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Screening Level Assessment of Risks Due to Dioxin Emissions from Burning Oil from the BP Deepwater Horizon Gulf of Mexico Spill

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Between April 28 and July 19 of 2010, the U.S. Coast Guard conducted in situ oil burns as one approach used for the management of oil spilled after the explosion and subsequent sinking of the BP Deepwater Horizon platform in the Gulf of Mexico. The purpose of this paper is to describe a screening level assessment of the exposures and risks posed by the dioxin emissions from these fires. Using upper estimates for the oil burn emission factor, modeled air and fish concentrations, and conservative exposure assumptions, the potential cancer risk was estimated for three scenarios: inhalation exposure to workers, inhalation exposure to residents on the mainland, and fish ingestion exposures to residents. U.S. EPA's AERMOD model was used to estimate air concentrations in the immediate vicinity of the oil burns and NOAA's HYSPLIT model was used to estimate more distant air concentrations and deposition rates. The lifetime incremental cancer risks were estimated as 6×10^{-8} for inhalation by workers, 6×10^{-12} for inhalation by onshore residents, and 6×10^{-8} for fish consumption by residents. For all scenarios, the risk estimates represent upper bounds and actual risks would be expected to be less.

Introduction

The explosion and subsequent sinking of the British Petroleum (BP) Deepwater Horizon platform in the Gulf of Mexico occurred on April 20, 2010. Since that time until July 15 when the oil flow was suspended, an estimated 4.9 million barrels of crude oil (uncertainty range of ±10%) leaked into the Gulf of Mexico (*1*). One approach used to reduce the spread of oil is the deliberate burning of crude oil on the sea surface. This practice is termed, "in situ burning". BP and the U.S. Coast Guard conducted controlled in situ burns of oil approximately 50−80 km offshore from April 28 to July 19, 2010. A total of 410 controlled burns were conducted resulting in the combustion of an estimated 222 000−313 000 barrels of oil (Supporting Information (SI)). Lubchenco et al. (*1*) estimated that 5% of the leaked oil was burned corresponding to a range of 220 000−270 000 barrels, estimated by applying the ±10% uncertainty range.

The fires have the potential to form polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) that would subsequently be released to the environment and potentially result in increased human exposure. PCDD/Fs are formed from the incomplete combustion of organic matter in the presence of chlorine. This paper focuses on the 17 PCDD/Fs which have established toxicity equivalents (TEQs, these 17 compounds are collectively referred to as dioxins hereafter). All TEQ quantities presented in this paper are based on the toxic equivalency factors developed in 2005 (*2*). Thirteen polychlorinated biphenyls, PCBs, are also considered dioxin-like (*2*) and often included in TEQ reporting. However, these dioxin-like PCBs are not addressed in the present study as their TEQ emissions are low compared to the PCDD/Fs for other combustion processes (*3*).

The purpose of this paper is to present the results of a screening level risk assessment to estimate potential cancer risks to human populations that may have resulted from exposure to dioxins created by the in situ oil burning in the Gulf of Mexico. This assessment is specific to releases from burning oil on the sea surface and does not address other types of oil burning or chemicals other than dioxin. The pathways considered include inhalation by workers, inhalation by residents living onshore, and ingestion of fish by residents. Exposure and risk via the terrestrial food chain will be less than those estimated for the marine food chain because the nearest farm is approximately 80 km from the burn area and the deposition rate would be lower than those used to estimated marine impacts.

Very little information was found on the generation of dioxins from "in situ" open burning of oil in water bodies. In a comprehensive review of in situ burn tests, Fingas (*4*) noted that limited measurements of PCDD/Fs in particulates downwind of such burning found only background levels, which led him to conclude that dioxins were not being produced by the burning of crude oil or diesel oil.

Materials and Methods

The approach used here is best described as a screening assessment that produces upper bound risk estimates. Upper estimates were selected for each of the exposure factors and exposure concentrations. When these are combined, they overestimate the exposure and risks that could reasonably be expected to occur in the impacted populations. In a screening level assessment, further evaluations are warranted if the estimates suggest that risks could be of concern.

The evaluation of each exposure pathway requires estimates of dioxin emissions. Aurell and Gullett (*5*) measured dioxin emissions during in situ burning in the Gulf of Mexico over the time period of July 13−16, 2010. They derived an emission factor of 1.7 ng TEQ/kg of oil burned assuming that congeners below detection limits equal zero. If congeners below detection limits were set to their full detection limit, the emission factor was estimated to be 3.0 ng TEQ/kg. The amount of oil burned during the entire period of burning was approximately 222 000−313 000 barrels (SI). This is equivalent to 31.8−44.8 million kg using a density of 0.9 kg/L, 42 gallons/barrel and 3.79 L/gallon. The lower estimate of

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total dioxin emissions was estimated by multiplying the lower estimates of the emission factor (1.7 ng TEQ/kg oil burned) and the amount of oil burned (31.8 million kg) to get 0.0541 g TEQ. The upper estimate of total dioxin emissions was estimated by multiplying the upper estimates of the emission factor (3.0 ng TEQ/kg oil burned) and the amount of oil burned (44.8 million kg) to get 0.134 g TEQ.

Two atmospheric dispersion/deposition models were used in the assessment. U.S. EPA's AERMOD model was used to estimate air concentrations in the immediate vicinity of the oil burns and NOAA's HYSPLIT model was used to estimate surface level air concentrations at the shoreline and deposition rates at various locations.

AERMOD Model Description. AERMOD is a steady-state plume model (*6*) that simulates dispersion of air pollutants based upon planetary boundary layer turbulence structure and scaling concepts. Because the model assumes steady state atmospheric conditions during a simulation period of typically one hour, its application is generally limited to distances of less than 50 km from the source of the pollutant. Additionally, the pollutants are assumed chemically inert over the short distances to the receptor locations. AERMOD model inputs include characterization of the source and the immediate atmospheric boundary layer, including wind speed, wind direction, air temperature, and height of the boundary layer and surface characteristics. AERMOD is currently EPA's recommended model for near-field dispersion applications in most regulatory assessments (*7*).

Since oil burns are a unique source type involving buoyant plumes, we supplemented the AERMOD dispersion calculations with the plume rise computations found in the open burning open detonation model or OBODM (*8*). The inputs to the plume rise calculations within OBODM include a characterization of the source (in this application that would include radius of the burn area, oil burn rate, density of oil, and heat content of oil) and near surface wind speeds.

HYSPLIT Model Description. To estimate the regional concentration and deposition impacts of dioxin emitted from the oil burns, simulations were carried out with a special research version of the NOAA Air Resources Laboratory's HYSPLIT atmospheric fate and transport model—configured to simulate semivolatile pollutants such as dioxin—called HYSPLIT-SV. The HYSPLIT modeling system (*9*) is used to simulate the atmospheric fate and transport of emitted compounds in numerous pollutant analysis and emergency response applications (*10*). It is primarily a Lagrangian model that considers the 3-dimensional atmospheric behavior of puffs or discrete point "particles" of pollutants; however, the latest version of the HYSPLIT model (v4.9), has several enhancements including an integrated Eulerian simulation option. For this screening analysis, HYSPLIT-SV was run in 3-dimensional puff mode, in which puffs of pollutants grow vertically and horizontally as a function of atmospheric dispersion characteristics. HYSPLIT utilizes gridded meteorological data as inputs (e.g., 3-dimensional values of wind direction, wind speed, temperature, relative humidity, etc.) and estimates the transport, mixing, chemical transformations, and deposition (wet and dry) of emitted pollutants. The base HYSPLIT model has been modified to provide a specialized treatment of the atmospheric fate and transport of PCDD/F (*11*), including congener-specific vapor/particle partitioning, reaction with hydroxyl radical, photolysis, particle size distributions, and deposition parameters.

Dates, times, and amounts of oil burned for each of the 410 surface burn events (see SI) were used as input to the model with dioxin emissions calculated using the upper estimates of the amount burned and congener-specific emission factors. The simulation period started on April 28, 2010, on the day that the first reported burn event took place, and the model was run continuously through July 22, a few days after the last reported burn event that occurred on July 19. The modeling period was chosen to be a few days longer than the burning period to ensure that any emitted dioxin would have time to travel to shoreline locations should meteorological conditions result in such transport. Archived hourly meteorological data fields from NOAA National Center for Environmental Prediction (NCEP) NAM weather model (*12, 13*) were utilized in the simulation. These data have a horizontal resolution of approximately 12 km and contain surface parameters as well as data at 39 vertical levels above the surface with 18 of those levels within the first ~1500 m. The overall modeling domain was 10 × 10 degrees, centered at the DWH site. The results of the HYSPLIT simulations were tabulated on a grid extending 2.5 degrees in each direction from the site, with a resolution of 0.1 deg (~10 km), and additional time-series and other information were tabulated at 14 selected sites in the region, for illustrative purposes. The simulation-results grid and these illustrative sites are shown in Figure 1.

A relatively large maximum limit of 100 000 puffs was utilized in the simulation to minimize the influence of inhibition of puff splitting due to numerical constraints. Buoyancy-driven plume rise was estimated in the model as the final-rise height using an estimate of the heat release rate (expressed in Watts), wind speed, and vertical stability, for each individual burn event following the approach of Briggs (*14*). Sensitivity analyses were carried out to investigate the influence of plume rise on the simulation - by comparison to simulations assuming a fixed plume rise (e.g., 200 m), and it was found that the inclusion of specific burn-by-burn plume rise estimates had a significant influence on the concentration and deposition results (see SI).

Simulations were performed for each of the seventeen 2,3,7,8-substituted PCDD/F congeners, using physical-chemical properties for each, as described in Cohen et al. (*11*). To summarize the results, the individual congener simulations were added together using the congener-specific emissions factor and congener-specific toxic-equivalence factor, in the usual manner, to create results expressed as TEQ.

Exposure Calculations. The general equation used to assess inhalation risks to workers and the general population was

$$\mathrm{CR} = \mathrm{LADD} \times \mathrm{SF} \tag{1}$$

$$\mathrm{LADD} = (C \times \mathrm{IR} \times \mathrm{HR} \times \mathrm{DY} \times \mathrm{ED})/(\mathrm{BW} \times \mathrm{LT}) \tag{2}$$

Where CR is the cancer risk (unitless); LADD is the lifetime average daily dose (pg/kg-day); SF is the cancer slope factor (1/[pg/kg-day]); C is the air concentration (pg TEQ/m^3); HR is hours per day of exposure (hours working or hours exposed by the general onshore population, hr/day); DY is days per year of exposure (days working or total days exposed for general population, day/yr); ED is exposure duration (yr); BW is body weight (kg); LT is lifetime (days).

For workers, assumptions include: an ED of 0.25 yr (burning occurred over 3 months), an IR of 2.2 m^3/h (based on 95th percentile rates for adults aged 21−60 years and assuming activity levels were 40% light, 40% moderate and 20% high from ref *15*), an HR of 10 h/day, a DY of 250 day/yr, a BW of 70 kg, and an LT of 25,550 day. For general residential populations, the same ED, BW, and LT were assumed, but the IR was 0.9 m^3/h or 21.3 m^3/day (95th percentile for adults aged 21−60 years from, ref *15*), the HR was 24 h/day, and the DY was 350 day/yr. The slope factor for TEQs was set to the EPA value for 2,3,7,8-TCDD (1.58×10^{-4} per pg/kg-day) (*16*). The air concentrations were based on measured and modeled values as described in the Results section.

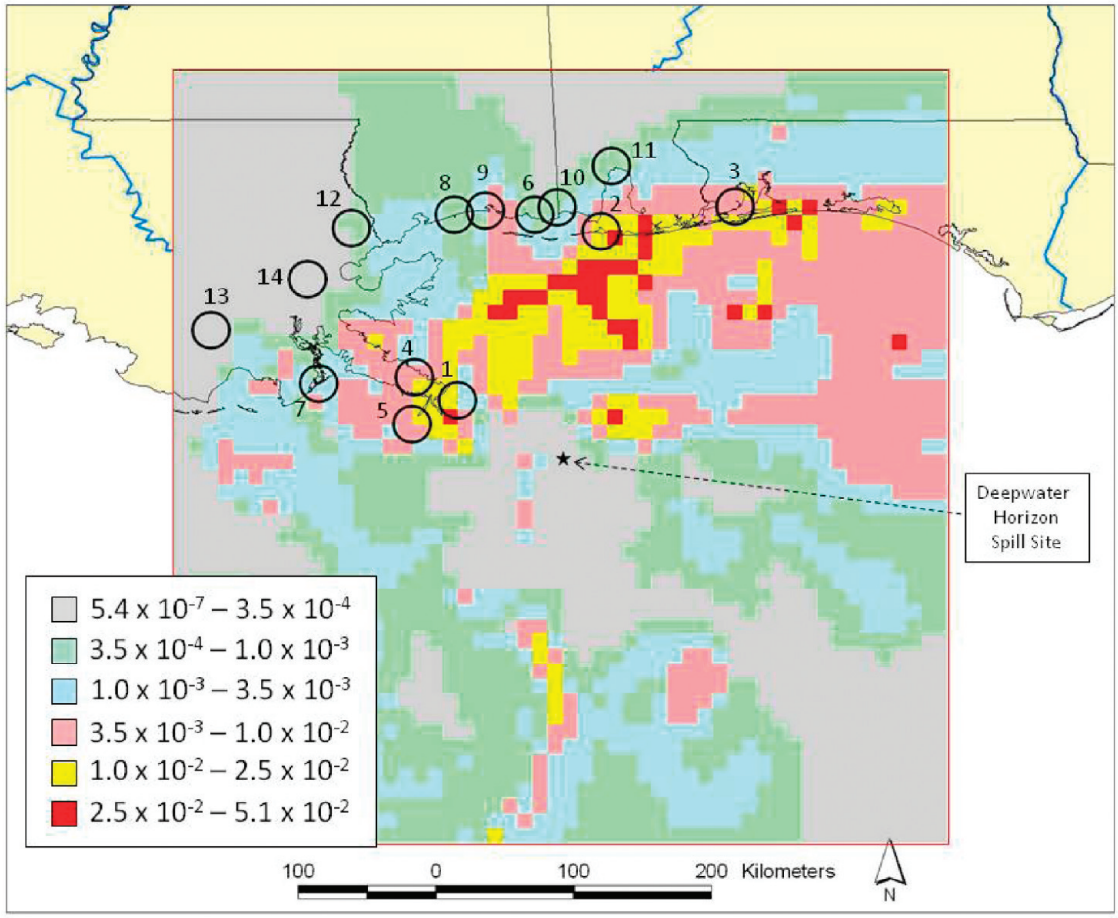

FIGURE 1. Average ground-level concentrations (fg TEQ/m3) for each grid square over the entire modeling period April 28−July 22, 2010. Illustrative locations shown, numbered in descending order from highest to lowest overall average concentration (fg TEQ/m3): 1, southeast Plaquemines (0.019); 2, Dauphin Island (0.016); 3, Pensacola (0.012); 4, Venice (0.0072); 5, Stake Island (0.0069); 6, Pascagoula (0.0011); 7, Grand Isle (0.0010); 8, Gulfport (0.00095); 9, Biloxi (0.00066); 10, Grand Bay National Estuarine Research Reserve (0.00065); 11, Mobile (0.00052); 12, Slidell (0.00025); 13, Houma (0.00018); 14, New Orleans (0.00008).

For assessing fish ingestion lifetime cancer risk, the same general equation, eq 1, was used, but LADD was instead calculated as

$$\mathrm{LADD} = (C \times I \times \mathrm{DY} \times \mathrm{ED})/(\mathrm{BW} \times \mathrm{LT}) \qquad (3)$$

Where C is the concentration in fish (pg TEQ/g fish) and I is the ingestion rate of fish (g/day).

The values used for LADD, DY, BW, and LT were the same as previously defined for residents. The ED was set to one year based on the assumption that consumption of impacted fish would occur for a period longer than the actual burn time. The length of time over which elevated dioxin levels in fish may persist depends on a number of factors including how quickly dioxin levels in water dissipate and how quickly dioxin levels in fish decline. None of these are known with certainty, but a period of one year was judged to be a conservative assumption. The concentration in fish was determined using the procedure described below. The marine fish and shellfish consumption rate was assumed to be the 95th percentile per capita estimate for general population adults. This was 81 g/day (Table 10-1 in ref *15*,).

Fish Tissue Concentration Calculations. The increase in dioxin concentration in caught fish due to deposition from the burn was estimated by applying a bioaccumulation factor (BAF) to an estimated water concentration. The BAF represents the process by which aquatic organisms accumulate chemicals via all routes of exposure (i.e., dermal contact with water, transport across the respiratory surface, and dietary uptake) (*17*), and accounts for potential biomagnification of dioxins in the food web. The first step was to estimate the total (sorbed phase plus dissolved phase) water concentration which was determined by dividing the deposition rate by a mixing depth. The deposition rate was set to 10 pg TEQ/m^2 based on the HYSPLIT modeling results discussed below. The mixing depth was assumed to be 10 m based on the 7−16 m range of measured pycnocline (surface mixed layer) depths reported by Lehrter et al. (*18*) from six sampling events on the Louisiana continental shelf. This yields a total water concentration of 0.001 pg TEQ/L. The second step was to estimate the dissolved phase water concentration. The PCDD/Fs will partition between the water and suspended particulates. Several factors affect this partitioning including the particulate concentration in the water and organic carbon content of the particulates. Also it will vary by congener, with the higher chlorinated congeners partitioning toward the particle phases more strongly than the lower chlorinated congeners. Muir et al. (*19*) studied this partitioning in lake waters and found that the portion of PCDD/Fs in the dissolved phase was <1% for OCDD and 10% for TCDD. For purposes of this screening analysis it is assumed that 10% of the total TEQ water concentration will be in the dissolved phase, yielding a dissolved concentration of 0.0001 pg TEQ/L.

This dissolved phase concentration was multiplied by a BAF to estimate fish concentration:

$$C_F = C_W \times \mathrm{BAF} \qquad (4)$$

TABLE 1. Near Surface Concentrations (pg TEQ/m^3) for Mixing Height =200 Meters, Emission Rate = 8.7 × 10^{-2} μg TEQ/sec, Three Wind Speeds at a Height of 2 Meters above the Surface

wind speed (m/s)↓ downwind distance (m) →	50	100	250	500	1000	1500	2500
1	0.017	0.017	0.018	0.019	0.021	0.023	0.027
5	0.484	0.056	0.005	0.004	0.005	0.006	0.008
10	4.584	0.818	0.049	0.006	0.003	0.004	0.006

Where C_W is the water concentration, pg TEQ/L and BAF is the bioaccumulation factor, L/kg.

Upper trophic level BAFs were estimated using the EPISUITE Model version 4.0 (*20*) for the four congeners with the highest TEQ concentrations measured in the oil fire plume by Aurell and Gullett (*5*). These ranged from 2.57 × 10^3 to 2.39 × 10^5 L/kg wet weight. For purposes of this screening assessment, the BAF at the upper end of the range was selected (2.39 × 10^5 L/kg wet weight). Multiplying this BAF and the TEQ dissolved water concentration yields a fish tissue concentration of 0.024 pg TEQ/g.

Bioaccumulation can also be modeled on the basis of the suspended sediment concentrations. As discussed in the SI, this approach predicted a very similar fish concentration of 0.018 pg TEQ/g.

A literature search was conducted to find data which could be used to support the modeled values. Very little data specific to the Gulf of Mexico could be found. The increase in fish concentration predicted here is about 7 times less than background levels in marine fish which are estimated to be 0.5 pg TEQ/g (*21*). Fish uptake of dioxin from atmospheric deposition has been studied in the Baltic Sea by Vikelsoe et al. (*22*). As discussed in the SI, an analysis was conducted using the Vikelsoe et al. data to predict fish levels resulting from the oil burns. The predicted concentration was about 3 times higher than the one obtained via the BAF method.

Results

AERMOD Dispersion Modeling Results. To estimate the potential inhalation exposure of workers in the vicinity of the in situ oil burns, AERMOD was used to simulate concentration fields near the water surface within a few kilometers of a burn. The duration of burn and total oil consumed for each of the 410 burns along with assumptions about burn area, and oil heat content were used to construct a "typical" oil-burn source for use in this screening analysis. Meteorological data (concurrent with the fires) from the nearest Gulf region buoy (*23*) and from the NOAA NCEP-NAM meteorological model were examined to develop a set of screening-level inputs.

Oil-Burn Source Characterization. The distribution of 410 individual oil burns (SI) showed burn rates varying significantly. Based on the relationship between the upper estimates for the amount of oil burned and emission factor provided by Aurell and Gullett (*5*), the emission rates of dioxin related to the distribution of all burns ranged from about 2.6 × 10^{-4} μg TEQ/sec to 2.7 μg TEQ/sec with a mean and median of 6.8 × 10^{-2} μg TEQ/sec and 2.6 × 10^{-2} μg TEQ/sec, respectively. For the screening analysis we chose a burn with an equivalent emission rate of 8.7 × 10^{-2} μg TEQ/sec (a large fire with slightly larger than average emissions). This selected emission rate is equivalent to a burn rate of approximately 500 gallons of oil per minute. Based on news videos and photographs, the horizontal radius of the modeled fire was set at 25 m. The heat content of the oil, 10 850 cal/g (5.8 × 10^6 BTU per barrel) was based on information for typical American crude (*24*).

Meteorology (Boundary Layer Characterization). Based on buoy data and NCEP-NAM output for the burn periods, the sea surface temperature was fairly constant (near 27 °C). The near surface air temperature was also in the same range yet typically 1−3 degrees cooler during the daylight hours. This yielded a very slight positive heat flux and thus a near-neutral or very weak convective boundary layer. The vertical potential temperature gradients suggest a well mixed layer in the 200−500 m height range with a moderate to weak stable layer above. Wind speeds during the burns ranged from less than 1 m/s up to approximately 6 m/s (10 m/s was the limit above which burns were not to be initiated). Since the goal of this analysis is to predict the maximum one hour concentration from a burn for any steady wind direction, the wind direction was fixed and concentrations were computed directly downwind of the burn.

For the AERMOD screening analysis, the range of meteorological conditions selected for input to the model was as follows. The 2 m wind speeds ranged from 1 to 10 m/s, the mixing height from 200 to 500 m, the friction velocity varied appropriately with wind speed from 0.095 to 0.95 m/s and the Monin-Obukhov length (stability parameter) varied from −80 to −8000 m. The surface roughness length was set at 0.03 m, the potential temperature gradient above the mixed layer at 0.01 °C/m and the sensible heat flux depending on wind speed in the range of 1−10 W/m^2.

Model Results. For the screening conditions outlined above, AERMOD-simulated, near-surface concentrations were lower for the mixing height equal to 500 m as compared to 200 m (with all other variables the same). This is not unexpected since the stable layer above the mixed layer tends to slow the plume rise and allow the plume to remain closer to the surface. With the lower mixed layer, this stable layer is reached sooner. Therefore we are only reporting near surface concentrations for the mixing height equal to 200 m (Table 1).

The SI presents discussions on how the modeled concentrations vary with assumptions regarding wind speed, mixing height and emission factor. Also the SI presents model runs using the conditions present during emission tests conducted by Aurell and Gullett (*5*). These runs predicted in-plume concentrations ranging from 0.17 to 0.54 pg TEQ/m^3 which bracket the average of 0.2 pg TEQ/m^3 measured by Aurell and Gullett (*5*).

HYSPLIT Modeling Results. Due to the variations in meteorological conditions (e.g., wind speed and direction) and intermittent nature of the burns, the deposition flux and atmospheric concentrations at any given location—even from the simulated continuous emissions—are highly variable or "episodic" (see SI). However, average concentrations and total deposition amounts over the entire burn period are utilized in this screening level risk assessment and so only these results will be presented here. Figure 1 shows the *average*, modeled ground-level (10 m) concentrations for each grid point over the entire modeling period April 28−July 22, 2010 and (in the caption) average concentrations for several illustrative locations in the region.. The highest, modeled grid-cell average 10 m concentration was 0.051 fg TEQ/m^3, and this occurred in an area approximately 125 km northeast from the spill site. The highest average modeled shoreline (or inland) concentrations was 0.034 fg TEQ/m^3, and this occurred about 50 km west of Pensacola, FL. As noted above, the maximum burn amounts and the maximum emissions

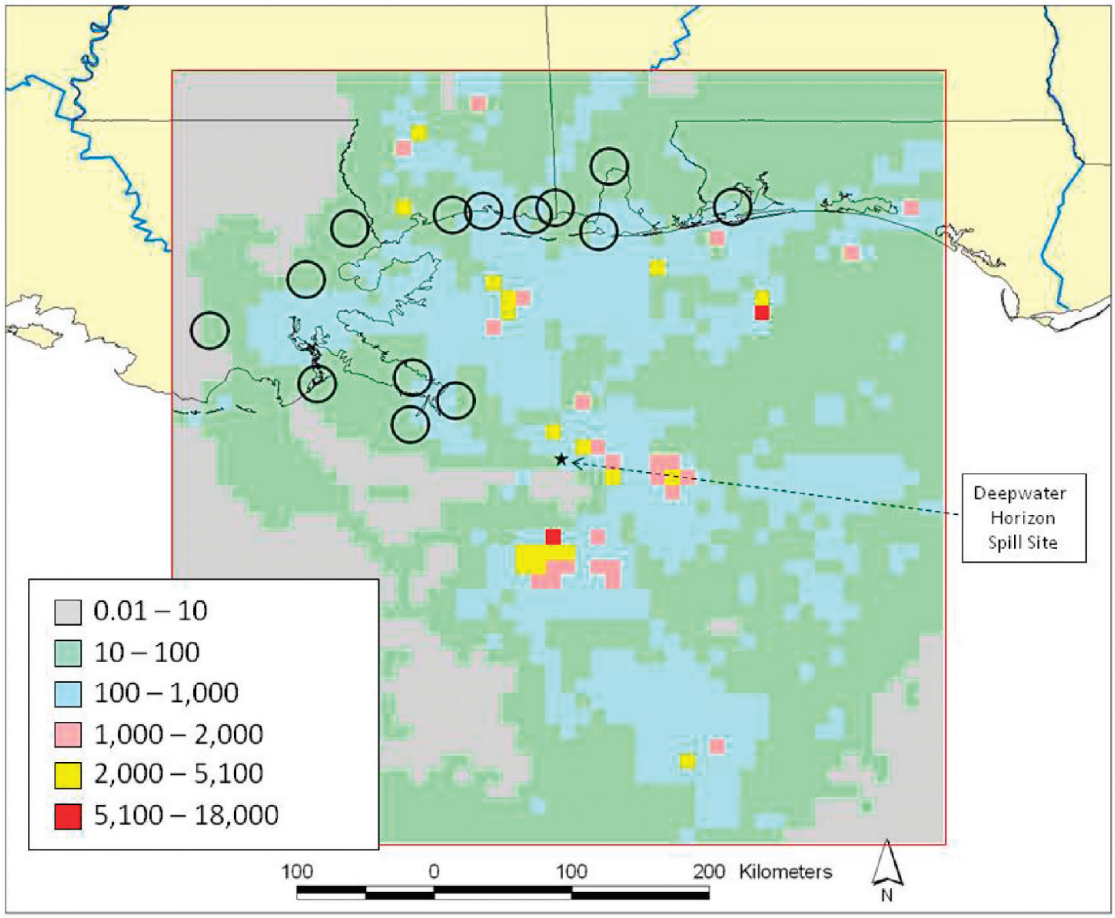

FIGURE 2. Total modeled atmospheric deposition (fg TEQ/m^2) for each grid square over the entire modeling period April 28–July 22, 2010.

factor (ND = DL) were used as inputs to the HYSPLIT modeling. Considering the range in estimated dioxin emissions factor for oil burning (using different assumptions for treating non-detected congeners), the range in maximum shoreline 10 m air concentration averaged over the burning period would be 0.028–0.034 fg TEQ/m^3.

To assess potential ecosystem-related exposure risk, an estimate of total atmospheric deposition to a given ecosystem is needed. The total modeled wet and dry deposition fluxes for the overall modeling period are shown in Figure 2 below. It can be seen that there are large spatial gradients in the estimated deposition, as would be expected. Thus, an estimate of the average deposition flux will depend greatly on the area being considered. The maximum estimated deposition flux of 17 200 fg TEQ/m^2 occurred at about 50 km south of the spill site. The continental shelf lies in the region *north* of the Deepwater Horizon spill site, and it is in these shelf regions that the deposition would be expected to have the greatest potential impact on food-web dioxin concentrations. The highest model-estimated PCDD/F fluxes to continental-shelf Gulf of Mexico ecosystem areas fall within the range of 1000–10 000 fg TEQ/m^2 (using the high-end of the emissions factor range and the high end of the amount-of-oil-burned range), and this range can be used to estimate screening-level ecological impacts.

A deposition mass balance analysis was performed for each of the seventeen 2,3,7,8-substituted congeners simulated with the HYSPLIT-SV model over the entire 10 × 10 degree modeling domain (see SI). For 2,3,7,8-TCDD, approximately 30% of the ~~emitted~~ mass was dry deposited in the vapor phase, about 2% was dry deposited in the particle phase, and the remaining 68% was wet deposited. Other congeners exhibited different behavior and the relative importance of different deposition pathways appears to be consistent with the expected vapor/particle partitioning behavior of the different congeners. The most important congeners contributing to deposition over the entire domain on a TEQ basis were 1,2,3,7,8-PeCDD and 2,3,4,7,8-PeCDF. Wet deposition was the most important deposition pathway for these two congeners. Results varied from congener to congener, but approximately 40% of the emitted amount of each congener was deposited within the 10 × 10 degree modeling domain.

Worker Inhalation Results. Upper bound worker inhalation exposures were calculated two ways. First, it was based on the plume measurements by Aurell and Gullett (*5*). They measured a concentration of 0.2 pg TEQ/m^3 at 200–300 m from the fire and about 75–200 m above sea level. Using this concentration and exposure assumptions outlined above, the LADD was 1.5×10^{-4} pg/kg-day and the lifetime incremental cancer risk was 2×10^{-8}. The second approach used the AERMOD modeled concentration from Table 1 for a location 50 m downwind of the burn site with a wind speed of 5 m/sec which was 0.48 pg TEQ/m^3 (the modeled values at 10 m/s (20 miles/hour) were considered unrealistically high for even an upper estimate of long-term conditions). Using this concentration and exposure assumptions outlined above, the LADD was 3.7×10^{-4} pg/kg-day and the lifetime incremental cancer risk was 6×10^{-8}.

Resident Inhalation Results. HYSPLIT modeling results suggest that the maximum long-term (82-day) average air concentration for shoreline exposure was 0.034 fg TEQ/m^3. This predicted incremental concentration is much less than the measured air concentrations in rural locations in the

United States which averaged 10 fg TEQ/m^3 (*25*). Using this concentration and exposure assumptions outlined above, the LADD was 3.6×10^{-8} pg/kg-day and the lifetime incremental cancer risk was 6×10^{-12}.

Fish Ingestion Results. As discussed above, the fish concentration at the point of maximum deposition was calculated to be 0.024 pg TEQ/g. Using this concentration and exposure assumptions outlined above, the LADD was 3.8×10^{-4} pg/kg-day and the lifetime incremental cancer risk was 6×10^{-8}. The discussion section below describes how these risk estimates may change for subpopulations with higher fish consumption rates.

Discussion

The overall approach and parameter assignments in this assessment were purposefully established to be conservative to meet the needs of a "screening level" assessment. For all scenarios, the risk estimates represent upper bounds and actual risks would be expected to be less.

Although the baseline screening risk assessment presented above is considered conservative for the adult general population, certain subpopulations may have higher fish ingestion risks. For example, 95th percentile fish ingestion rates are about two times higher for children than adults when expressed on a per body weight basis (*15*). This implies that their risks would also increase by a factor of 2. Also, a number of investigators have identified subsistence fish consumers in the Gulf Coast region as a population of concern with regard to impacts from the oil spill (*26*). Only one study was found that includes information that may be relevant to subsistence fishing in this region. Degner et al. (*27*) conducted a study of fish and shellfish ingestion in Florida. Westat (*28*) analyzed the raw data from this study to estimate fish consumption rates for various Florida populations, including Native American Indians assumed to be subsistence fishers (*15*). The 95th percentile consumer only intake rate was 5.7 g/kg-day. Assuming an average body weight of 70 kg, this would be equivalent to an intake rate of approximately 400 g/day. The 1997 Exposure Factors Handbook (*29*) recommended a fish consumption rate of 170 g/day as a 95th percentile for Native American subsistence populations. The 2009 draft update of the Handbook (*15*) presents a summary of Native American subsistence fish intakes from various studies, including the study from Florida. The 95th percentiles from these studies average about 300 g/day. This is very similar to the 95th percentile marine fish and shellfish ingestion estimate for consumers only of 270 g/day (*15*). Accordingly, a fish/shellfish consumption rate of 300 g/day fish appears to be a reasonable upper percentile estimate for Gulf Coast subsistence fish consumers. This rate is 3.7 times greater than the upper percentile fish consumption rate (81 g/day) assumed for the general population. The upper excess cancer risk estimates for the subsistence populations would be linearly proportional to the consumption rate (i.e., 3.7 times greater, or 2×10^{-7}).

Even with the increases due to subsistence fish consumers discussed above, none of the cancer risks exceeded 1×10^{-6}. EPA typically considers the risk range of 10^{-6} to 10^{-4} to be a range where consideration is given to additional actions, such as site cleanup or establishment of regulatory policy.

Another perspective can be gained by comparing these exposures and risks with those that are otherwise incurred by the general population. In 2003, EPA provided an estimate of general population exposures to all dioxin-like compounds (including dioxin-like PCBs) of 61 pg TEQ/day. That estimate was recently updated to 41 pg TEQ/day (*30*). The average daily intake from fish ingestion during the exposure period is 1.9 pg TEQ/day, about 5% of current background exposures. As a way to assess noncancer risks, this daily intake can be converted to a per kg basis (0.028 pg/kg-day) and shown to be much less than the ATSDR chronic minimum risk level (MRL) of 1 pg/kg-day (*31*).

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Supporting Information Available

Detailed data on amount of oil burned and additional information on modeling results. This material is available free of charge via the Internet at http://pubs.acs.org.

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