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Supplemental Material

Human Health Benefits from Fish Consumption vs. Risks from Inhalation Exposures Associated with Contaminated Sediment Remediation: Dredging of the Hudson River

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References

Table S1. Descriptions of primary model parameters for each considered health impact pathway.

Parameter (unit)	Description
$\overline{C(t)}_{fish,PCB}$ (kg_{PCB}/kg_{fish})	Time-dependent, species- and river-section weighted average, wet-weight, fish tissue Tri+ PCB concentration (the sum of trichloro through decachloro PCB homologs), adjusted for cooking losses
$\overline{IR}_p$ (kg_{fish}/person-y)	Annual average individual fish ingestion rate from the Site for subpopulation (p)
$DR_{ADD_{p,fish\_PCB},e}$ ($cases/kg_{PCB\_intake}$)	Dose-response factor for oral intake of PCBs for health effect (e)
$SF_{PCB,e}$ (DALY/case)	Severity factor for oral intake of PCBs, converting cases of effect (e) into DALYs
N_p (persons)	Annual number of fish consumers in subpopulation (p)
$C_{air,PCB,s}$ (kg/m^3)	Above-baseline average ambient air concentration of total PCBs for dredging season (s)
BR_p (m^3/d)	Average individual breathing rate for subpopulation (p)
$D_{p,s}$ (person-d)	Cumulative exposure duration for subpopulation (p) and for dredging season (s)
$DR_{ADD_{p,air\_PCB},e}$ ($cases/kg_{PCB\_intake}$)	Dose-response factor for inhalation of PCBs for health effect (e)
$M_{i,j}$ ($kg_{i\_emitted}$)	Total emitted mass of $PM_{2.5}$ precursor (i) for emission source category (j)
iF_i ($kg_{PM2.5\_intake}/kg_{i\_emitted}$)	$PM_{2.5}$ intake fraction for precursor (i)
$DR_{PM_{2.5}}$ ($deaths/kg_{PM2.5\_intake}$)	Dose-response factor for inhalation of $PM_{2.5}$ accounting for cardiopulmonary and lung-cancer mortality
$SF_{PM_{2.5}}$ (DALY/death)	Corresponding severity factor for inhalation of $PM_{2.5}$, converting cardiopulmonary and lung-cancer

	deaths into DALYs
$C_{PM_{2.5},p}$ (kg/m^3)	Above-background personal exposure concentration of diesel $PM_{2.5}$ during a work-shift for worker subpopulation (p)
PF_c (unitless)	Probability of a fatal occupational incident for one full-time equivalent worker in general labor category (c)
$N_{c,s}$ (persons)	Number of full-time equivalent workers in general labor category (c) for dredging season (s)
LE_c (y)	Average life expectancy for a worker in general labor category (c)

Table S2. Input parameterization for estimating the health burden of fatal occupational incidents and associated uncertainty.

General labor category	SOC category match[a]	PF_c	$N_{c,s}$ (persons)						LE_c (yr)
			2009	2011	2012	2013	2014	2015	
Sediment processing facility									
Management & Admin.	43-9061	5.E-06	5	11	21	21	22	25	45
Sediment Unloading	53-7030	3.E-04	13	12	24	12	12	14	44
Size Separation	47-2073, 53-7011	1.E-04	13	15	57	37	38	43	44
Thickening & Dewatering	51-8031	8.E-05	18	12	31	22	23	25	39
Water Treatment	51-8031	8.E-05	9	3	5	5	5	5	39
Staging Area	47-2073	1.E-04	4	1	5	2	2	3	43
Rail Car Loading	53-7121, 53-4031	1.E-04	11	10	14	14	15	16	46
Health and Safety & QC	29-9012	6.E-05	5	6	11	11	11	12	45
Maintenance & Operations	49-9043, 37-2011	3.E-05	3	8	18	18	18	20	43
Dredging corridor									
Dredge operator	53-7030	3.E-04	48	19	20	19	30	22	44
Dredge support crew	53-1031	7.E-05	99	45	44	43	71	47	43
Vessel captain	53-5020	1.E-04	24	27	34	33	52	46	44
Vessel deckhand	53-5021	3.E-04	48	55	68	66	104	91	44

Note: See **Table S1** for a description of primary input parameters.
[a]Matching was based on work descriptions for project general labor categories in the Remedial Action Work Plans (Parsons and Anchor QEA 2009, 2011, 2012, 2013, 2015) and work descriptions for the Standard Occupational Classification (SOC) system category occupations at www.bls.gov.

Table S3. Uncertainty analysis (Monte Carlo) input data for several time-independent parameters pertaining to oral PCB exposure from fish consumption, dose-response and severity.

Parameter	Unit	Input distribution	Input parameter
Individual fish ingestion rates (IR_p)[a]			
Twice per year	kg_{fish}/person-yr	Uniform	Min = 0.227, Max = 0.681
Twice per month	kg_{fish}/person-yr	Uniform	Min = 1.940, Max = 5.821
Twice per week	kg_{fish}/person-yr	Uniform	Min = 8.431, Max = 25.294
Number of fish consumers (N_p)[b]			
Upper Hudson, twice per year	persons/yr	Triangular	Min = 79, Mo = 316, Max = 1,271
Upper Hudson, twice per month	persons/yr	Triangular	Min = 23, Mo = 94, Max = 377
Upper Hudson, twice per week	persons/yr	Triangular	Min = 17, Mo = 70, Max = 282
Lower Hudson, twice per year	persons/yr	Triangular	Min = 1,538, Mo = 6,187, Max = 24,883
Lower Hudson, twice per month	persons/yr	Triangular	Min = 365, Mo = 1,469, Max = 5,908
Lower Hudson, twice per week	persons/yr	Triangular	Min = 136, Mo = 547, Max = 2,201
Body weight[c]	kg	Lognormal	GM = 70, GSD = 1.5
PCB non-cancer severity factor ($SF_{PCB,e}$)[d]	DALY/case	Lognormal	GM = 2.7, GSD = 3.7
PCB cancer severity factor (SF_{PCB})[e]	DALY/case	Lognormal	GM = 4.3, GSD = 1.01
PCB non-cancer dose-response ($DR_{ADD_{p,fish\_PCB,e}}$)[f]	cases/kg_{PCB_intake}	See Figure S2	See Figure S2
PCB cancer slope factor[g]	$(mg/kg\text{-}d)^{-1}$	Lognormal	GM = 1.0, GSD = 1.4
Interspecies conversion factor[h]	unitless	Lognormal	GM = 1.0, GSD = 4.5
Cooking loss[i]	kg/kg	Uniform	Min = 0, Max = 0.4
Species weights[j]	unitless	Lognormal	GM = 1, GSD = 1.4

[a] Ordinal classification scheme chosen by the New York State Department of Health survey administrators for convenience. As such, uniform distributions were applied, bounded between one and three meal-per-week equivalents, to account for potentially greater inter-individual variability.
[b] Uncertainty distribution developed to account for an observed factor-of-four discrepancy between surveys (see footnote *a* in **Table S5**).
[c] Based on Ruffle et al. (2018).
[d] Based on Huijbregts et al. (2005) with considerably greater uncertainty than for cancer arising from use of an average severity factor, in DALY per case, across 49 diverse, non-communicable diseases.
[e] Based on the greatest 95[th] uncertainty interval for the corresponding DALY and incidence data as calculated by the Institute for Health Metrics and Evaluation (IHME 2017). This assumes that the relative fractions of incidence for the three cancer types in these exposed populations are similar to those for the greater United States population (age- and sex-adjusted). Assuming these fractions are unknown would result in a maximum GSD^2 of 1.3 for this parameter. This would have a negligible (1%) effect on the total uncertainty in cancer health risk, since this uncertainty is driven by uncertainty in the interspecies conversion factor.
[f] Total uncertainty is displayed on Figure S2. Separate uncertainty distribution was applied in allometric scaling by body weight, accounting for chemical-specific interspecies differences. Inter-individual variability was addressed by assuming a lognormal distribution for human variation, with an additional uncertainty distribution for the GSD of

human variation. No subchronic uncertainty factor was applied, since the duration of the study by Tryphonas et al. (1991) was 55 months.
[g]Accounts for experimental uncertainty (sample size), based on the ratio of upper bound and central estimate cancer slope factors (U.S. EPA 1996).
[h]Accounts for uncertainty in the extrapolation of rodent data to humans as calculated by Huijbregts et al. (2005).
[i]Uncertainty distribution developed to reflect the wide range in cooking loss estimates reported by TAMS Consultants and Gradient Corporation (2000).
[j]Reflects variability between species, based on the range of FISHRAND forecasts in Figure 2-6 of TAMS Consultants and Gradient Corporation (2000). Data were digitized using Plot Digitizer v.2.6.8 (Joe's Java Programs).

Table S4. Uncertainty analysis (Monte Carlo) input data for time-dependent, lognormally distributed fish-tissue PCB concentrations ($\overline{C(t)}_{fish,PCB}$, mg_{PCB}/kg_{fish}).

Exposure timeframe	Remedial scenario		
	NA	SC	SC&ED
Upper Hudson			
2004-2009	GM = 1.836, GSD = 1.10	GM = 1.623, GSD = 1.13	GM = 1.338, GSD = 1.07
2010-2015	GM = 1.193 GSD = 1.19	GM = 0.864, GSD = 1.29	GM = 0.378, GSD = 1.01
2016-2021	GM = 1.002 GSD = 1.23	GM = 0.579, GSD = 1.44	GM = 0.257, GSD = 1.01
2022-2027	GM = 0.824, GSD = 1.27	GM = 0.381, GSD = 1.64	GM = 0.184, GSD = 1.00
2028-2033	GM = 0.722, GSD = 1.30	GM = 0.263, GSD = 1.85	GM = 0.146, GSD = 1.00
2034-2039	GM = 0.605, GSD = 1.35	GM = 0.193, GSD = 2.05	GM = 0.131, GSD = 1.00
2040-2045	GM = 0.578, GSD = 1.34	GM = 0.158, GSD = 2.17	GM = 0.121, GSD = 1.00
2046-2051	GM = 0.571, GSD = 1.30	GM = 0.153, GSD = 2.11	GM = 0.105, GSD = 1.00
2052-2057	GM = 0.571, GSD = 1.29	GM = 0.132, GSD = 2.20	GM = 0.100, GSD = 1.00
2058-2062	GM = 0.531, GSD = 1.29	GM = 0.110, GSD = 2.33	GM = 0.091, GSD = 1.00
2063-2067	GM = 0.547, GSD = 1.27	GM = 0.104, GSD = 2.34	GM = 0.096, GSD = 1.00
Lower Hudson			
2004-2009	GM = 0.596, GSD = 1.10	GM = 0.549, GSD = 1.13	GM = 0.540, GSD = 1.07
2010-2015	GM = 0.511, GSD = 1.19	GM = 0.346, GSD = 1.29	GM = 0.265, GSD = 1.01
2016-2021	GM = 0.310, GSD = 1.23	GM = 0.182, GSD = 1.44	GM = 0.128, GSD = 1.01
2022-2027	GM = 0.260, GSD = 1.27	GM = 0.131, GSD = 1.64	GM = 0.091, GSD = 1.00
2028-2033	GM = 0.248, GSD = 1.30	GM = 0.103, GSD = 1.85	GM = 0.076, GSD = 1.00
2034-2039	GM = 0.273, GSD = 1.35	GM = 0.133, GSD = 2.05	GM = 0.113, GSD = 1.00
2040-2045	GM = 0.298, GSD = 1.34	GM = 0.107, GSD = 2.17	GM = 0.093, GSD = 1.00

Note: See **Figure S1** for the underlying data and sources. For NA and SC scenarios, assumed-lognormal uncertainty distributions are based on the ratios of Estimated Upper Bound and central estimate forecasts averaged across six-year periods. Uncertainty distributions for SC&ED were calculated similarly using the "REM (6-yr 2.5% resuspension)" as the equivalent Estimated Upper Bound. In the Monte Carlo simulation, the same seed was used for the random number generator for each timeframe and scenario.

Table S5. Uncorrected[a] estimates of individual Hudson River fish and crab consumption.

Parameter	Value		
	Twice/yr	Twice/mo	Twice/wk
Individual ingestion rate (meal/person-yr)	2	17	74
Upper Hudson anglers & family			
Number of sampled fish consumers, n	27	8	6
Number of fish consumers, N	1,300	400	300
Population ingestion rate (meal/yr)	2,500	6,400	21,000
Proportion of total consumption	0.08	0.21	0.70
Lower Hudson anglers & family			
Number of sampled fish consumers, n	576	137	51
Number of fish consumers, N	17,200	4,700	1,600
Number of crab consumers, N	7,700	1,200	600
Population ingestion rate (meal/yr)	49,800	101,000	163,500
Proportion of total meals/yr	0.16	0.32	0.52

Note: Data sources are summarized in **Table S7**.
[a]Estimates of the number of fish and crab consumers were eventually corrected such that corresponding estimates of total population-level consumption (kg_{fish}/yr) matched those calculated using data from two more comprehensive, site-specific creel surveys (Normandeau Associates 2003, 2007). **Table S6** summarizes these population-level estimates. **Table S3** summarizes the corrected estimates of the number of consumers (N_p).

Table S6. Population-level fish and crab consumption (kg/yr) from the Lower Hudson by survey, season, and species.

	Spring[a]	Summer-Fall[b]	Winter[c]	All seasons	Grand Total
2001-2002 Survey (Day)					
American eel	98	100			198
American shad	271				271
Atlantic menhaden				7	7
Atlantic tomcod				2	2
Blue crab		816			816
Bluefish		76			76
Bullhead catfishes				4	4
Channel catfish				17	17
Common carp	4,015	21			4,036
Largemouth bass		2			2
Pumpkinseed			1		1
Rock bass				0.1	0.1
Smallmouth bass		0.5			0.5
Striped bass	13,310	465			13,774
Walleye			4	146	150
White catfish	125	230			355
White catfish/brown bullhead			10		10
White perch	97	208	0.3		305
White sucker			7		7
Yellow perch	25		27		52
Yellow/Brown bullhead				30	30
2001-2002 Survey (Night)					
American eel	16				16
Common carp	34				34
2005 Survey (Day)					
American eel	56				56
American shad	87				87
Atlantic tomcod	6				6
Blue crab	15				15

Bluefish	41	41
Brown bullhead	8	8
Bullhead catfishes	50	50
Channel catfish	39	39
Common carp	1,851	1,851
Herrings	274	274
Striped bass	10,467	10,467
Sunfishes	46	46
White catfish	468	468
White perch	76	76
Yellow perch	17	17

Note: Data sources are summarized in **Table S8 a)** through **c)**.
[a]Spring = March 16th - June 15th
[b]Summer-Fall = June 16th - November 30th
[c]Winter = December 1st - March 15th

Table S7. Background data used to estimate population-level fish consumption from the Site.

Parameter estimated	Background data sources, main assumptions and limitations
a) Annual number of anglers fishing from the Site, Upper and Lower Hudson	• Sources: Questionnaire data from the *2007 New York Statewide Angler Survey* (Connelly and Brown 2009), specific to counties adjacent to the Site, provided by the survey administrator, supplemented by personal communication (N. Connelly). • Limitations: Although administrators corrected results for recall bias, adjusted response rates were <50%.
b) Proportions of anglers consuming fish from Site (twice/year, twice/month, and twice/week)	• Sources: Two surveys administered by the New York State Department of Health (DOH), specific to counties adjacent to the Site: 1.) *Hudson River Fish Survey (2012-2017)* and *Saratoga Hudson Fish Survey (2014-2017)* (U.S. EPA 2017). Data summarized in Table S5. • Limitations: Convenience samples, survey design focused on assessing the effectiveness of public outreach techniques, and small sample sizes for Upper Hudson. Notwithstanding, the percentage of respondents who reported having fished the Upper Hudson and ate their catch (19%) compares favorably with the 1991-1992 Creel Survey results (22%) (Barclay 1993).
c) Number of individuals who consume fish from the Site at each ingestion rate	• Sources: Combination of a) and b) above. • Assumptions: maximum 37 weeks consumption per year, based on a year-long Hudson River creel survey (Normandeau Associates 2003) suggesting that 99% of total 2001 consumption occurred between March 16th and November 30th (Table S6). Consumption of crabs excluded for Upper Hudson due to low sample size and since this appears to be minor compared to fish (NYSDOH 1999).
d) Serving size	• Source: 227 g/meal, consistent with prior human health risk assessment for the Site (TAMS Consultants and Gradient Corporation 2000).
e) Number of family members consuming	• Sources: Proportion of Hudson River anglers from b) who reported sharing fish/crabs with their families (U.S. EPA 2017). • Assumption: household size of three persons based on the *U.S. Census Bureau Current Population Survey* (2005-2017) (U.S. Census Bureau 2017).

Table S8. Background data used to correct estimates of population-level fish consumption from the Site.

Parameter	Background data sources, main assumptions and limitations
a) Species-specific numerical harvest and b) proportion of anglers intending to consume their catch	• Sources: Two comprehensive, site-specific creel surveys conducted by Normandeau Associates Inc. (2001-2002, and 2005). Results are summarized in Table S6.
c) Species-specific edible-yield fractions	• Sources: Data for primary species obtained from literature sources (Crapo et al. 1993; Food and Agricultural Organization of the United Nations Rome 1989; Luzzana et al. 2002; Türeli et al. 2000). • Assumption: Mean edible-yield fraction for these species is representative of species with no available data. These comprised <5% of total consumption by mass in Table S6.

Table S9. Background data used to estimate non-linear dose-response relationship for oral[a] intake of PCBs.

Parameter	Background data sources, main assumptions and limitations
Non-linear, non-cancer dose-response factor for oral intake of PCBs ($DR_{ADD_{p,fish\_PCB},e}$)	• Sources: Geometric mean (GM) Immunoglobulin M data from Table 2 of Tryphonas et al. (1991). This study reported changes in immunological parameters in rhesus monkeys that had been administered Aroclor 1254 orally over four years. • Assumptions: Data were (natural) log-transformed assuming ln(GM) is equal to the mean on the log-scale and that log-transformed standard deviations (ln-sd), fitted to reported p-values, are constant.

[a]The same dose-response factor was applied for inhalation exposures, due to a lack of dose-response data for this exposure pathway.

Table S10. Summary of input parameterization for estimating above-baseline ambient air PCB exposures and risks during dredging.

Parameter	Value					
	2009	2011	2012	2013	2014	2015
Dredge corridor						
Operation duration (d)	178	157	195	188	181	153
$C_{air,PCB,s}$ (ng/m^3)	49	18	27	22	10	11
Worker $D_{p,s}$ (person-h)	436,000	458,000	333,000	321,000	514,000	412,000
Community $D_{p,s}$ (person-d)	286,000	239,000	94,000	4,584,000	1,444,000	1,433,000
N workers (person)	360	330	400	360	470	450
N community (person)	1,610	1,520	480	24,380	7,980	9,360
UCB incidence, workers[a]	3.E-13	1.E-15	1.E-13	3.E-14	2.E-16	8.E-16
UCB incidence, community[a]	3.E-11	5.E-13	1.E-12	5.E-13	1.E-14	5.E-14
Sediment processing facility						
Operation duration (d)	178	161	230	230	237	265
$C_{air,PCB,s}$ (ng/m^3)	25	50	31	26	24	8
Worker $D_{p,s}$ (person-h)	163,000	154,000	370,000	284,000	293,000	327,000
N workers (person)	90	110	180	140	140	140
UCB incidence, workers[a]	2.E-15	1.E-13	2.E-15	1.E-15	5.E-16	4.E-19

Note: See **Table S1** for a description of primary input parameters. Values for ambient air concentrations of total PCBs ($C_{air,PCB,s}$) are based on arithmetic means calculated from the site-specific dataset. More details about the underlying data sources and analyses are provided in the main text ("Exposure assessment" under "Health burden of increased air emissions of PCBs).

[a]Upper confidence bound (90th percentile) on the non-cancer population incidence, representing the fraction of exposed population exhibiting an effect greater than or equal to a 50% reduction in Immunoglobulin M (Chiu et al. 2018).

Table S11. Summary of input parameterization for estimating emissions of primary $PM_{2.5}$ and NO_x from project diesel-powered, nonroad heavy equipment.

Parameter	Excavators Tier 4 ; Tier 3	Cranes Tier 4 ; Tier 3	Dump trucks Tier 4 ; Tier 3	Wheel loaders Tier 4 ; Tier 3	Skid steers Tier 4 ; Tier 3
Rated power (bhp)[a]	418	355	385	357	80
Load factor[b]	0.44	0.44	0.33	0.33	0.37
Effective power (bhp)[a]	185	157	128	119	30
Displacement (L)[a]	15	15	11	15	3
Effective operation					
Duration (h)[c]	81,200	32,600	37,500	37,500	32,400
$PM_{2.5}$ (g/bhp-h)[b]	0.006 ; 0.14	0.006 ; 0.14	0.001 ; 0.03	0.001 ; 0.03	0.002 ; 0.04
NO_x (g/bhp-h)[b]	0.43 ; 1.43	0.43 ; 1.43	0.49 ; 1.65	0.49 ; 1.65	0.46 ; 1.53
$PM_{2.5}$ emissions (kg)	86 ; 2,100	30 ; 700	5 ; 130	5 ; 120	2 ; 43
NO_x emissions (kg)	6,400 ; 21,000	2,200 ; 7,300	2,400 ; 7,900	2,200 ; 7,400	440 ; 1,500
Idling operation					
Duration (h)[c]	56,200	21,500	24,700	24,700	21,300
$PM_{2.5}$ (g/h-L)[a]	0.001 ; 0.17	0.001 ; 0.17	0.001 ; 0.11	0.001 ; 0.11	0.001 ; 0.08
NO_x (g/h-L)[a]	9.93 ; 15.95	9.93 ; 15.95	6.95 ; 10.78	6.95 ; 10.78	4.96 ; 7.69
$PM_{2.5}$ emissions (kg)	1 ; 140	0.2 ; 53	0.2 ; 30	0.4 ; 42	0.04 ; 5
NO_x emissions (kg)	8,200 ; 13,000	3,200 ; 5,100	1,900 ; 2,900	2,600 ; 4,000	320 ; 490

Note: Tiers 3 and 4 standards are detailed in U.S. EPA 1998 and U.S. EPA 2004, respectively.
[a]Equipment specifications are based on data provided by equipment manufacturers and distributors (Sennebogen 2017; Caterpillar 303.5C CR Mini Excavator; Caterpillar 320dl Hydraulic Excavator; Caterpillar 345C L Hydraulic Excavator; Caterpillar 385C L Hydraulic Excavator; Caterpillar 246 Skid Steer Loader; Komatsu WA500-6 Wheel Loader; Terex TA30 Articulated Dump Truck).
[b]Emission factor data are from Cao et al. (2016). Specific equipment models (*e.g.*, Caterpillar 385 excavator) were assigned to an equipment class (Excavators), and emissions were calculated based on class weighted-average parameters using operation durations of equipment models as weights.

[c]Estimates of hours of effective operation and idling are based on data in the Weekly Productivity Summaries (Louis Berger Group 2010; Parsons 2012, 2013, 2014, 2015, 2016).

Table S12. Summary of input parameterization for estimating emissions of primary $PM_{2.5}$ and NO_x from barge traffic.

Parameter	Value[a]	Data sources
To processing facility		
Transported load (tons)	1,010	(Louis Berger Group 2010; Parsons 2012, 2013, 2014, 2015, 2016)
Total distance (miles)	46,300	(Louis Berger Group et al. 2017)
$PM_{2.5}$ emission factor (g/ton-mile)	0.0056 ; 0.0012	(U.S. EPA 2016)
NO_x emission factor (g/ton-mile)	0.34 ; 0.47	(U.S. EPA 2016)
$PM_{2.5}$ emissions (kg)	260 ; 60	
NO_x emissions (kg)	16,000 ; 22,000	
From processing facility		
Weight of tug and barge (tons)	822	(Sterling Equipment, Inc. SEI-2003; Ironhead – Pushboat)
Allocation factor[b]	0.45	
Total distance (miles)	46,300	(Louis Berger Group et al. 2017)
$PM_{2.5}$ emissions (kg)	100 ; 20	
NO_x emissions (kg)	6,000 ; 8,000	

[a]Lower emission factor scenario ; higher emission factor scenario, representing the range of reported emission factors between 2013-2014 from the EPA SmartWay Carrier Performance database (U.S. EPA 2016).
[b]Multiplicative factor to account for unloaded barge returns, calculated as the ratio of equipment weights (unloaded / loaded).

Table S13. Route characteristics, intake fractions (iF), and estimated air emissions from rail transport of PCB waste to and from seven hazardous waste landfills across the United States.

Landfill (state)	One-way distance (miles)[a]	N trips	Mass of transported load (ton/trip)[b]	iF_i ($kg_{PM2.5\_intake}/kg_{i\_emitted}$)		Mean emissions per trip (kg)	
				Primary $PM_{2.5}$	NO_x	Primary $PM_{2.5}$	NO_x
Clean Harbors (UT)	2,330	10	8,477	7.2E-07	1.4E-07	300	10,800
Clean Harbors (OK)	1,573	174	9,732	6.1E-07	1.6E-07	230	8,300
CWM Chemical Services (NY)	334	2	25	7.2E-07	1.2E-07	0.2	7
Tunnel Hill Partners (OH)	649	56	9,710	5.8E-07	1.3E-07	100	3,400
U.S. Ecology (ID)	2,532	45	9,465	6.0E-07	1.3E-07	370	13,000
Wayne Disposal Inc. (MI)	653	44	6,580	7.3E-07	1.4E-07	70	2,400
WCS (TX)	2,124	16	8,034	7.1E-07	1.6E-07	260	9,400

Note: See **Table S1** for a description of primary input parameters. Project manifest data provided detailed records of each shipment, including the destination, number of railcars, and weights of project railcars and transported sediments (Louis Berger Group 2010; Parsons 2012, 2013, 2014, 2015, 2016).
[a]Assumes project trains used the shortest path to and from each landfill facility.
[b]Arithmetic mean across all trips

Table S14. Summary of project workers and cumulative exposure durations by general labor category.

General labor category	N workers			$D_{p,s}$ (person-h)		
	Min	Mean	Max	Min	Mean	Max
Sediment processing facility[a]						
Management & Administration	9	23	27	11,000	35,200	49,100
Sediment Unloading	10	13	20	23,200	28,600	47,300
Size Separation	14	29	48	25,600	67,500	113,600
Thickening and Dewatering	14	20	26	23,200	43,600	61,500
Water Treatment	4	5	10	6,600	10,800	18,300
Staging Area	1	3	4	1,700	5,600	9,500
Rail Car Loading	12	12	12	19,900	26,800	32,700
Health and Safety & QC	6	8	9	11,000	18,600	24,500
Maintenance & Site Operations	5	22	28	5,100	28,400	40,900
Dredging corridor[b]						
Dredge operator	20	29	52	38,700	62,100	95,200
Dredge support crew	44	65	108	85,100	134,100	197,700
Vessel captain	26	40	58	47,600	72,000	104,300
Vessel deckhand	52	81	116	95,200	144,000	208,500

Note: See **Table S1** for a description of primary input parameters. Presented statistics are based on variability across all dredging seasons (2009-2015).
[a]Number (N) of workers are based on projections in the Remedial Action Work Plans (Parsons and Anchor QEA 2009, 2011, 2012, 2013, 2015). Hours at work are based on facility operation dates reported in the Weekly Productivity Summaries (Louis Berger Group 2010; Parsons 2012, 2013, 2014, 2015, 2016).
[b]Number (N) of workers are based on an estimated project inventory of primary diesel-powered, nonroad heavy equipment provided by M. Cheplowitz (personal communication.

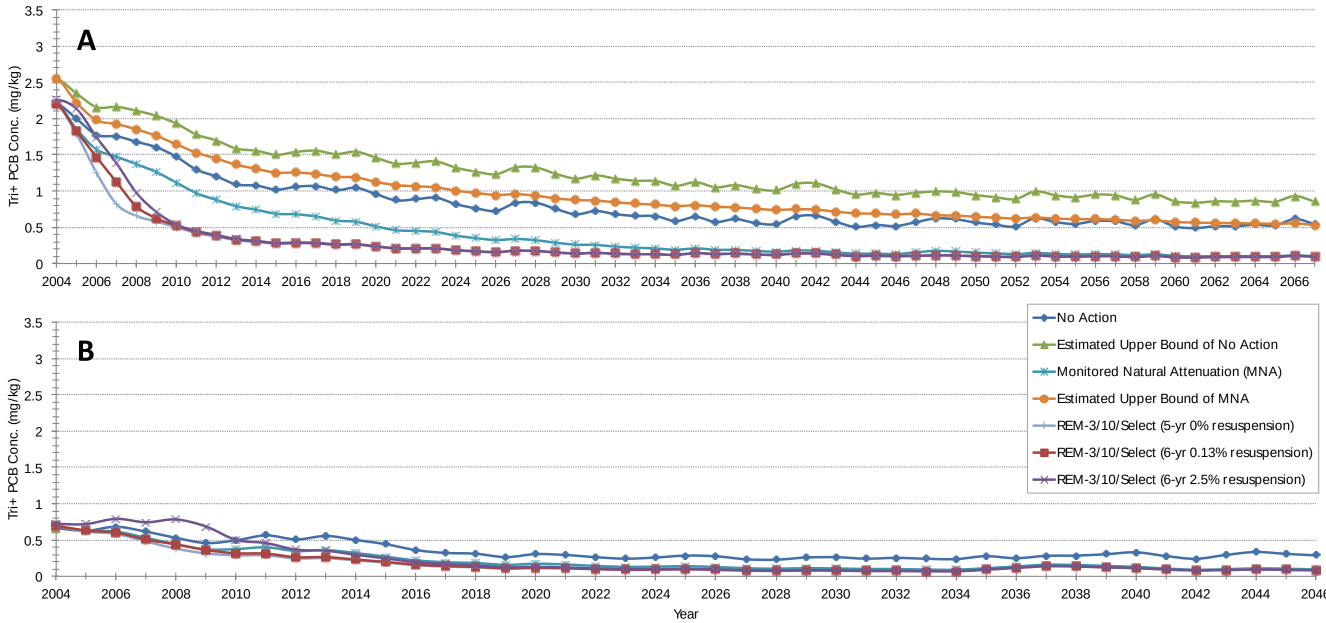

Figure S1. Species- and river-section weighted annual average, wet-weight fish tissue concentrations of Tri+ PCBs, projected by U.S. EPA's FISHRAND bioaccumulation model for different remedial alternatives. A) Upper Hudson and B) Lower Hudson forecasts. Model forecasts are from the EPA's Record of Decision (Table 11-2) (U.S. EPA 2002) and Responsiveness Summary (Tables 313699-1 and 363176-1) (TAMS Consultants 2002). In the present study, MNA = Source Control (SC), and REM-3/10/Select (6-yr 0.13% resuspension) = Source Control with Environmental Dredging (SC&ED).

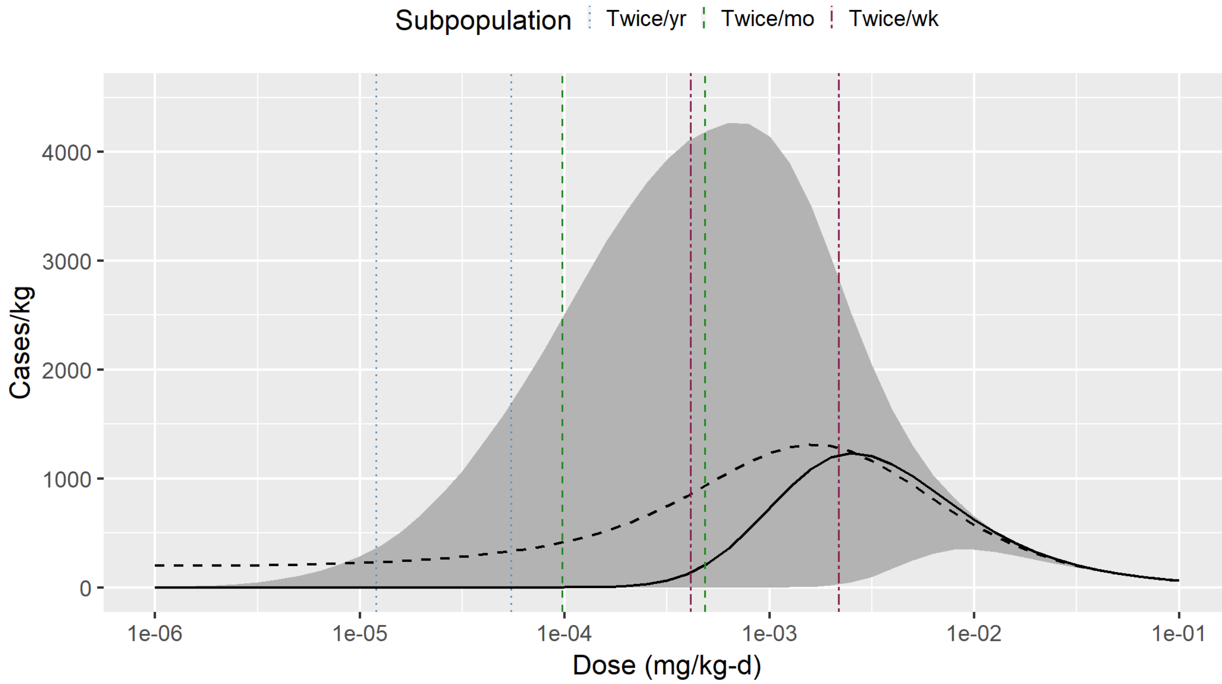

Figure S2. Slope of the PCB dose-response relationship corresponding to a 50% decrease in immunoglobulin M. Curved (black) solid line = median. Curved (black) dashed line = arithmetic mean. Surrounding (dark grey) area = 95% confidence interval. Vertical (colored) dashed lines = 95% confidence intervals of average daily doses (mg/kg-d) for three subpopulations: Upper Hudson anglers and their family members consuming fish at frequencies of 1) twice per year, 2) twice per month, and 3) twice per week during the 2004-2009 timeframe.

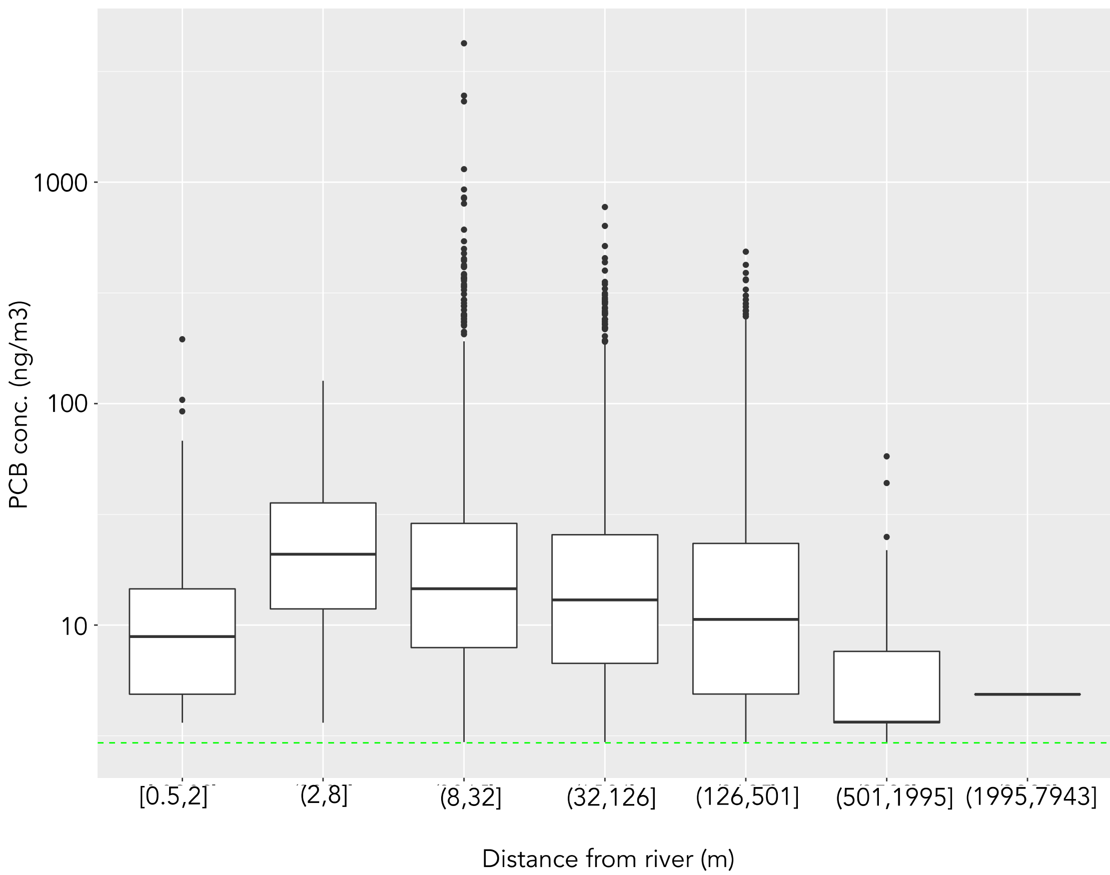

Figure S3. Ambient air total PCB concentrations measured along the dredging corridor during the remediation (2009-2015) by distance from the Site. Results were obtained from a site-specific ambient air PCB monitoring program (Anchor QEA and Environmental Standards 2009; Ecology and Environment 2004, 2017). Solid (black) horizontal lines represent the median, interquartile range (IQR), and 1.5×IQR. Dashed (green) horizontal line = mean background concentration.

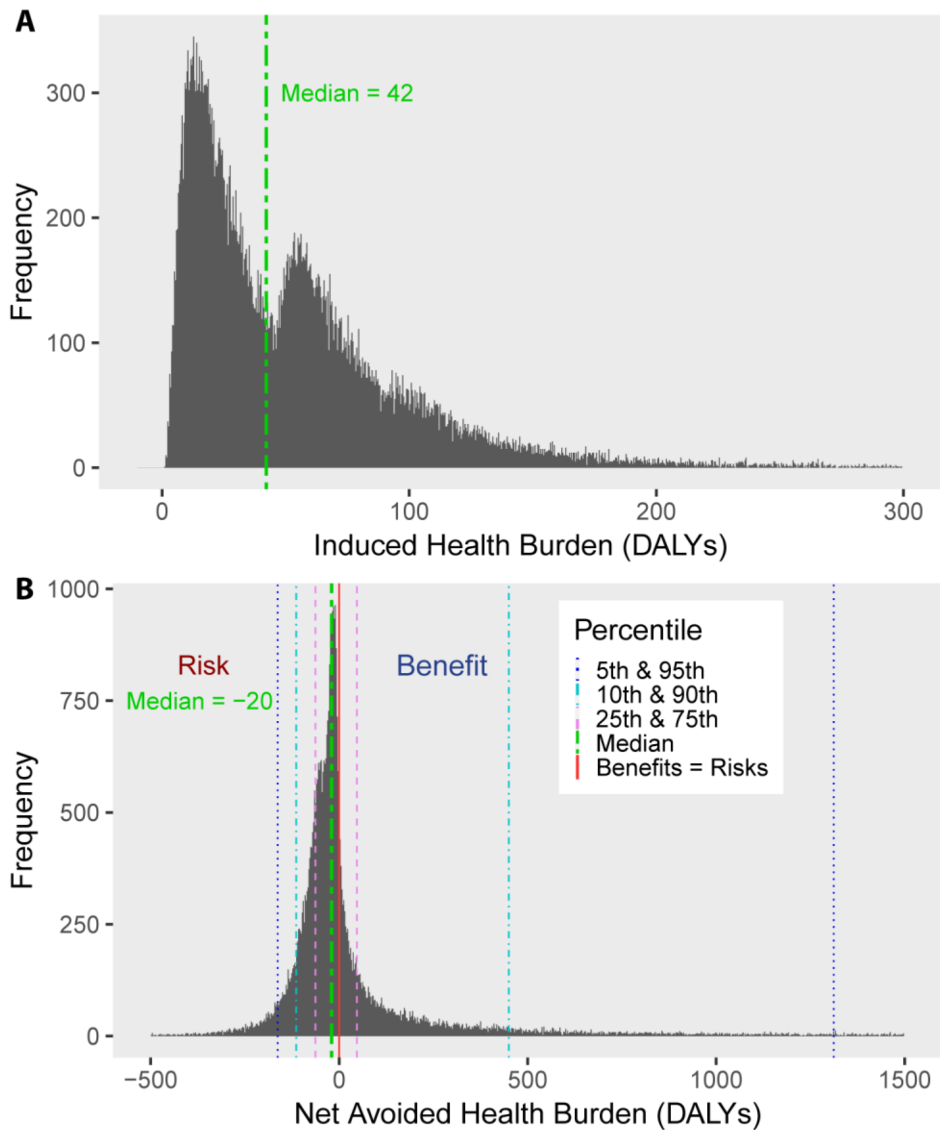

Figure S4. Stochastic health benefit-risk comparison for the Hudson River PCBs Superfund Site Environmental Dredging (ED) remediation: Sensitivity analysis including worker impacts. Results were generated via Monte Carlo simulations accounting for parameter variability and uncertainty. A) Induced Health Burden ($IB_{ED,sensitivity}$) = total health burden of ED from increased air emissions of PCBs, primary and secondary $PM_{2.5}$, and fatal occupational incidents; B) Net Avoided Health Burden ($\text{Net health benefit}_{ED}$) = $AB_{ED} - IB_{ED,sensitivity}$, with AB_{ED} being the Avoided Health Burden of ED as defined in the main text (Figure 4A). Dotted or dashed vertical lines correspond to the fifth, 10th, 25th, 50th, 75th, and 90th percentiles when read from left to right. The solid (red) vertical line through zero denotes a net of 0 avoided DALYs (i.e., benefits = risks). Values to the left of this line represent net risks while values to the right of this line represent net benefits.

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