** | **5.2** | **0.7** | **1.5** | **0.3** | **1.8** | **11.9** | **3.4** | **7.2** | **13.7** | **21.6** | **14.3** | **1.9** | **5.2** | **2.6** | **1.5** | **6.6** | **2.1** | **3.7** | **1.4** | **3.2** | **6.1** | **2835** | **1819** | **507** | **419** | **422** | **155** |

**Table 11. Paired Data Used in Generalized Linear Model – Calculated WHO 2005, Nondetects = 0**

| | | Calculated 2005 WHO TEQ Calculated Nondetects = 0 | |
|---|---|---|---|
| Source | Sample Identifier | Soil (pg/g) | Free Range Egg (pg/g fat) |
| Dykema and Groetsch | Riverside | 1752 | 383 |
| Dykema and Groetsch | Riverside | 1752 | 314 |
| Dykema and Groetsch | Riverside | 1752 | 318 |
| Dykema and Groetsch | Riverside | 1752 | 116 |
| Hsu | F1 | 0.50 | 4.3 |
| Hsu | F2 | 0.60 | 1.3 |
| Schuler | site A | 10 | 4.8 |
| Schuler | site B | 11 | 15.9 |
| Schuler | site C | 1.7 | 3.5 |
| Schuler | site D | 1.3 | 5.8 |
| Schuler | site E | 1.9 | 3.3 |
| Van Overmeire | A2 Autumn | 6.4 | 12.9 |
| Van Overmeire | A2 Spring | 4.3 | 17.7 |
| Van Overmeire | H1 Autumn | 2.6 | 8.0 |
| Van Overmeire | H1 Spring | 5.8 | 15.3 |
| Van Overmeire | H5 Autumn | 1.9 | 5.1 |
| Van Overmeire | H5 Spring | 1.6 | 6.4 |
| Van Overmeire | L3 Autumn | 2.5 | 4.3 |
| Van Overmeire | L3 Spring | 2.4 | 1.8 |
| Van Overmeire | LB1 Autumn | 2.7 | 3.9 |
| Van Overmeire | LB1 Spring | 2.6 | 3.7 |
| Van Overmeire | N2 Autumn | 1.8 | 4.0 |
| Van Overmeire | N2 Spring | 1.7 | 0.7 |
| Van Overmeire | OV3 Autumn | 3.0 | 3.8 |
| Van Overmeire | OV3 Spring | 3.2 | 3.4 |
| Van Overmeire | VB4 Autumn | 3.3 | 8.1 |
| Van Overmeire | VB4 Spring | 2.4 | 9.5 |
| Van Overmeire | WB1 Autumn | 2.0 | 1.9 |
| Van Overmeire | WB1 Spring | 1.8 | 3.3 |
| Van Overmeire | WV1 Autumn | 9.1 | 8.0 |
| Van Overmeire | WV1 Spring | 4.8 | 15.4 |

**Table 12. Paired Data Used in Generalized Linear Model – Calculated WHO 2005, Nondetects = DL**

| | | Calculated 2005 WHO TEQ nondetects = detection limit | |
|---|---|---|---|
| Source | Sample Identifier | Soil (pg/g) | Free Range Egg (pg/g fat) |
| Dykema and Groetsch | Riverside | 1752 | 386 |
| Dykema and Groetsch | Riverside | 1752 | 325 |
| Dykema and Groetsch | Riverside | 1752 | 318 |
| Dykema and Groetsch | Riverside | 1752 | 122 |
| Hsu et al | F1 | 0.50 | 4.3 |
| Hsu et al | F2 | 0.60 | 1.3 |
| Schuler | site A | 10 | 3.1 |
| Schuler et al | site A | 10 | 6.4 |
| Schuler et al | site B | 11 | 19 |
| Schuler et al | site B | 11 | 13 |
| Schuler et al | site C | 1.7 | 4.7 |
| Schuler et al | site C | 1.7 | 2.3 |
| Schuler et al | site D | 1.3 | 5.8 |
| Schuler et al | site E | 1.9 | 3.3 |
| Van Overmeire et al | A2 Autumn | 6.4 | 13 |
| Van Overmeire et al | A2 Spring | 4.3 | 18 |
| Van Overmeire et al | H1 Autumn | 2.6 | 8.0 |
| Van Overmeire et al | H1 Spring | 5.8 | 15 |
| Van Overmeire et al | H5 Autumn | 1.9 | 5.1 |
| Van Overmeire et al | H5 Spring | 1.6 | 6.4 |
| Van Overmeire et al | L3 Autumn | 2.5 | 4.3 |
| Van Overmeire et al | L3 Spring | 2.4 | 1.8 |
| Van Overmeire et al | LB1 Autumn | 2.7 | 3.9 |
| Van Overmeire et al | LB1 Spring | 2.6 | 3.7 |
| Van Overmeire et al | N2 Autumn | 1.8 | 4.0 |
| Van Overmeire et al | N2 Spring | 1.7 | 0.70 |
| Van Overmeire et al | OV3 Autumn | 3.0 | 3.8 |
| Van Overmeire et al | OV3 Spring | 3.2 | 3.4 |
| Van Overmeire et al | VB4 Autumn | 3.3 | 8.1 |
| Van Overmeire et al | VB4 Spring | 2.4 | 9.5 |
| Van Overmeire et al | WB1 Autumn | 2.0 | 1.9 |
| Van Overmeire et al | WB1 Spring | 1.8 | 3.3 |
| Van Overmeire et al | WV1 Autumn | 9.1 | 8.0 |
| Van Overmeire et al | WV1 Spring | 4.8 | 15 |

**Table 13. Paired Data Used in Generalized Linear Model – Calculated WHO 1998, Nondetects = as reported**

| | | Calculated 1998 WHO TEQ nondetects = as reported | |
|---|---|---|---|
| Source | Sample Identifier | Soil (pg/g) | Free Range Egg (pg/g fat) |
| Dykema and Groetsch | Riverside | 2327 | 510 |
| Dykema and Groetsch | Riverside | 2327 | 430 |
| Dykema and Groetsch | Riverside | 2327 | 422 |
| Dykema and Groetsch | Riverside | 2327 | 162 |
| Fernandes | FCB Hen Age Day 133 | 4.8 | 0.47 |
| Fernandes | FCN Hen Age Day 134 | 4.8 | 0.41 |
| Fernandes | FCZ Hen Age Day 162 | 4.8 | 1.4 |
| Fernandes | FDI Hen Age Day 211 | 4.8 | 1.3 |
| Fernandes | FDN Hen Age Day 244 | 4.8 | 1.0 |
| Fernandes | FDP Hen Age Day 244 | 4.8 | 1.2 |
| Hsu | F1 | 0.57 | 5.2 |
| Hsu | F2 | 0.73 | 1.5 |
| Pirard 2005 | 1 | 13 | 71 |
| Pirard 2005 | 2 | 11 | 122 |
| Pirard 2005 | 3 | 13 | 24 |
| Pirard 2005 | 4 | 20 | 95 |
| Pirard 2005 | 5 | 59 | 86 |
| Pirard 2005 | 6 | 12 | 6.3 |
| Pirard 2005 | 7 | 12 | 5.1 |
| Pirard 2005 | 8 | 37 | 26 |
| Pirard 2005 | 10 | 3.3 | 11 |
| Pirard 2005 | 11 | 6.6 | 4.4 |
| Pirard 2005 | 12 | 0.30 | 7.70 |
| Pirard 2005 | 13 | 5.6 | 8.1 |
| Pirard 2005 | 14 | 2.6 | 6.7 |
| Pirard 2005 | 15 | 1.6 | 11 |
| Pirard 2005 | 16 | 3.0 | 3.1 |
| Schuler | site A | 12 | 3.4 |
| Schuler | site A | 12 | 7.2 |
| Schuler | site B | 14 | 22 |
| Schuler | site B | 14 | 14 |
| Schuler | site C | 1.9 | 5.2 |
| Schuler | site C | 1.9 | 2.6 |
| Schuler | site D | 1.5 | 6.6 |
| Schuler | site E | 2.1 | 3.7 |

**Table 13. Paired Data used in Generalized Linear Model – Calculated WHO 1998, Nondetects = as reported (continued)**

| | | Calculated 1998 WHO TEQ nondetects = as reported | |
|---|---|---|---|
| Source | Sample Identifier | Soil (pg/g) | Free Range Egg (pg/g fat) |
| Van Overmeire | A2 Autumn | 7.3 | 15 |
| Van Overmeire | A2 Spring | 4.9 | 20 |
| Van Overmeire | Average | 3.2 | 6.1 |
| Van Overmeire | H1 Autumn | 3.0 | 9.0 |
| Van Overmeire | H1 Spring | 6.6 | 17 |
| Van Overmeire | H5 Autumn | 2.2 | 5.8 |
| Van Overmeire | H5 Spring | 1.9 | 7.3 |
| Van Overmeire | L3 Autumn | 2.8 | 4.8 |
| Van Overmeire | L3 Spring | 2.7 | 2.1 |
| Van Overmeire | LB1 Autumn | 3.0 | 4.4 |
| Van Overmeire | LB1 Spring | 3.0 | 4.2 |
| Van Overmeire | N2 Autumn | 2.0 | 4.5 |
| Van Overmeire | N2 Spring | 2.0 | 0.79 |
| Van Overmeire | OV3 Autumn | 3.5 | 4.3 |
| Van Overmeire | OV3 Spring | 3.6 | 3.9 |
| Van Overmeire | VB4 Autumn | 3.7 | 9.2 |
| Van Overmeire | VB4 Spring | 2.7 | 11 |
| Van Overmeire | WB1 Autumn | 2.3 | 2.1 |
| Van Overmeire | WB1 Spring | 2.0 | 3.7 |
| Van Overmeire | WV1 Autumn | 10 | 9.0 |
| Van Overmeire | WV1 Spring | 5.5 | 17 |

## Appendix B – Exposure Data Including Egg Consumption Rates, Comparison Data, and Hazard Quotients

**Table 14. Egg Consumption Rates and Other Exposure Assumptions Used in Evaluation – with Source Information from EPA EFH (EPA, 2011a) or *Estimated***

| | ***Home-Produced Eggs Consumption Rate for Children 5 and under*** *(ESTIMATED)* | **Home-Produced Eggs Consumption Rate for Adults 20-39** (EPA, 2011a; Table 13-40) | **Consumers Only Consumption Rate for Children 5 and under** (EPA, 2011a; Table 11-20) | **Consumers Only Consumption Rate for Adults 20-49** (EPA, 2011a; Table 11-20) | **Per Capita Consumption Rate for Children 5 and under** (EPA, 2011a; Table 11-13) | **Per Capita Consumption Rate for Adult Females over 20** (EPA, 2011a; Table 11-12) |
|---|---|---|---|---|---|---|
| Daily Consumption Rate (g/day) | | | | | 13 | 15.5 |
| Daily Consumption Rate (g/kg bw-day) | *2.2* | 0.63 | 1.1 | 0.33 | 0.87 | 0.25 |
| Weekly Consumption Rate - # of Medium Eggs (44 g serving size) | *5.3* | 7.6 | 2.7 | 4.0 | 2.1 | 2.5 |
| Body Weight (kg bw) | 15 | 75 | 15 | 75 | 15 | 75 |
| Notes | The EFH indicated there was insufficient data for children less than 5 years old, so the average the child/adult ratio for the per capita and consumers only consumption rates was used to estimate a consumption rate for children less than 5 years old from the adult home-produced rate | The EFH Table 13-40 egg consumption rate in g/kg bw-day, based on USDA NCFS 1987-88 data (EPA analysis). | The EFH Table 11-20 egg consumption rate in g/kg bw-day, edible portion, uncooked weight, age-adjusted average based on USDA CSFII 1994-1996, 1998 data (EPA analysis). | The EFH Table 11-20 egg consumption rate in g/kg bw-day, edible portion, uncooked weight, based on USDA CSFII 1994-1996, 1998 data (EPA analysis). | The EFH Table 11-13 egg consumption rate in g/day, as consumed, based on USDA CSFII 1994-1996, 1998 data (USDA, 1999a). | The EFH Table 11-12 egg consumption rate in g/day, as consumed, average between two years based on USDA CSFII 1994 and 1995 data for day 1 (USDA, 1996 a&b). |

**Table 15.** ***Estimated***

**Consumption Rate for Home-Produced Eggs for Child 5 and under.**

| | Consumer Only (g egg/kg bw-day) | Per Capita (g egg/kg bw-day) | Home-Produced (g egg/kg bw-day) |
|---|---|---|---|
| Adult | 0.33 | 0.21 | 0.63 |
| Child | 1.1 | 0.87 | ***2.4 (estimated)*** |
| Ratio Child/Adult | 3.4 | 4.1 | ***3.8***# |

#Average of published child/adult ratios from Per Capita and Consumer Only data

**Table 16. Weekly Egg Consumption Rates for Egg Consumption Rate Categories and USDA Egg Weight Classes**

| | | | | | **Home-Produced Weekly Egg Consumption** | | **Consumers Only Weekly Egg Consumption** | | **Per Capita Weekly Egg Consumption** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **USDA Weight Class** | **USDA* Minimum net weight per dozen** | **(USDA based minimum) net metric weight per dozen** | **(USDA based minimum) net metric weight per egg** | **(USDA based) metric weight per egg without shell#** | ***Child 5 and under 2.4 g/kg bw-day (ESTIMATED)*** | **Adults 20-39 0.63 g/kg bw-day (EFH 2011)** | **Child 5 and under 1.1 g/kg bw-day (EFH 2011)** | **Adults 20-49 0.33 g/kg bw-day (EFH 2011)** | **Child 5 and under 0.87 g/kg bw-day (EFH 2011)** | **Adult female over 20 0.21 g/kg bw-day (EFH 2011)** |
| **Units** | **ounces** | **g** | **g** | **g** | **eggs/week** | **eggs/week** | **eggs/week** | **eggs/week** | **eggs/week** | **eggs/week** |
| **Peewee** | 15 | 425 | 35 | 31 | 7.4 | 10.6 | 3.8 | 5.6 | 2.9 | 3.5 |
| **Small** | 18 | 510 | 43 | 37 | 6.2 | 8.9 | 3.2 | 4.6 | 2.4 | 3.0 |
| **Medium** | 21 | 595 | 50 | 44 | 5.3 | 7.6 | 2.7 | 4.0 | 2.1 | 2.5 |
| **Large** | 24 | 680 | 57 | 50 | 4.6 | 6.7 | 2.4 | 3.5 | 1.8 | 2.2 |
| **X-Large** | 27 | 765 | 64 | 56 | 4.1 | 5.9 | 2.1 | 3.1 | 1.6 | 2.0 |
| **Jumbo** | 30 | 850 | 71 | 62 | 3.7 | 5.3 | 1.9 | 2.8 | 1.5 | 1.8 |

*United States Standards, Grades, and Weight Classes for Shell Eggs, Agricultural Marketing Service, U.S. Department of Agriculture, as AMS 56, July 20, 2000, §56.218

# Conversion Factor from Appendix B: List of Conversion Factors, USDA, 2013 - Bowman SA, Martin CL, Carlson JL, Clemens JC, Lin B-H, and Moshfegh AJ. 2013. Food Intakes Converted to Retail Commodities Databases: 2003-08: Methodology and User Guide. U.S. Department of Agriculture, Agricultural Research Service, Beltsville, MD, and U.S. Department of Agriculture, Economic Research Service, Washington, D.C.

**Table 17. Hazard Quotients for Egg Consumption Dioxin Intake at Soil Cleanup Levels with Details for Calculations**

| | | Generalized Linear Model Estimates | | | | Child | | | | | | Adult | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *Home-Produced* | | Consumers Only | | Per Capita | | Home-Produced | | Consumers Only | | Per Capita | |
| | Soil TEQ | HQ Reported (Average and 95% Confidence Intervals) | Egg Fat TEQ | Egg TEQ wet weight * | pg TEQ/ medium egg | TEQ Intake from 2.4 g/kg bw-day Egg Consumption | HQ | TEQ Intake from 1.1 g/kg bw-day Egg Consumption | HQ | TEQ Intake from 0.87 g/kg bw-day Egg Consumption | HQ | TEQ Intake from 0.63 g/kg bw-day Egg Consumption | HQ | TEQ Intake from 0.33 g/kg bw-day Egg Consumption | HQ | TEQ Intake from 0.21 g/kg bw-day Egg Consumption | HQ |
| | (pg/g) | *(unitless)* | (pg/g fat) | (pg/g) | (pg/egg) | (pg/kg-day) | (unitless) | (pg/kg-day) | (unitless) | (pg/kg-day) | (unitless) | (pg/kg-day) | (unitless) | (pg/kg-day) | (unitless) | (pg/kg-day) | (unitless) |
| **EPA Residential Soil Screening Level** | **50** | ***LCL*** | 26 | 2.6 | 120 | 6.3 | 8.2 | 3.0 | 4.2 | 2.3 | 3.2 | 1.6 | 2.4 | 0.9 | 1.2 | 0.5 | 0.8 |
| | | ***Average HQ*** | 34 | 3.4 | 150 | 8.2 | 11 | 3.8 | 5.5 | 3.0 | 4.2 | 2.1 | 3.1 | 1.1 | 1.6 | 0.7 | 1.0 |
| | | ***UCL*** | 45 | 4.4 | 200 | 11 | 14 | 5.0 | 7.2 | 3.9 | 5.5 | 2.8 | 4.0 | 1.5 | 2.1 | 0.9 | 1.3 |
| **MDEQ Generic Residential Direct Contact Criterion** | **90** | ***LCL*** | 36 | 3.6 | 160 | 8.6 | 11 | 4.0 | 5.8 | 3.1 | 4.5 | 2.3 | 3.2 | 1.2 | 1.7 | 0.8 | 1.1 |
| | | ***Average HQ*** | 49 | 4.8 | 210 | 12 | 15 | 5.5 | 7.8 | 4.2 | 6.0 | 3.0 | 4.4 | 1.6 | 2.3 | 1.0 | 1.5 |
| | | ***UCL*** | 66 | 6.5 | 290 | 16 | 21 | 7.1 | 11 | 5.7 | 8.1 | 4.1 | 5.9 | 2.2 | 3.1 | 1.4 | 2.0 |
| **Site-Specific Residential Direct Contact Cleanup Level** | **250** | ***LCL*** | 62 | 6.1 | 270 | 15 | 19 | 6.9 | 10 | 5.4 | 7.6 | 3.9 | 5.5 | 2.0 | 2.9 | 1.3 | 1.8 |
| | | ***Average HQ*** | 90 | 8.9 | 390 | 21 | 28 | 10 | 14 | 7.8 | 11 | 5.6 | 8.0 | 2.9 | 4.2 | 1.9 | 2.7 |
| | | ***UCL*** | 130 | 13 | 570 | 31 | 41 | 15 | 21 | 11 | 16 | 8.2 | 12 | 4.3 | 6.1 | 2.7 | 3.9 |
| **Site-Specific Other Direct Contact Cleanup Level** | **2,000** | ***LCL*** | 183 | 18 | 800 | 44 | 57 | 21 | 29 | 16 | 23 | 12 | 16 | 6 | 9 | 3.8 | 5.5 |
| | | ***Average HQ*** | 312 | 31 | 1400 | 74 | 97 | 35 | 50 | 27 | 38 | 20 | 28 | 10 | 15 | 6.5 | 9 |
| | | ***UCL*** | 530 | 53 | 2300 | 130 | 166 | 60 | 85 | 46 | 65 | 33 | 47 | 17 | 25 | 11 | 16 |
| **Average TEQ Outside 8-year Floodplain of Tittabawassee River** | **20** | ***LCL*** | 16 | 1.6 | 69 | 3.8 | 5.0 | 1.8 | 2.5 | 1.4 | 2.0 | 1.0 | 1.4 | 0.5 | 0.7 | 0.3 | 0.5 |
| | | ***Average HQ*** | 20 | 2.0 | 87 | 4.7 | 6.2 | 2.2 | 3.2 | 1.7 | 2.4 | 1.2 | 1.8 | 0.6 | 0.9 | 0.4 | 0.6 |
| | | ***UCL*** | 25 | 2.5 | 110 | 6 | 7.7 | 2.8 | 4.0 | 2.1 | 3.0 | 1.5 | 2.2 | 0.8 | 1.2 | 0.5 | 0.7 |
| **Michigan Default Background TEQ (Mean + 1 std. dev.)** | **12** | ***LCL*** | 12 | 1.2 | 52 | 2.9 | 4.1 | 1.3 | 1.9 | 1.0 | 1.5 | 0.75 | 1.1 | 0.39 | 0.56 | 0.25 | 0.36 |
| | | ***Average HQ*** | 15 | 1.5 | 66 | 3.6 | 5.1 | 1.7 | 2.4 | 1.2 | 1.9 | 0.94 | 1.3 | 0.49 | 0.70 | 0.31 | 0.45 |
| | | ***UCL*** | 18 | 1.8 | 79 | 4.3 | 6.1 | 2.0 | 2.9 | 1.6 | 2.2 | 1.1 | 1.6 | 0.59 | 0.84 | 0.38 | 0.54 |
| **Average Michigan Background TEQ** | **5.8** | ***LCL*** | 7.7 | 0.8 | 34 | 1.8 | 2.6 | 0.86 | 1.2 | 0.67 | 1.0 | 0.48 | 0.69 | 0.16 | 0.23 | 0.25 | 0.36 |
| | | ***Average HQ*** | 9.4 | 0.9 | 41 | 2.2 | 3.2 | 1.1 | 1.5 | 0.81 | 1.2 | 0.59 | 0.84 | 0.20 | 0.28 | 0.31 | 0.44 |
| | | ***UCL*** | 11 | 1.1 | 48 | 2.6 | 3.7 | 1.2 | 1.8 | 1.0 | 1.4 | 0.69 | 1.0 | 0.23 | 0.33 | 0.36 | 0.52 |

**Table 18. Hazard Quotients for Comparison Values with Details for Calculations and Different Treatments for Nondetect Data**

| | | | | Child | | | | | | Adult | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Home-Produced | | Consumers Only | | Per Capita | | Home-Produced | | Consumers Only | | Per Capita | |
| | Egg Fat TEQ | Egg TEQ wet weight * | pg TEQ/ medium egg | TEQ Intake from 2.4 g/kg-day Egg Consumption | HQ | TEQ Intake from 1.13 g/kg-day Egg Consumption | HQ | TEQ Intake from 0.87 g/kg-day Egg Consumption | HQ | TEQ Intake from 0.63 g/kg-day Egg Consumption | HQ | TEQ Intake from 0.33 g/kg-day Egg Consumption | HQ | TEQ Intake from 0.21 g/kg-day Egg Consumption | HQ |
| | (pg/g fat) | (pg/g) | (pg/egg) | (pg/kg-day) | (unitless) | (pg/kg-day) | (unitless) | (pg/kg-day) | (unitless) | (pg/kg-day) | (unitless) | (pg/kg-day) | (unitless) | (pg/kg-day) | (unitless) |
| EU TEQ egg standard 2011 (2.5 pg TEQ/g fat) | 2.5 | 0.25 | 10.9 | 0.60 | 0.85 | 0.28 | 0.40 | 0.22 | 0.31 | 0.16 | 0.22 | 0.082 | 0.12 | 0.052 | 0.075 |
| EU TEQ egg standard 2006 (3 pg TEQ/g fat) | 3 | 0.30 | 13.1 | 0.72 | 1.0 | 0.34 | 0.48 | 0.26 | 0.37 | 0.19 | 0.27 | 0.098 | 0.14 | 0.063 | 0.089 |
| FDA cooked eggs (TDS) nd=0 | 0.14 | 0.014 | 0.62 | 0.048 | 0.044 | 0.016 | 0.023 | 0.013 | 0.018 | 0.0089 | 0.013 | 0.0047 | 0.0067 | 0.0030 | 0.0042 |
| FDA cooked eggs (TDS) nd=1/2 dl | 0.23 | 0.023 | 1.0 | 0.079 | 0.072 | 0.026 | 0.037 | 0.020 | 0.029 | 0.014 | 0.021 | 0.0076 | 0.011 | 0.0048 | 0.0069 |
| FDA cooked eggs (TDS) nd=dl | 0.32 | 0.032 | 1.4 | 0.11 | 0.10 | 0.036 | 0.051 | 0.028 | 0.040 | 0.020 | 0.029 | 0.010 | 0.015 | 0.0067 | 0.0095 |
| FDA raw eggs (Non-TDS) nd=0 | 0.27 | 0.027 | 1.2 | 0.091 | 0.09 | 0.031 | 0.044 | 0.024 | 0.034 | 0.017 | 0.024 | 0.0090 | 0.013 | 0.0057 | 0.008 |
| FDA raw eggs (Non-TDS) nd=1/2 dl | 0.37 | 0.038 | 1.7 | 0.13 | 0.12 | 0.043 | 0.061 | 0.033 | 0.047 | 0.024 | 0.034 | 0.012 | 0.018 | 0.0079 | 0.011 |
| FDA raw eggs (Non-TDS) nd=dl | 0.48 | 0.048 | 2.1 | 0.17 | 0.15 | 0.055 | 0.078 | 0.042 | 0.060 | 0.030 | 0.043 | 0.016 | 0.023 | 0.010 | 0.014 |

## Appendix B – Exposure Data Including Egg Consumption Rates, Comparison Data, and Hazard Quotients

**Table 19. Dioxin Intake Rate from Eggs (Per Capita) Comparison, FDA TDS Exposure Estimates (1998 WHO TEQs) and MDEQ Exposure Estimates (both 2005 WHO TEQs and 1998 WHO TEQs) both using 2001-2004 TDS Egg Concentration Data**

| | **FDA TDS Average Exposure Estimates** (2001-2004 for Eggs and Mixtures) | | | | | | **MDEQ Dioxin Intake Estimates** (Per Capita Egg Consumption Rates) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Reported Monthly DF Intakes (pg 1998 DF WHO-TEQ/kg bw/month) | | | Daily Intakes based on Reported Monthly Intakes (pg 1998 DF WHO-TEQ/kg bw-day) | | | | Child 5 and under average daily intake estimate (pg 2005 DF WHO-TEQ/kg body weight-day) | | | Adult female over 20 (75 kg bw) average daily intake estimate (pg 2005 DF WHO-TEQ/kg body weight-day) | | |
| | ND=0 | ND=½DL | ND=DL | ND=0 | ND=½DL | ND=DL | | ND=0 | ND=½DL | ND=DL | ND=1 | ND=½DL | ND=DL |
| Infant 6-11 months | 0.3 | 0.5 | 0.7 | 0.010 | 0.017 | 0.023 | | | | | | | |
| Children 2 years | 0.5 | 0.9 | 1.3 | 0.017 | 0.030 | 0.043 | | | | | | | |
| Children 6 years | 0.2 | 0.5 | 0.7 | 0.007 | 0.017 | 0.023 | 2005 WHO | 0.012 | 0.020 | 0.028 | | | |
| ***Estimated age-adjusted 5 and under*** | | | | ***0.009*** | ***0.020*** | ***0.028*** | ***1998 WHO*** | ***0.013*** | ***0.022*** | ***0.030*** | | | |
| Women 25-30 years | 0.1 | 0.2 | 0.3 | 0.0033 | 0.0067 | 0.0100 | 2005 WHO | | | | 0.0030 | 0.0048 | 0.0067 |
| Women 40-45 years | 0.1 | 0.2 | 0.2 | 0.0033 | 0.0067 | 0.0067 | | | | | | | |
| ***Estimated age-adjusted adult female*** | | | | ***0.0033*** | ***0.0067*** | ***0.0083*** | ***1998 WHO*** | | | | ***0.0032*** | ***0.0052*** | ***0.0073*** |

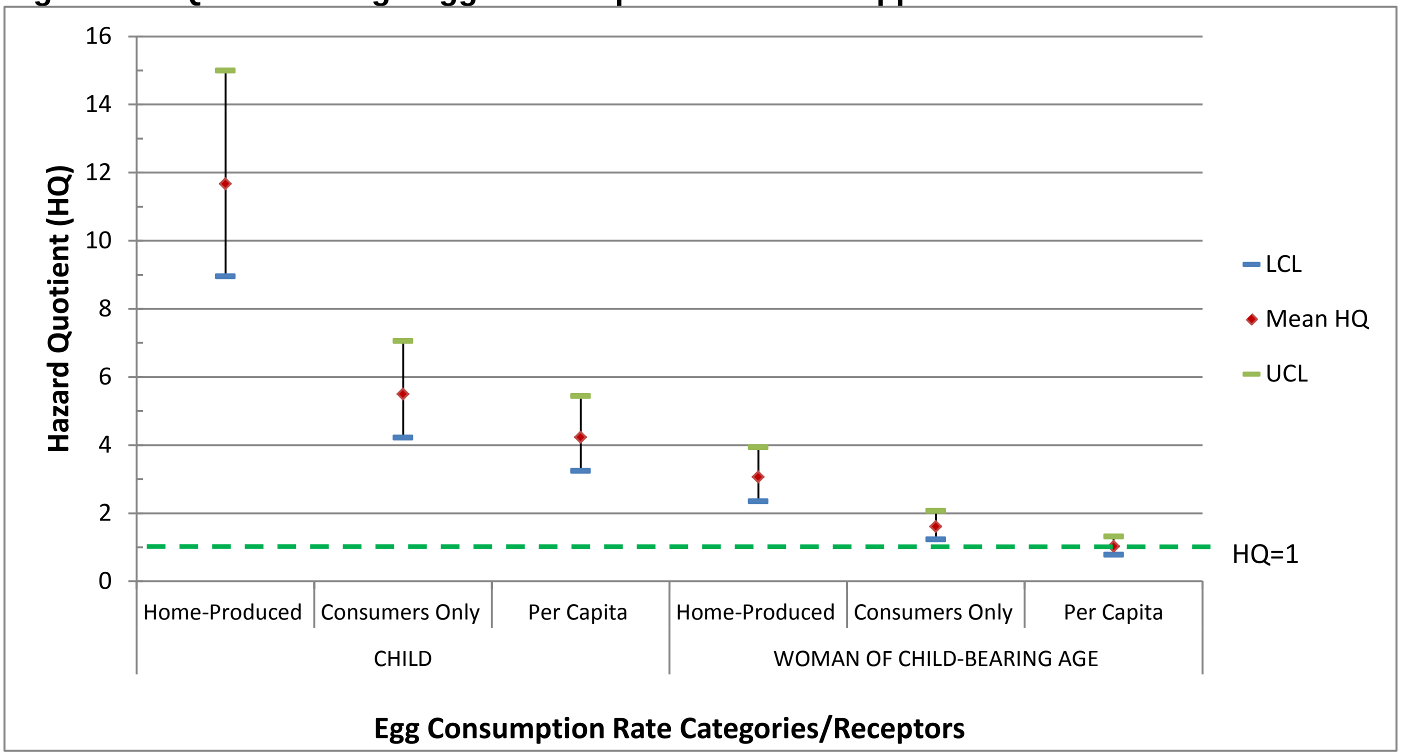
## Appendix B – Hazard Quotients

### Table 20. Hazard Quotients with 95% Upper and Lower Confidence Limits

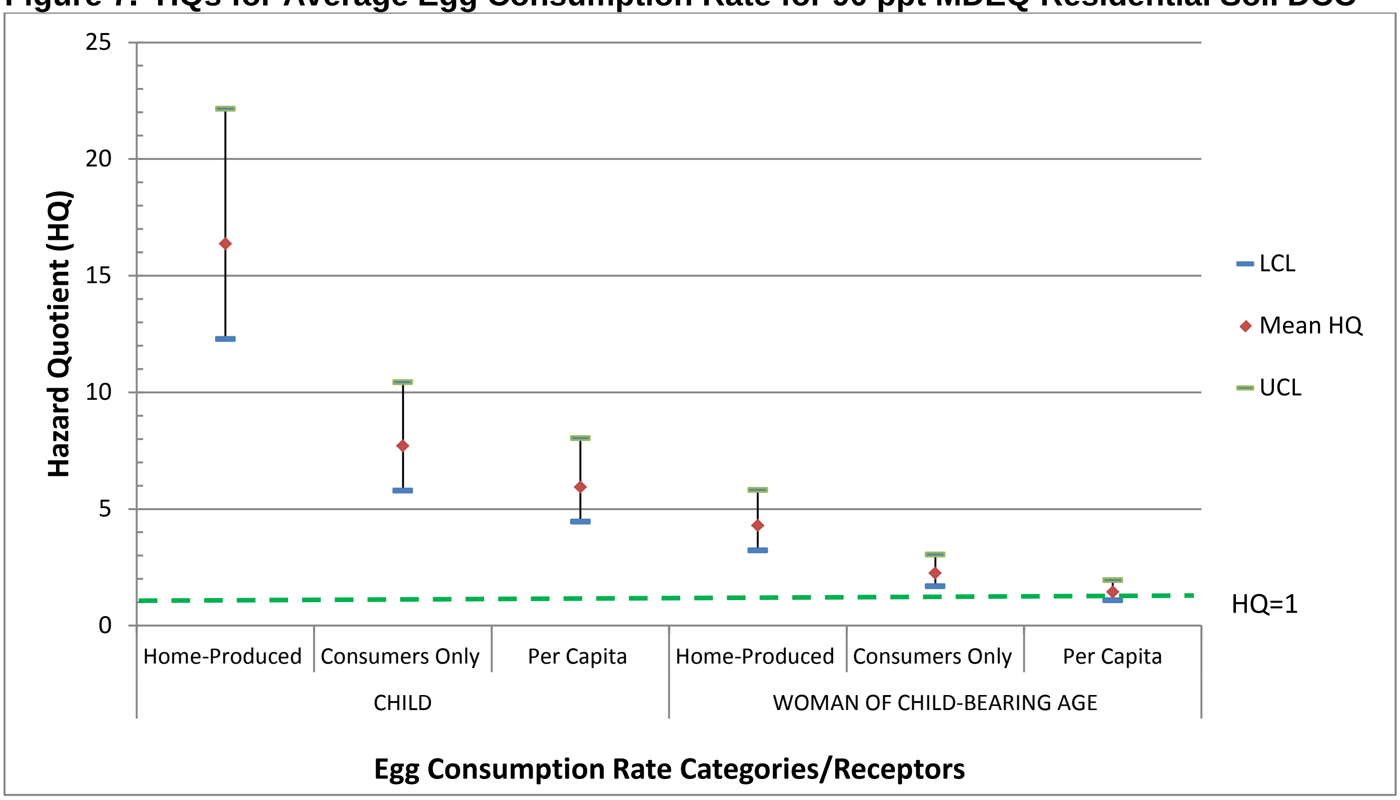
| | | | Child | | | Adult | | |
|---|---|---|---|---|---|---|---|---|
| | Soil (pg/g) | GLM Estimate | Home-Produced | Consumers Only | Per Capita | Home-Produced | Consumers Only | Per Capita |
| Site-Specific Residential Direct Contact Cleanup Level | 250 | LCL | 21 | 10 | 7.6 | 5.5 | 2.9 | 1.8 |
| | | Mean HQ | 31 | 14 | 11 | 8.0 | 4.2 | 2.7 |
| | | UCL | 47 | 21 | 16 | 12 | 6.1 | 3.9 |
| Site-Specific Other Direct Contact Cleanup Level | 2,000 | LCL | 62 | 29 | 23 | 16 | 9 | 5.5 |
| | | Mean HQ | 106 | 50 | 38 | 28 | 15 | 9 |
| | | UCL | 181 | 85 | 65 | 47 | 25 | 16 |
| EPA Residential Soil Regional Screening Level | 50 | LCL | 9.0 | 4.2 | 3.2 | 2.4 | 1.2 | 0.8 |
| | | Mean HQ | 12 | 5.5 | 4.2 | 3.1 | 1.6 | 1.0 |
| | | UCL | 15 | 7.2 | 5.5 | 4.0 | 2.1 | 1.3 |
| MDEQ Generic Residential Direct Contact Criterion | 90 | LCL | 12 | 5.8 | 4.5 | 3.2 | 1.7 | 1.1 |
| | | Mean HQ | 17 | 7.8 | 6.0 | 4.4 | 2.3 | 1.5 |
| | | UCL | 22 | 11 | 8.1 | 5.9 | 3.1 | 2.0 |
| Average TEQ Outside 8-yr Floodplain of Tittabawassee River | 20 | LCL | 5.4 | 2.5 | 2.0 | 1.4 | 0.7 | 0.5 |
| | | Mean HQ | 6.7 | 3.2 | 2.4 | 1.8 | 0.9 | 0.6 |
| | | UCL | 8.4 | 4.0 | 3.0 | 2.2 | 1.2 | 0.7 |
| Michigan Mean + 1 Standard Deviation TEQ | 12 | LCL | 4.1 | 1.9 | 1.5 | 1.1 | 0.56 | 0.36 |
| | | Mean HQ | 5.1 | 2.4 | 1.9 | 1.3 | 0.70 | 0.45 |
| | | UCL | 6.1 | 2.9 | 2.2 | 1.6 | 0.84 | 0.54 |
| Average Michigan Background TEQ | 5.8 | LCL | 2.6 | 1.2 | 1.0 | 0.69 | 0.36 | 0.23 |
| | | Mean HQ | 3.2 | 1.5 | 1.2 | 0.84 | 0.44 | 0.28 |
| | | UCL | 3.7 | 1.8 | 1.4 | 1.0 | 0.52 | 0.33 |

## Appendix B – Hazard Quotients

### Figure 6. HQs for Average Egg Consumption Rate for 50 ppt EPA Residential Soil PRG




### Figure 7. HQs for Average Egg Consumption Rate for 90 ppt MDEQ Residential Soil DCC



## Appendix B – Hazard Quotients

**Figure 8.** HQs for Average Egg Consumption Rate for 20 ppt Average Soil TEQ Outside 8-year Floodplain of Tittabawassee River

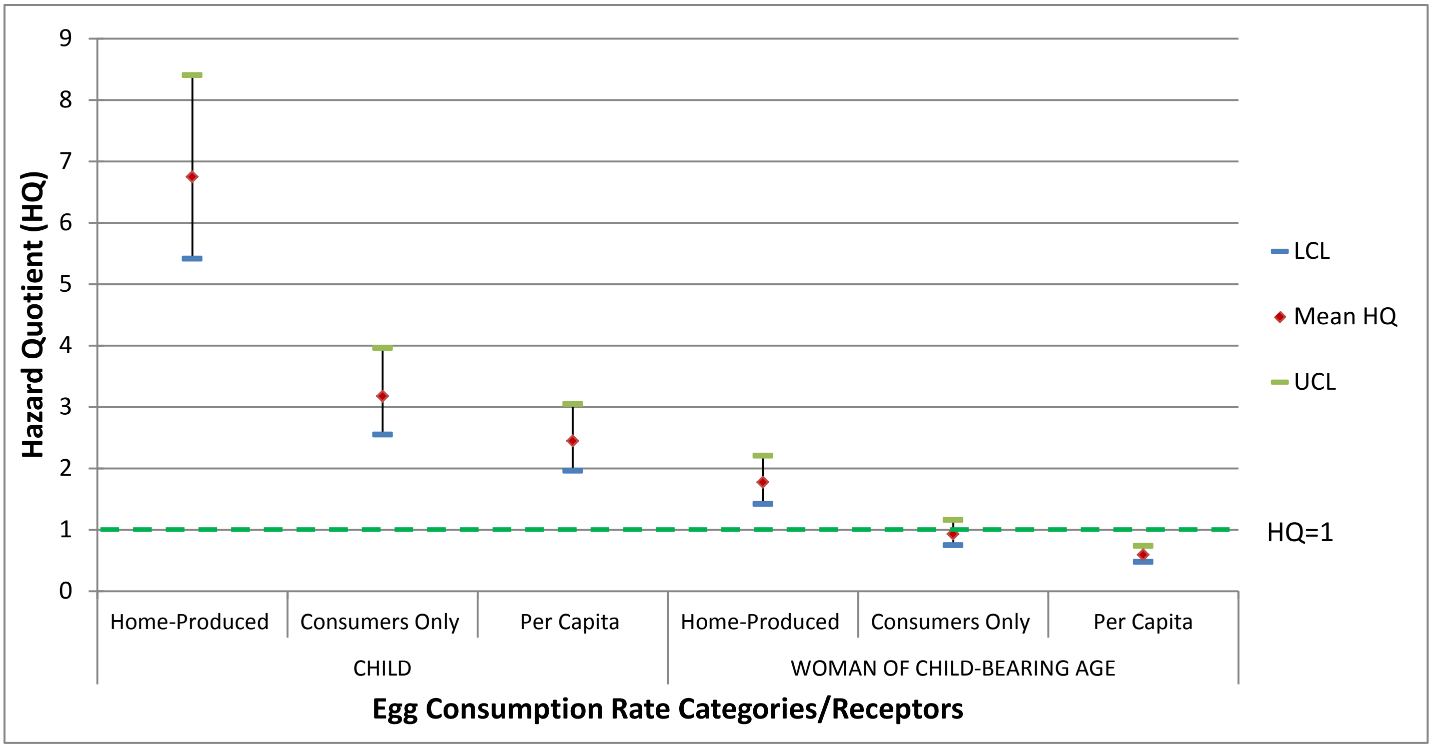
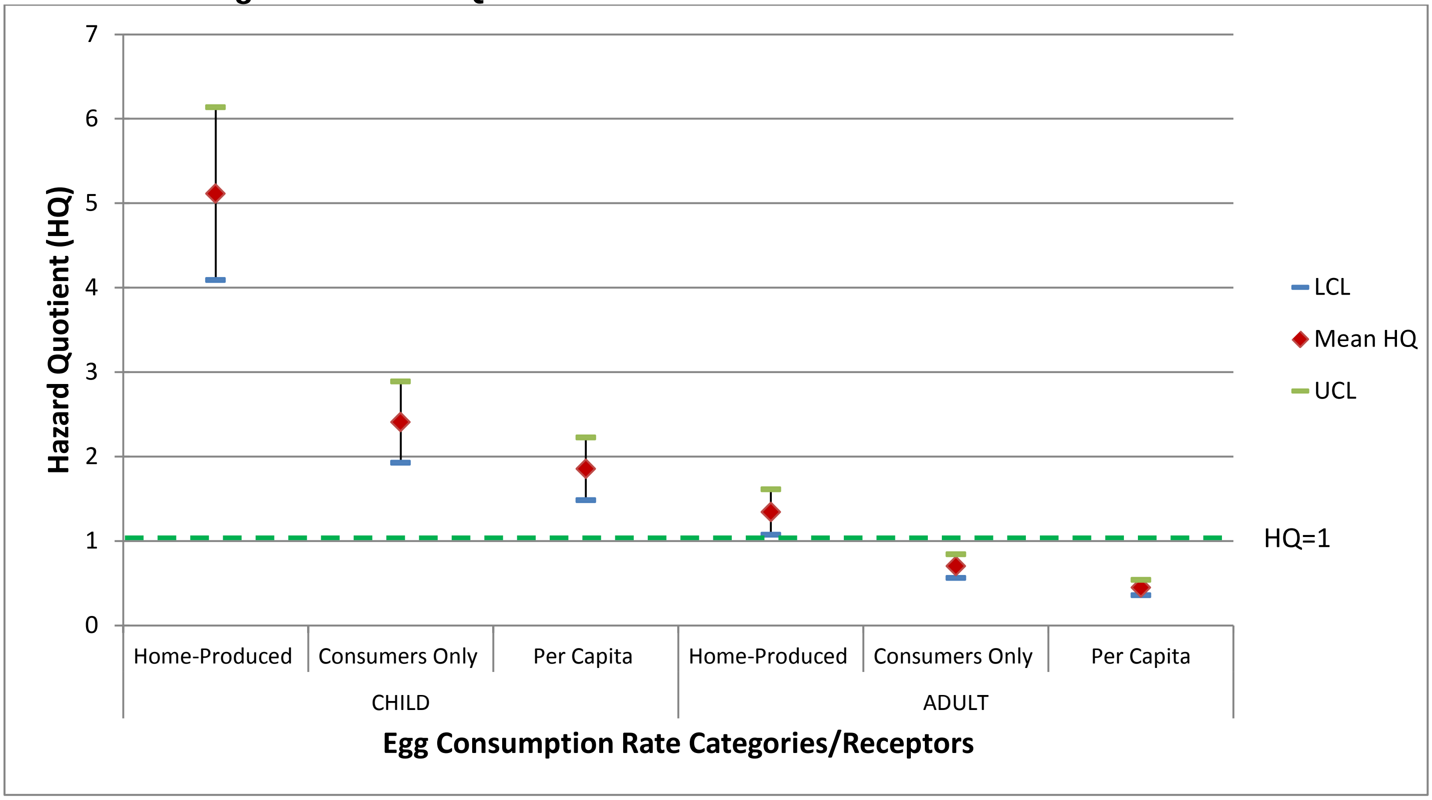



**Figure 9. HQs for Average Egg Consumption Rate for 12 ppt Michigan Mean +1 Standard Deviation Background Soil TEQ**



## Appendix B – Hazard Quotients

**Figure 10. HQs for Average Egg Consumption Rate for 5.8 ppt Average Michigan Background Soil TEQ**

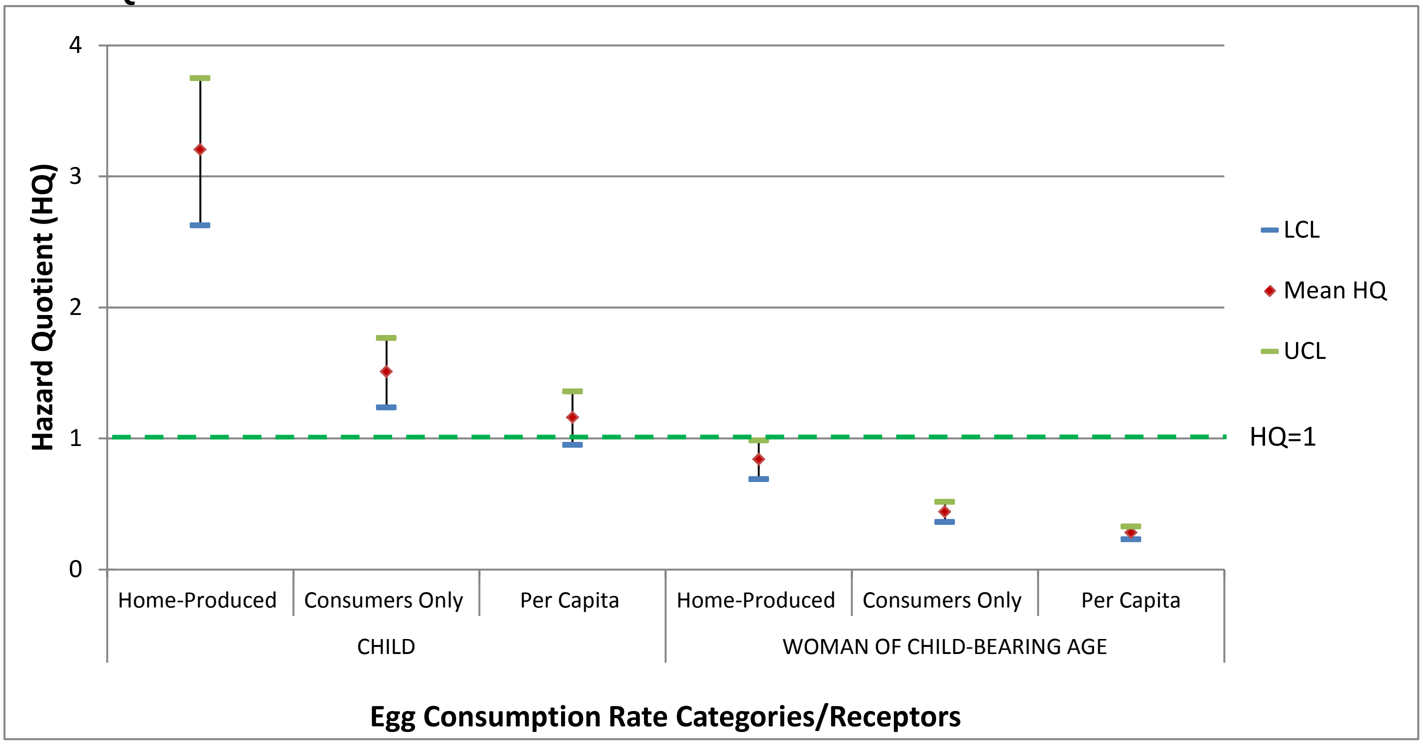
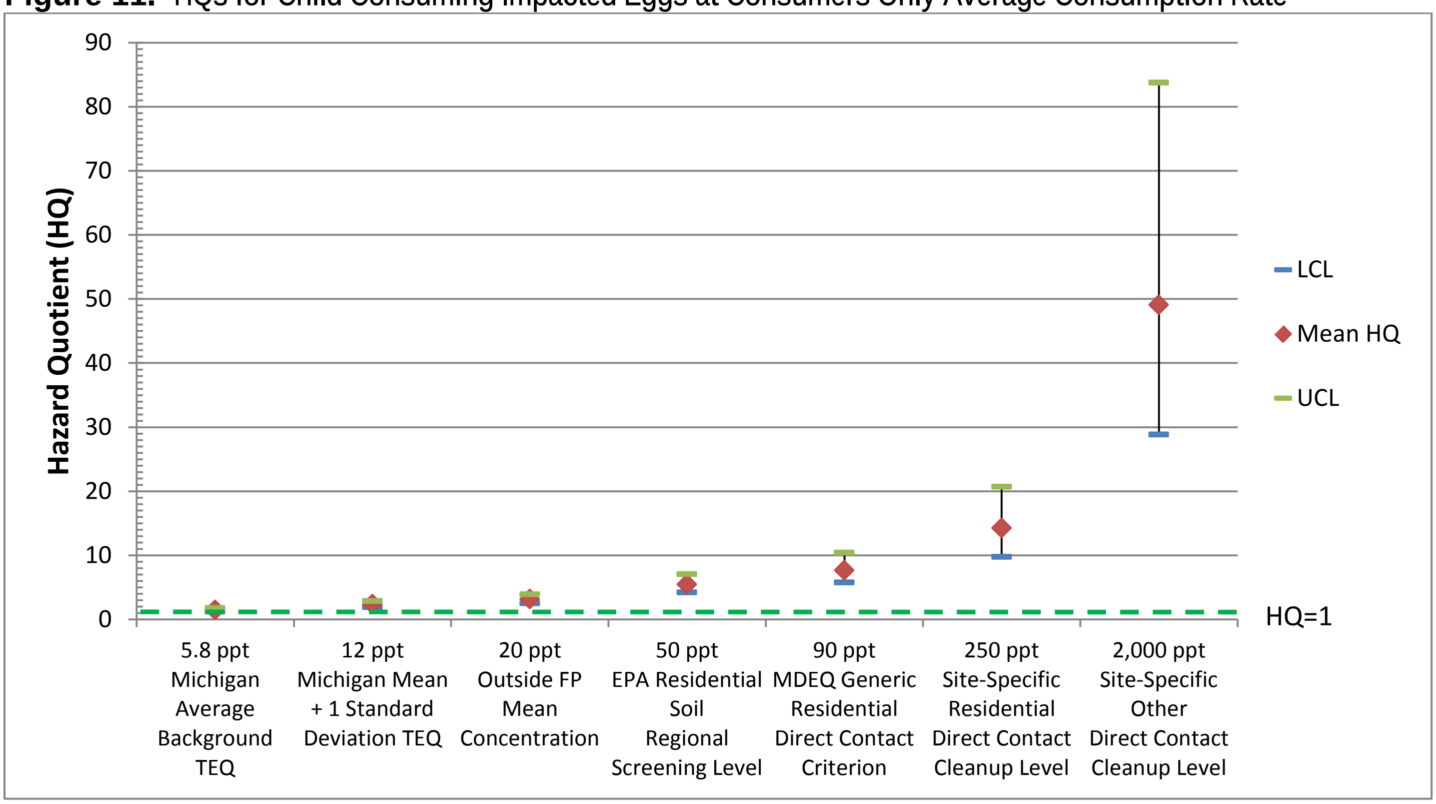



**Figure 11.** HQs for Child Consuming Impacted Eggs at Consumers Only Average Consumption Rate



## Appendix B – Hazard Quotients

**Figure 12.** HQs for Child Consuming Impacted Eggs at Per Capita Average Consumption Rate

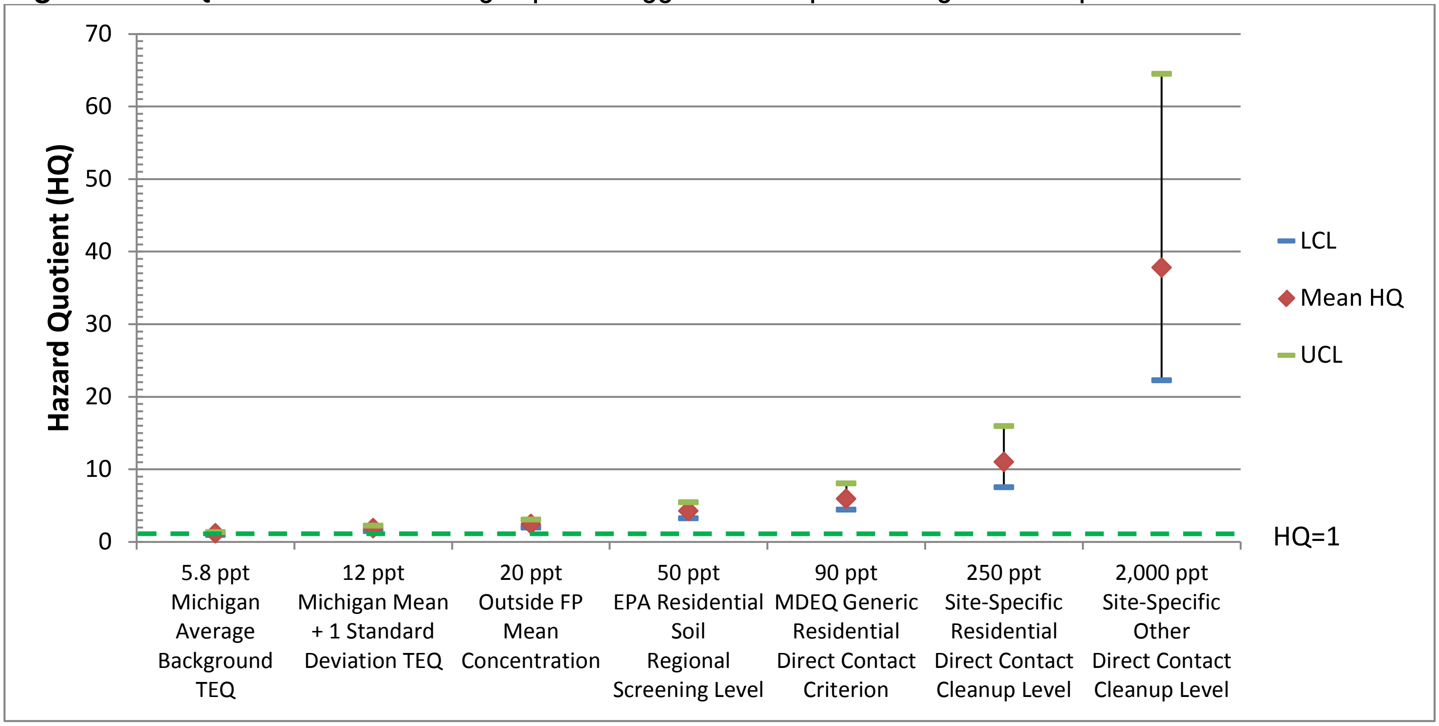
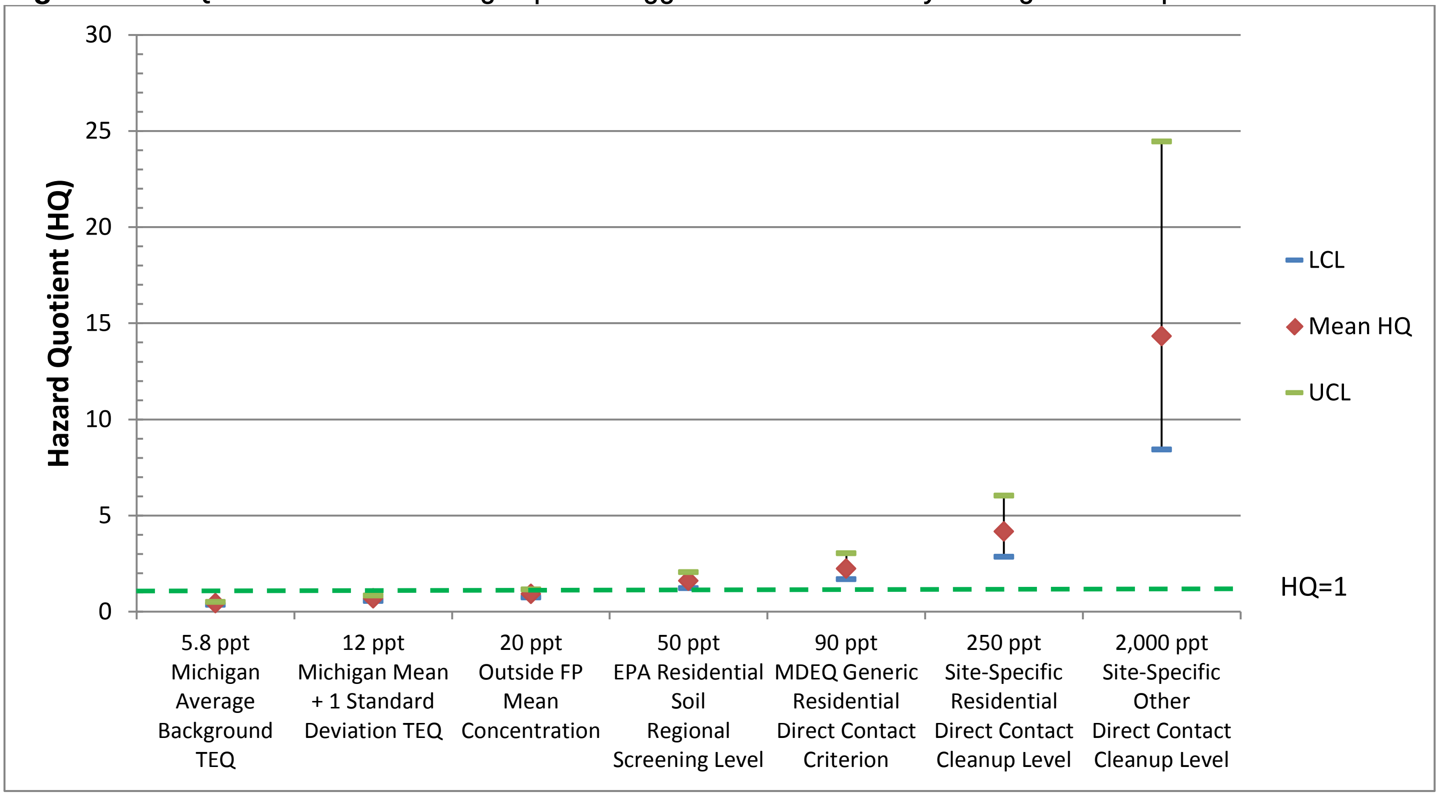
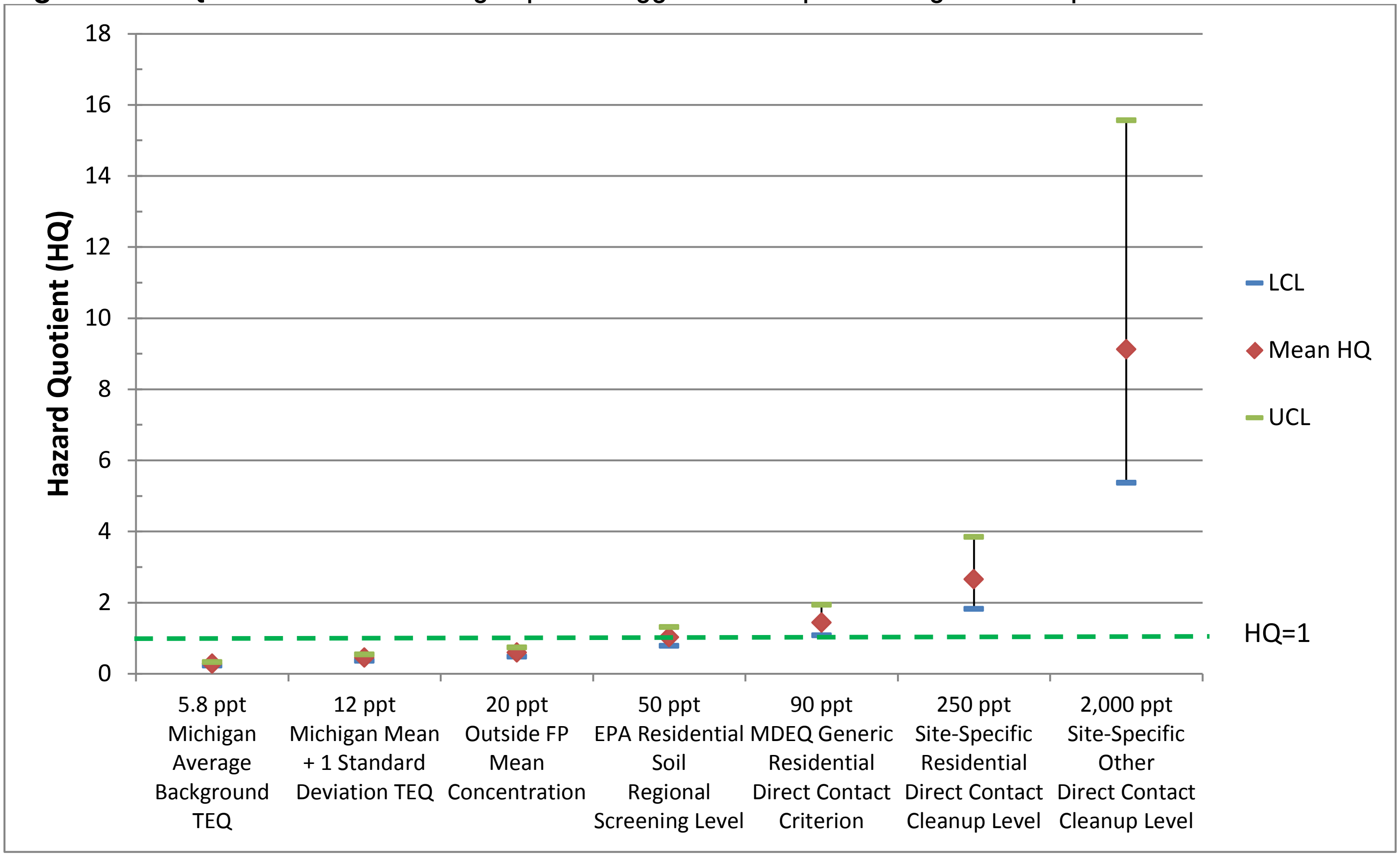



**Figure 13.** HQs for Adult Consuming Impacted Eggs at Consumers Only Average Consumption Rate



## Appendix B – Hazard Quotients

**Figure 14**. HQs for Adult Consuming Impacted Eggs at Per Capita Average Consumption Rate



# Appendix C – Additional Evaluation of Generalized Linear Model Stability

## Appendix C – Additional Evaluation of Generalized Linear Model Stability

**Figure 15. Generalized Linear Model for All Paired Soil and Egg 2005 TEQ Data with Non-detects Equal to Zero and 95% Confidence Intervals**

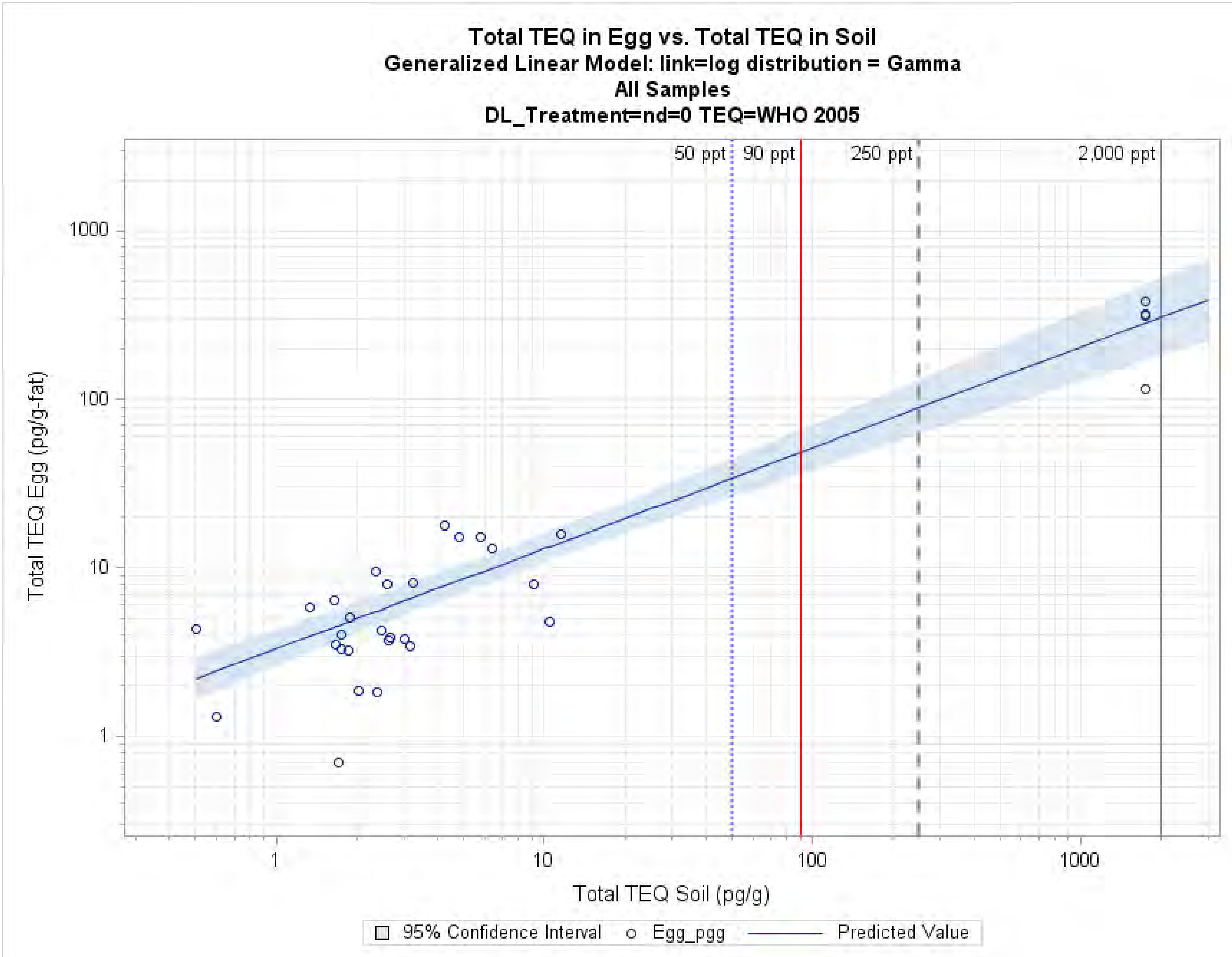
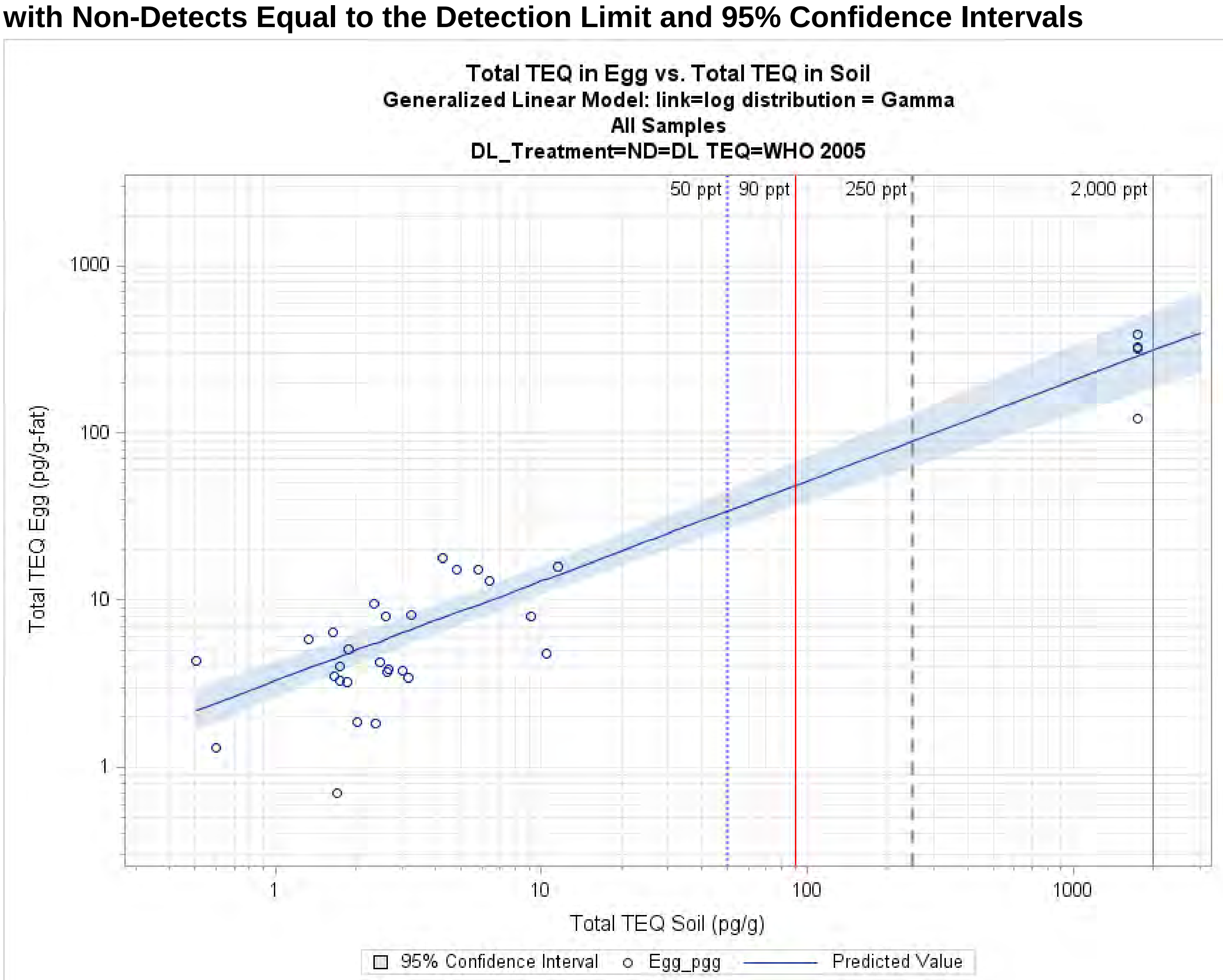



**Figure 16. Generalized Linear Model for All Paired Soil and Egg 2005 TEQ Data with Non-Detects Equal to the Detection Limit and 95% Confidence Intervals**



## Appendix C – Additional Evaluation of Generalized Linear Model Stability

**Figure 17. Generalized Linear Model for All Paired Soil and Egg 1998 TEQ Data with Non-Detects as Reported and 95% Confidence Intervals**

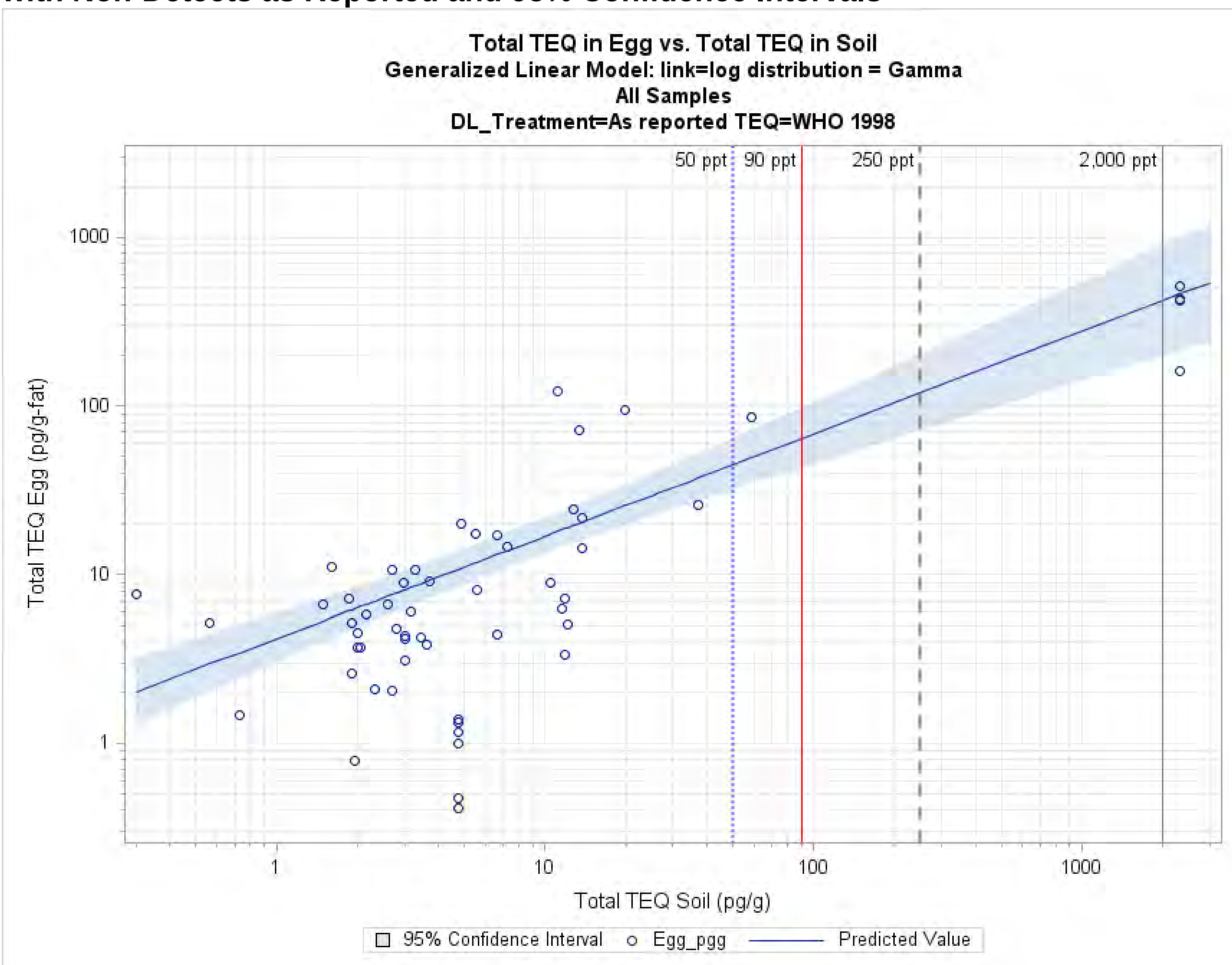



**Figure 18. Generalized Linear Model for Paired Soil and Egg 2005 TEQ Data without Highest Sample Set with Non-Detects Equal to Zero and 95% Confidence Intervals**

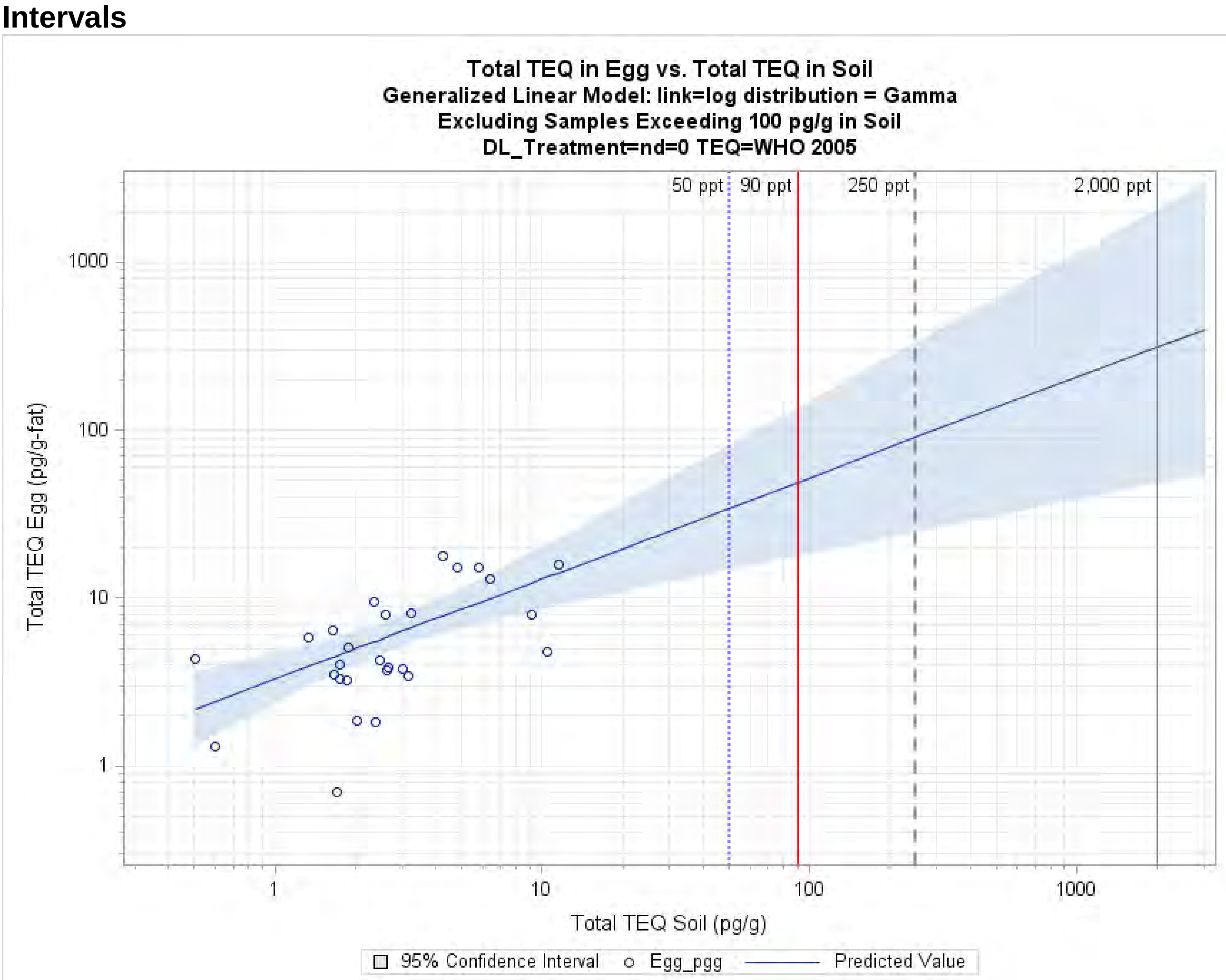


**Figure 19. Generalized Linear Model for Paired Soil and Egg 2005 TEQ Data without Highest Sample Set with Non-Detects Equal to the Detection Limit and 95% Confidence Intervals**

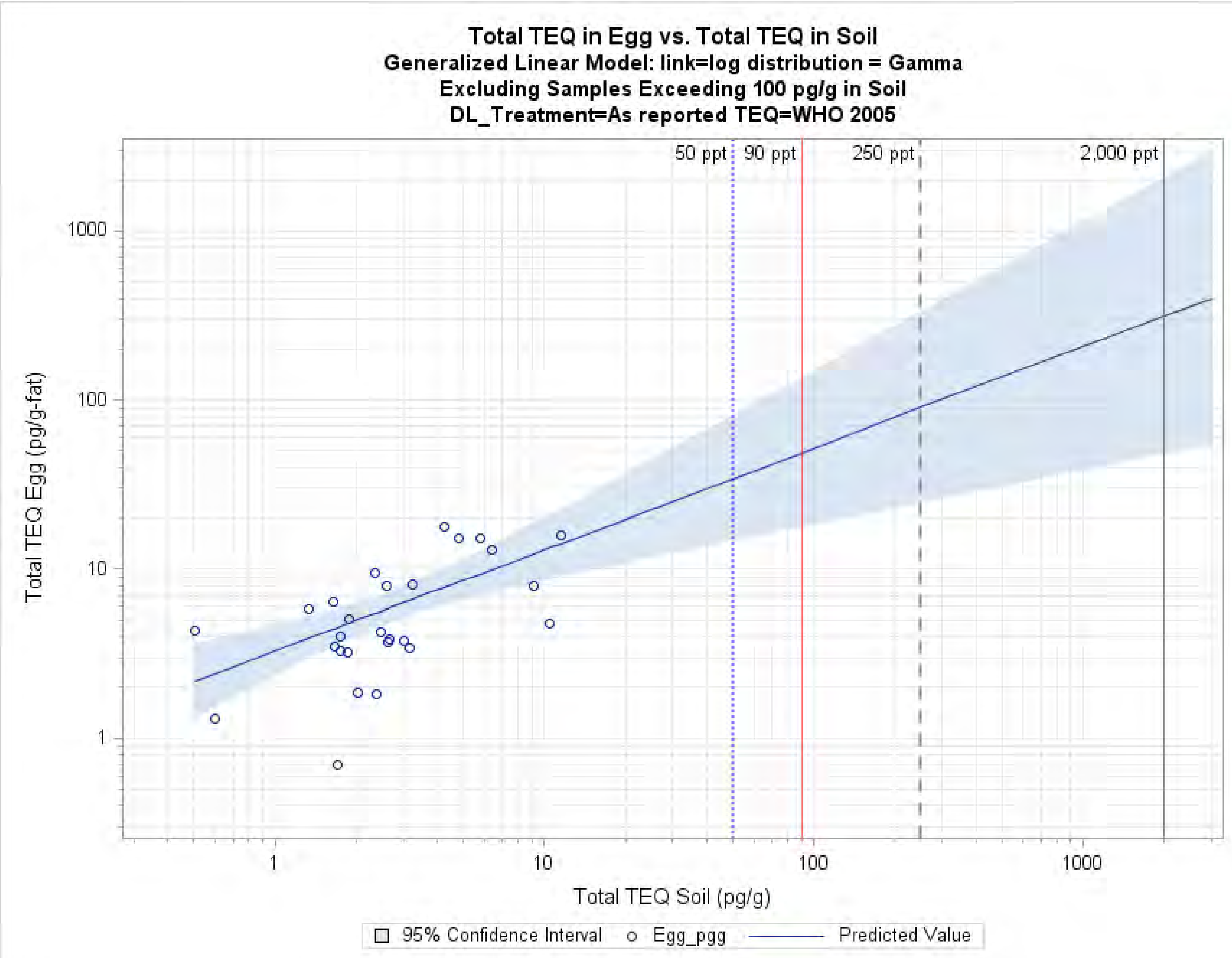
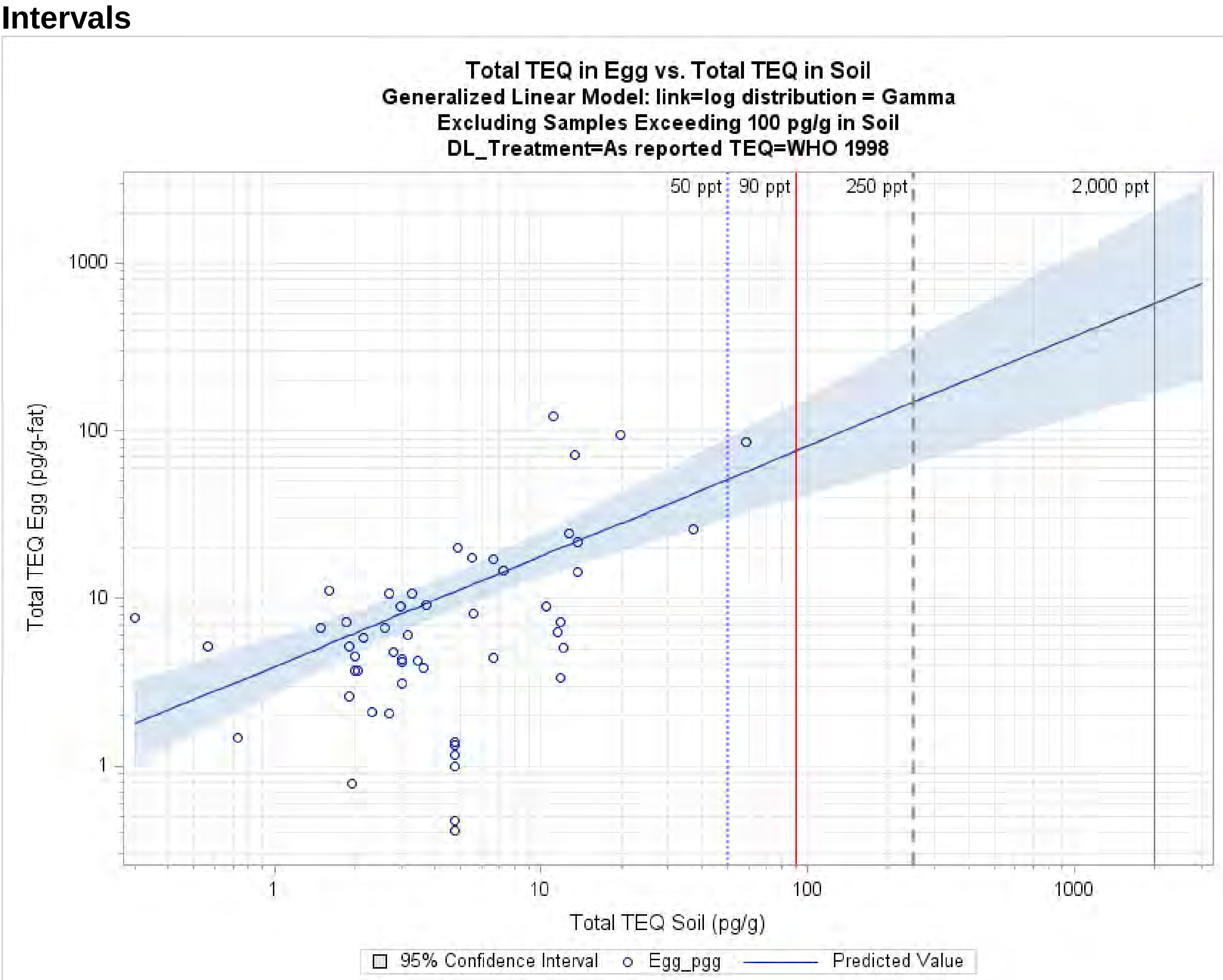



**Figure 20. Generalized Linear Model for Paired Soil and Egg 1998 TEQ Data without Highest Sample Set with Non-Detects as Reported and 95% Confidence Intervals**



# Appendix D - SAS Statistic Software Output Files for Generalized Linear Model

# Total TEQ in Egg vs. Total TEQ in Soil
## Generalized Linear Model: link=log distribution = Gamma
## Excluding Samples Exceeding 100 pg/g in Soil

The GENMOD Procedure

DL_Treatment=As reported TEQ=WHO 1998

| Model Information | | |
|---|---|---|
| Data Set | WORK.SOILEGGS | |
| Distribution | Gamma | |
| Link Function | Log | |
| Dependent Variable | Egg_pgg | Egg_pgg |

| | |
|---|---|
| Number of Observations Read | 68 |
| Number of Observations Used | 52 |
| Missing Values | 16 |

| Criteria For Assessing Goodness Of Fit | | | |
|---|---|---|---|
| Criterion | DF | Value | Value/DF |
| Deviance | 50 | 52.6554 | 1.0531 |
| Scaled Deviance | 50 | 59.2344 | 1.1847 |
| Pearson Chi-Square | 50 | 66.9416 | 1.3388 |
| Scaled Pearson X2 | 50 | 75.3056 | 1.5061 |
| Log Likelihood | | -172.6553 | |
| Full Log Likelihood | | -172.6553 | |
| AIC (smaller is better) | | 351.3106 | |
| AICC (smaller is better) | | 351.8106 | |
| BIC (smaller is better) | | 357.1644 | |

Algorithm converged.

| Analysis Of Maximum Likelihood Parameter Estimates | | | | | | | |
|---|---|---|---|---|---|---|---|
| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Wald Chi-Square | Pr > ChiSq |
| Intercept | 1 | 1.3714 | 0.1979 | 0.9836 | 1.7593 | 48.03 | <.0001 |
| lSoil_pgg | 1 | 0.6564 | 0.1023 | 0.4559 | 0.8569 | 41.16 | <.0001 |
| Scale | 1 | 1.1249 | 0.1963 | 0.7992 | 1.5835 | | |

Note: The scale parameter was estimated by maximum likelihood.

# Total TEQ in Egg vs. Total TEQ in Soil
## Generalized Linear Model: link=log distribution = Gamma
## Excluding Samples Exceeding 100 pg/g in Soil

The GENMOD Procedure

DL_Treatment=As reported TEQ=WHO 2005

| Model Information | | |
|---|---|---|
| Data Set | WORK.SOILEGGS | |
| Distribution | Gamma | |
| Link Function | Log | |
| Dependent Variable | Egg_pgg | Egg_pgg |

| | |
|---|---|
| Number of Observations Read | 43 |
| Number of Observations Used | 27 |
| Missing Values | 16 |

| Criteria For Assessing Goodness Of Fit | | | |
|---|---|---|---|
| Criterion | DF | Value | Value/DF |
| Deviance | 25 | 9.3562 | 0.3742 |
| Scaled Deviance | 25 | 28.4639 | 1.1386 |
| Pearson Chi-Square | 25 | 8.1280 | 0.3251 |
| Scaled Pearson X2 | 25 | 24.7275 | 0.9891 |
| Log Likelihood | | -68.0102 | |
| Full Log Likelihood | | -68.0102 | |
| AIC (smaller is better) | | 142.0203 | |
| AICC (smaller is better) | | 143.0638 | |
| BIC (smaller is better) | | 145.9078 | |

Algorithm converged.

| Analysis Of Maximum Likelihood Parameter Estimates | | | | | | | |
|---|---|---|---|---|---|---|---|
| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Wald Chi-Square | Pr > ChiSq |
| Intercept | 1 | 1.1910 | 0.1791 | 0.8401 | 1.5420 | 44.24 | <.0001 |
| lSoil_pgg | 1 | 0.5994 | 0.1447 | 0.3158 | 0.8831 | 17.15 | <.0001 |
| Scale | 1 | 3.0423 | 0.7868 | 1.8325 | 5.0507 | | |

Note: The scale parameter was estimated by maximum likelihood.

# Total TEQ in Egg vs. Total TEQ in Soil
# Generalized Linear Model: link=log distribution = Gamma
# Excluding Samples Exceeding 100 pg/g in Soil

The GENMOD Procedure

DL_Treatment=nd=0 TEQ=WHO 2005

| Model Information | | |
|---|---|---|
| Data Set | WORK.SOILEGGS | |
| Distribution | Gamma | |
| Link Function | Log | |
| Dependent Variable | Egg_pgg | Egg_pgg |

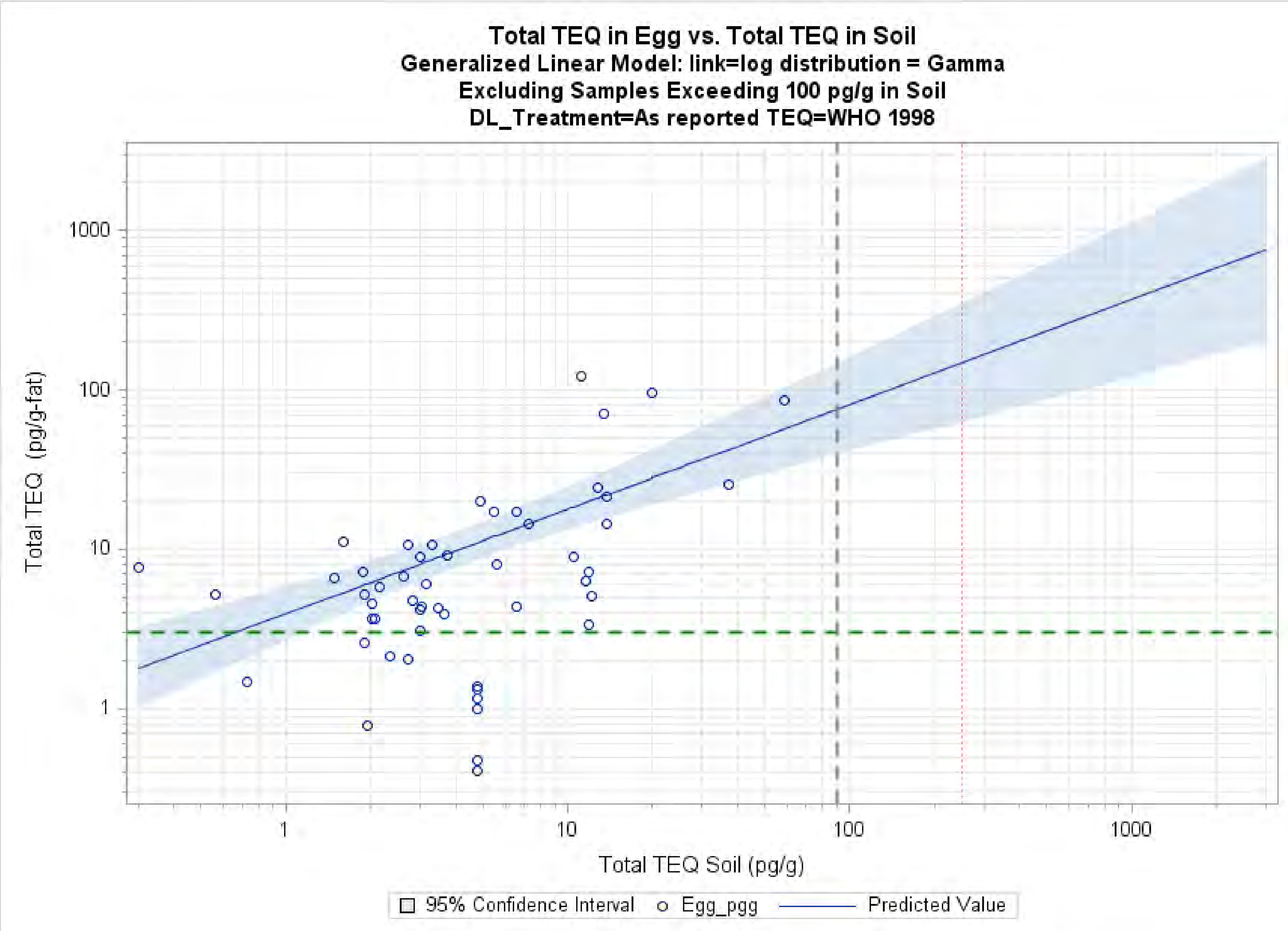
| | |
|---|---|
| Number of Observations Read | 43 |
| Number of Observations Used | 27 |
| Missing Values | 16 |

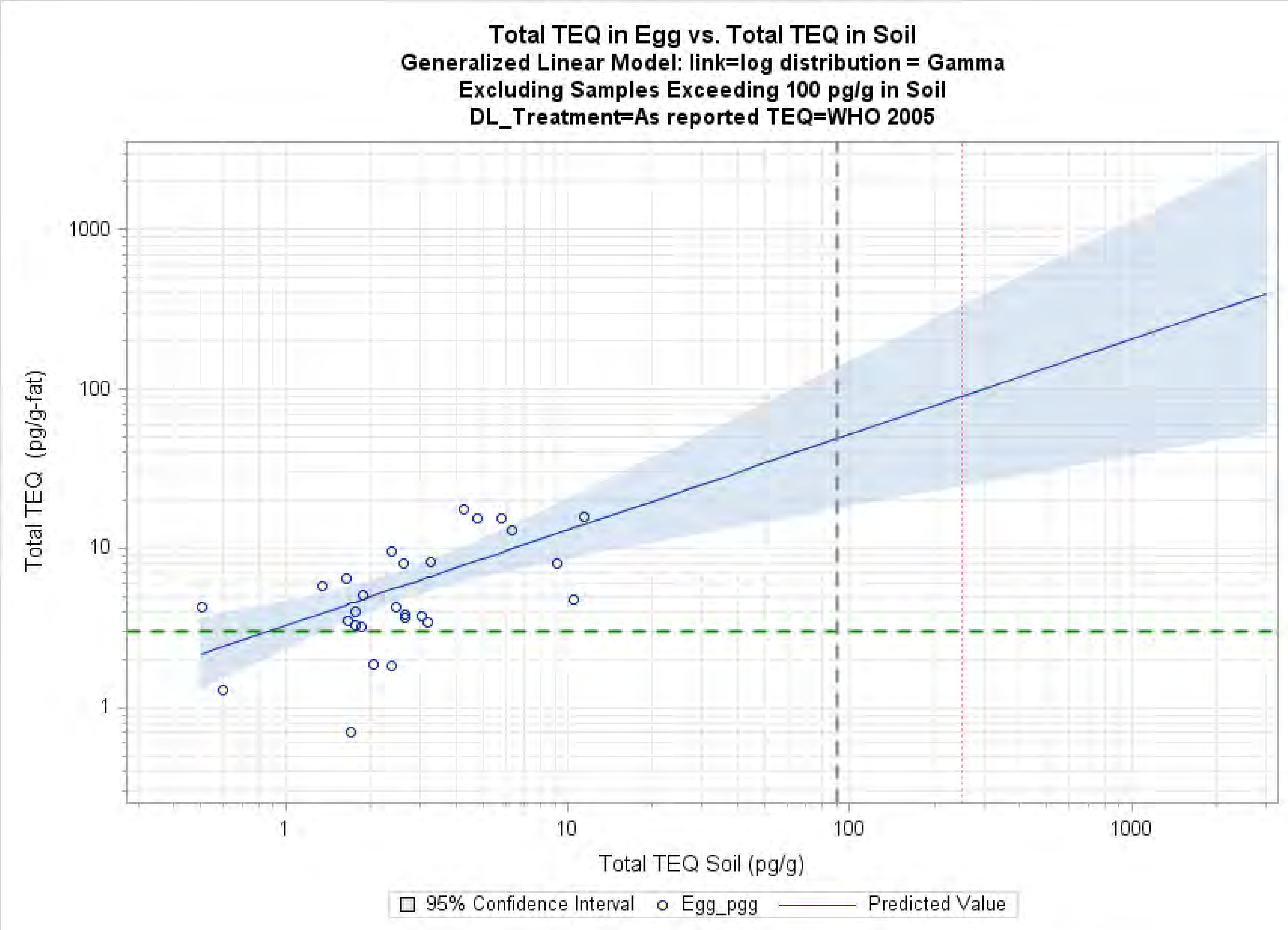
| Criteria For Assessing Goodness Of Fit | | | |
|---|---|---|---|
| Criterion | DF | Value | Value/DF |
| Deviance | 25 | 9.3562 | 0.3742 |
| Scaled Deviance | 25 | 28.4639 | 1.1386 |
| Pearson Chi-Square | 25 | 8.1280 | 0.3251 |
| Scaled Pearson X2 | 25 | 24.7275 | 0.9891 |
| Log Likelihood | | -68.0102 | |
| Full Log Likelihood | | -68.0102 | |
| AIC (smaller is better) | | 142.0203 | |
| AICC (smaller is better) | | 143.0638 | |
| BIC (smaller is better) | | 145.9078 | |

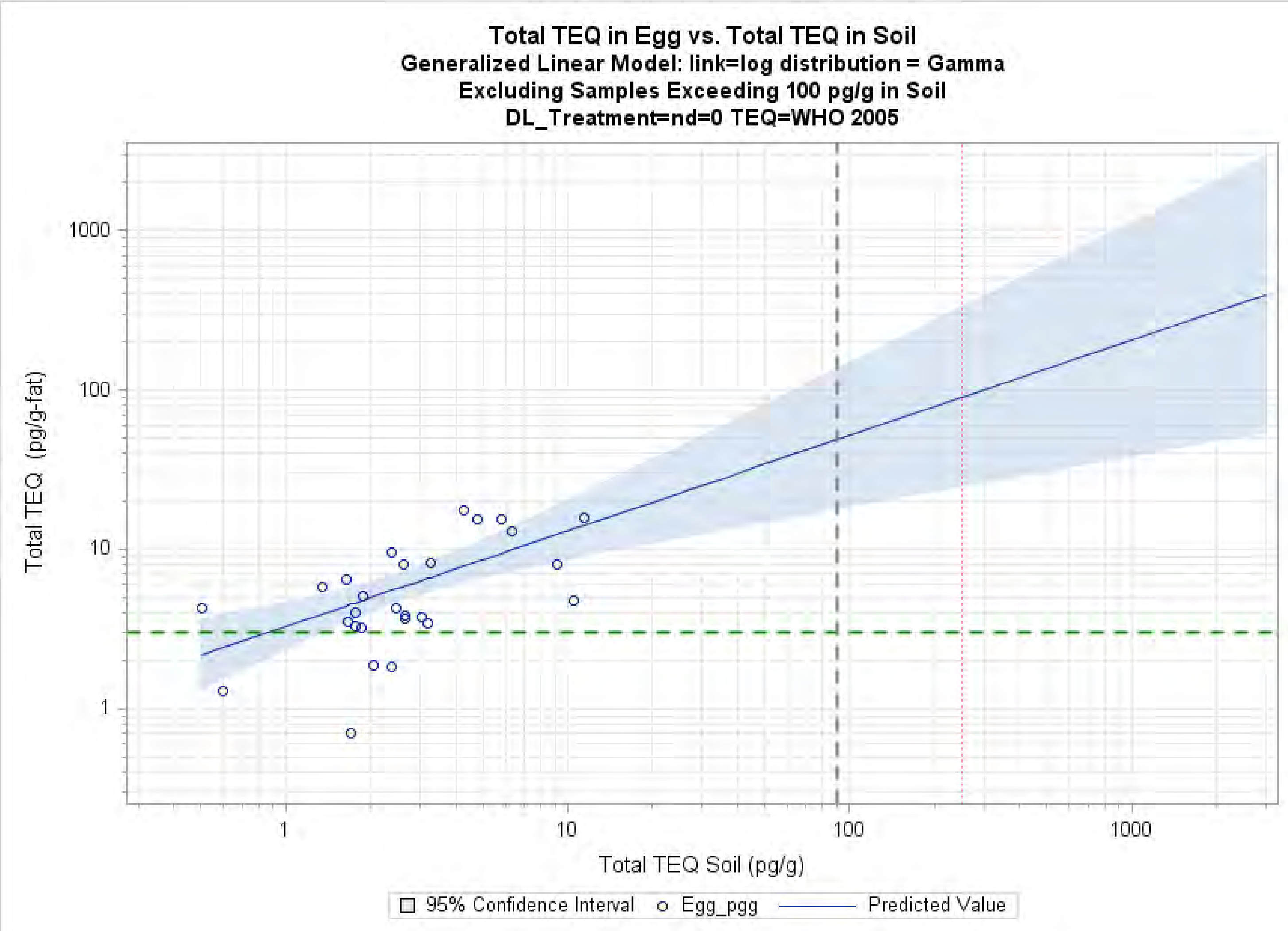
Algorithm converged.

| Analysis Of Maximum Likelihood Parameter Estimates | | | | | | | |
|---|---|---|---|---|---|---|---|
| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Wald Chi-Square | Pr > ChiSq |
| Intercept | 1 | 1.1910 | 0.1791 | 0.8401 | 1.5420 | 44.24 | <.0001 |
| lSoil_pgg | 1 | 0.5994 | 0.1447 | 0.3158 | 0.8831 | 17.15 | <.0001 |
| Scale | 1 | 3.0423 | 0.7868 | 1.8325 | 5.0507 | | |

Note: The scale parameter was estimated by maximum likelihood.


Total TEQ in Egg vs. Total TEQ in Soil
Generalized Linear Model: link=log distribution = Gamma
Excluding Samples Exceeding 100 pg/g in Soil
DL_Treatment=As reported TEQ=WHO 1998
Total TEQ (pg/g-fat)
1000
100
10
1
Total TEQ Soil (pg/g)
95% Confidence Interval
Egg_pgg
Predicted Value


Total TEQ in Egg vs. Total TEQ in Soil
Generalized Linear Model: link=log distribution = Gamma
Excluding Samples Exceeding 100 pg/g in Soil
DL_Treatment=As reported TEQ=WHO 2005
Total TEQ (pg/g-fat)
1000
100
10
1
Total TEQ Soil (pg/g)
1
10
100
1000
95% Confidence Interval
Egg_pgg
Predicted Value


Total TEQ in Egg vs. Total TEQ in Soil
Generalized Linear Model: link=log distribution = Gamma
Excluding Samples Exceeding 100 pg/g in Soil
DL_Treatment=nd=0 TEQ=WHO 2005
1000
100
10
1
Total TEQ (pg/g-fat)
1
10
100
1000
Total TEQ Soil (pg/g)
95% Confidence Interval
Egg_pgg
Predicted Value

# Total TEQ in Egg vs. Total TEQ in Soil
# Generalized Linear Model: link=log distribution = Gamma
# All Samples

The GENMOD Procedure

DL_Treatment=As reported TEQ=WHO 1998

| Model Information | | |
|---|---|---|
| Data Set | WORK.SOILEGGS | |
| Distribution | Gamma | |
| Link Function | Log | |
| Dependent Variable | Egg_pgg | Egg_pgg |

| | |
|---|---|
| Number of Observations Read | 72 |
| Number of Observations Used | 56 |
| Missing Values | 16 |

| Criteria For Assessing Goodness Of Fit | | | |
|---|---|---|---|
| Criterion | DF | Value | Value/DF |
| Deviance | 54 | 53.6948 | 0.9943 |
| Scaled Deviance | 54 | 63.4535 | 1.1751 |
| Pearson Chi-Square | 54 | 71.2158 | 1.3188 |
| Scaled Pearson X2 | 54 | 84.1588 | 1.5585 |
| Log Likelihood | | -200.3552 | |
| Full Log Likelihood | | -200.3552 | |
| AIC (smaller is better) | | 406.7104 | |
| AICC (smaller is better) | | 407.1719 | |
| BIC (smaller is better) | | 412.7864 | |

Algorithm converged.

| Analysis Of Maximum Likelihood Parameter Estimates | | | | | | | |
|---|---|---|---|---|---|---|---|
| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Wald Chi-Square | Pr > ChiSq |
| Intercept | 1 | 1.4341 | 0.1735 | 1.0941 | 1.7740 | 68.36 | <.0001 |
| lSoil_pgg | 1 | 0.6057 | 0.0643 | 0.4796 | 0.7318 | 88.62 | <.0001 |
| Scale | 1 | 1.1817 | 0.1995 | 0.8488 | 1.6452 | | |

Note: The scale parameter was estimated by maximum likelihood.

# Total TEQ in Egg vs. Total TEQ in Soil
## Generalized Linear Model: link=log distribution = Gamma
## All Samples

The GENMOD Procedure

DL_Treatment=As reported TEQ=WHO 2005

| Model Information | | |
|---|---|---|
| Data Set | WORK.SOILEGGS | |
| Distribution | Gamma | |
| Link Function | Log | |
| Dependent Variable | Egg_pgg | Egg_pgg |

| | |
|---|---|
| Number of Observations Read | 47 |
| Number of Observations Used | 31 |
| Missing Values | 16 |

| Criteria For Assessing Goodness Of Fit | | | |
|---|---|---|---|
| Criterion | DF | Value | Value/DF |
| Deviance | 29 | 10.0391 | 0.3462 |
| Scaled Deviance | 29 | 32.5777 | 1.1234 |
| Pearson Chi-Square | 29 | 8.6035 | 0.2967 |
| Scaled Pearson X2 | 29 | 27.9188 | 0.9627 |
| Log Likelihood | | -92.8801 | |
| Full Log Likelihood | | -92.8801 | |
| AIC (smaller is better) | | 191.7601 | |
| AICC (smaller is better) | | 192.6490 | |
| BIC (smaller is better) | | 196.0621 | |

Algorithm converged.

| Analysis Of Maximum Likelihood Parameter Estimates | | | | | | | |
|---|---|---|---|---|---|---|---|
| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Wald Chi-Square | Pr > ChiSq |
| Intercept | 1 | 1.1917 | 0.1272 | 0.9425 | 1.4410 | 87.84 | <.0001 |
| lSoil_pgg | 1 | 0.5986 | 0.0435 | 0.5133 | 0.6840 | 188.99 | <.0001 |
| Scale | 1 | 3.2451 | 0.7856 | 2.0191 | 5.2154 | | |

Note: The scale parameter was estimated by maximum likelihood.

# Total TEQ in Egg vs. Total TEQ in Soil
## Generalized Linear Model: link=log distribution = Gamma
## All Samples

The GENMOD Procedure

DL_Treatment=nd=0 TEQ=WHO 2005

| Model Information | | |
|---|---|---|
| Data Set | WORK.SOILEGGS | |
| Distribution | Gamma | |
| Link Function | Log | |
| Dependent Variable | Egg_pgg | Egg_pgg |

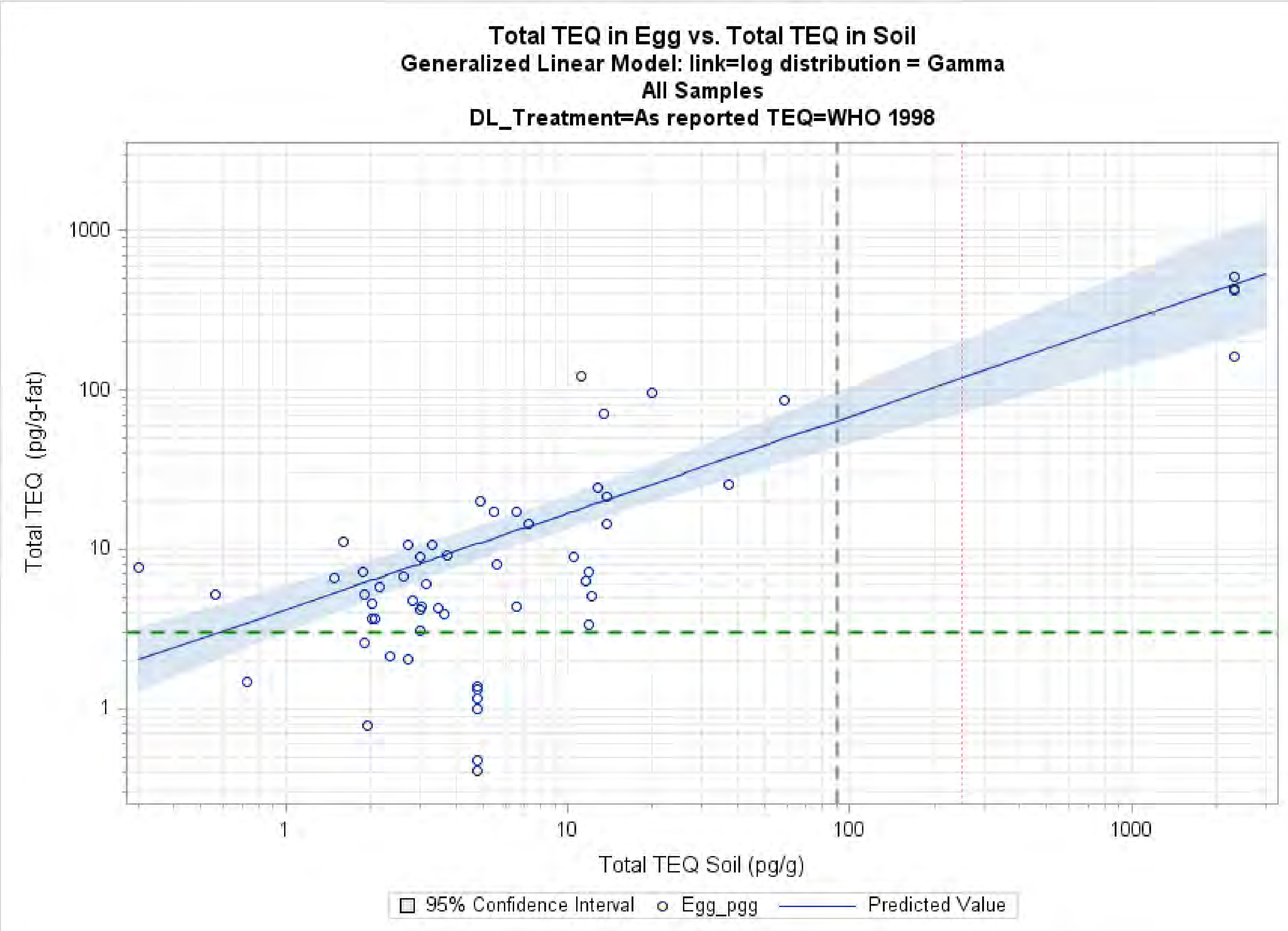
| | |
|---|---|
| Number of Observations Read | 47 |
| Number of Observations Used | 31 |
| Missing Values | 16 |

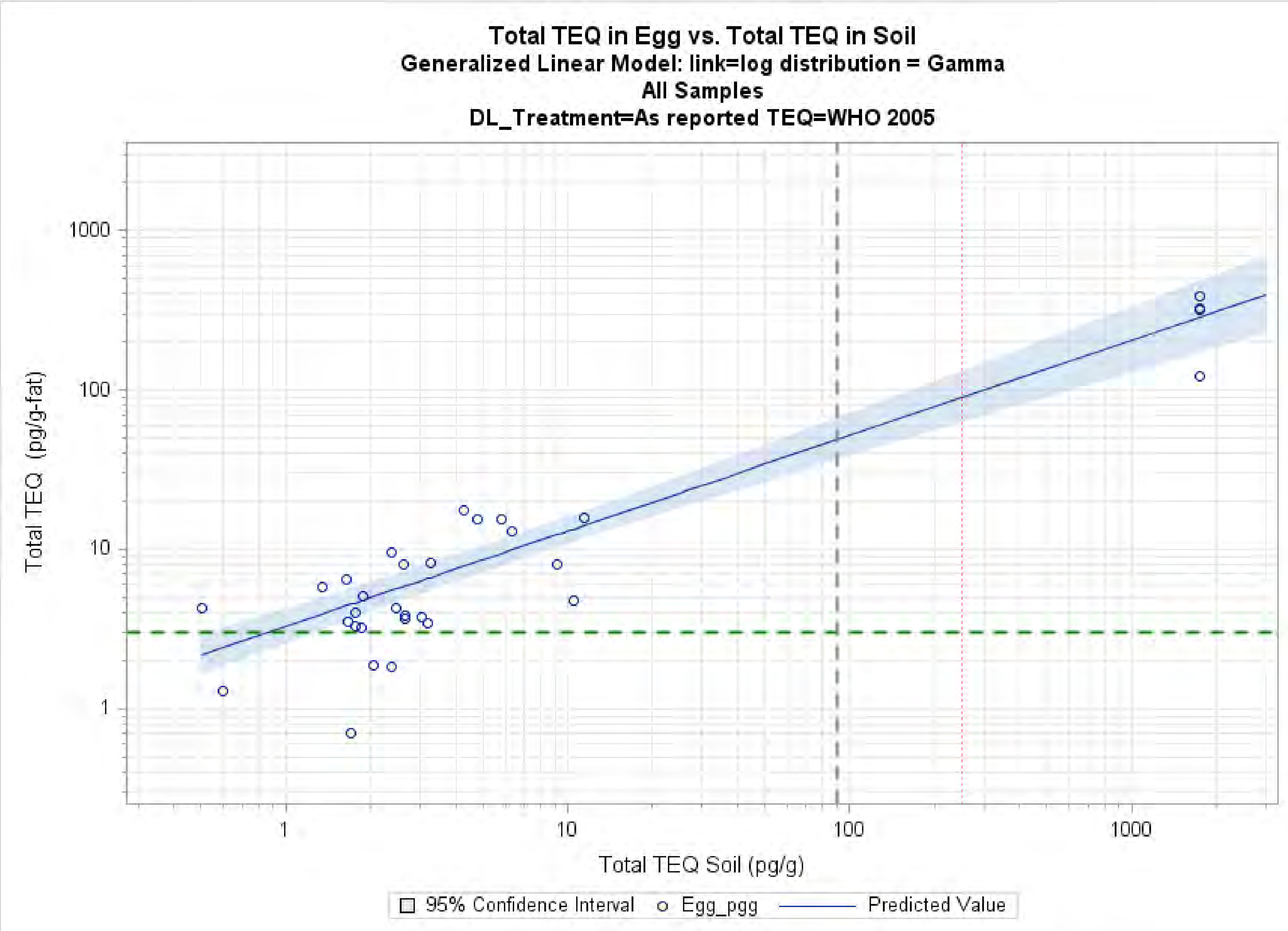
| Criteria For Assessing Goodness Of Fit | | | |
|---|---|---|---|
| Criterion | DF | Value | Value/DF |
| Deviance | 29 | 10.0878 | 0.3479 |
| Scaled Deviance | 29 | 32.5848 | 1.1236 |
| Pearson Chi-Square | 29 | 8.6305 | 0.2976 |
| Scaled Pearson X2 | 29 | 27.8774 | 0.9613 |
| Log Likelihood | | -92.8625 | |
| Full Log Likelihood | | -92.8625 | |
| AIC (smaller is better) | | 191.7251 | |
| AICC (smaller is better) | | 192.6140 | |
| BIC (smaller is better) | | 196.0270 | |

Algorithm converged.

| Analysis Of Maximum Likelihood Parameter Estimates | | | | | | | |
|---|---|---|---|---|---|---|---|
| Parameter | DF | Estimate | Standard Error | Wald 95% Confidence Limits | | Wald Chi-Square | Pr > ChiSq |
| Intercept | 1 | 1.1940 | 0.1275 | 0.9441 | 1.4438 | 87.71 | <.0001 |
| lSoil_pgg | 1 | 0.5961 | 0.0437 | 0.5105 | 0.6817 | 186.25 | <.0001 |
| Scale | 1 | 3.2301 | 0.7818 | 2.0100 | 5.1908 | | |

Note: The scale parameter was estimated by maximum likelihood.


Total TEQ in Egg vs. Total TEQ in Soil
Generalized Linear Model: link=log distribution = Gamma
All Samples
DL_Treatment=As reported TEQ=WHO 1998
Total TEQ (pg/g-fat)
1000
100
10
1
1
10
100
1000
Total TEQ Soil (pg/g)
95% Confidence Interval
Egg_pgg
Predicted Value


Total TEQ in Egg vs. Total TEQ in Soil
Generalized Linear Model: link=log distribution = Gamma
All Samples
DL_Treatment=As reported TEQ=WHO 2005
Total TEQ (pg/g-fat)
1000
100
10
1
Total TEQ Soil (pg/g)
1
10
100
1000
95% Confidence Interval
Egg_pgg
Predicted Value


Total TEQ in Egg vs. Total TEQ in Soil
Generalized Linear Model: link=log distribution = Gamma
All Samples
DL_Treatment=nd=0 TEQ=WHO 2005
Total TEQ (pg/g-fat)
1000
100
10
1
1
10
100
1000
Total TEQ Soil (pg/g)
95% Confidence Interval
Egg_pgg
Predicted Value