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Hazard/Risk Assessment

ECOLOGICAL AND HUMAN HEALTH RISKS AT AN OUTDOOR FIRING RANGE

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Abstract—This is the first report in the refereed literature of a quantitative ecological and human health risk assessment at an outdoor recreational shooting range. Contaminants of concern (COC) included lead, other metals, and polycyclic aromatic hydrocarbons (PAH) associated with the clay targets on the shotgun range. Ecological receptors included raptors, deer, foxes, birds, and small mammals. The risk associated with potential incidental ingestion of lead shot by mammals was estimated for the first time. With the exception of lead, risks were minimal to all ecological receptors from all COC acting through all exposure pathways. Lead posed minimal risk to raptors, foxes, or deer. Lead in dietary items posed a small risk to individual birds. The only substantive risk was to individual small mammals and grit-ingesting birds from the incidental ingestion of lead shot within the shotfall zone at the trap and skeet range. Although effects associated with lead ingestion may occur at the level of individual organisms, ecological impacts are not expected at the population, community, or ecosystem level. This is because density-dependent compensation mechanisms would likely offset any site-related loss of a few individuals that might occur. Human receptors included shooters, range workers, and trespassers. Cancer risks to all receptors from all COC via all exposure pathways were less than 10^{-4}, generally considered an acceptable upper bound excess lifetime cancer risk to an individual. The only noncarcinogenic risk of HQ $>$ 1 was associated with inhalation of copper by those engaged in the voluntary activity of shooting. Two approaches were taken to modeling blood lead in children associated with intermittent exposure. Under the most likely exposure scenario, the mean blood lead level of trespassing children was approx. 2 μg/dL, with less than 1% of children exceeding the 10-μg/dL level of concern. Higher blood lead levels could be possible if children were to trespass in off-limit areas of the shooting range.

Keywords—Lead Firing range Blood lead Copper Mammals

BACKGROUND

Target shooting is a popular recreation, with approx. 12,800,000 annual participants in the United States, including nearly 5,000,000 women (http://www.nsga.org/guests/research/participation/participation.html; [1]). Outdoor rifle, pistol, and shotgun ranges can introduce substantial amounts of lead and other metals into the environment in the form of spent bullets and shot. Several authors [e.g., 2–4] have studied various aspects of the potential environmental implications of outdoor shooting ranges. However, this is the first quantitative ecological and human health risk assessment of outdoor shooting ranges in the peer-reviewed literature.

The Blue Mountain Sportsman's Center (Center) is a recreational outdoor shooting facility operated by Westchester County, New York, approx. 40 mi north of New York City (NY, USA). The facility includes pistol, large-bore, and trap and skeet ranges. The ranges are located sequentially down the valley of a small stream in wooded hilly terrain and are interspersed with wooded and vegetated wetland areas on and between the ranges. Both upland and wetland areas contain spent bullets and shot, and the trap and skeet range contains fragments of clay targets. Throughout this paper, ''on site'' refers to areas of the Center occupied by shooting ranges where spent bullets, shot, or other residues from shooting activities are present. ''Off site'' refers to the much larger remaining area of the Center unaffected by shooting.

The five metals and 16 polycyclic aromatic hydrocarbons identified as contaminants of concern in the ecological and human health risk assessment are identified in Table 1.

The metals derive primarily from bullets and shot. The PAHs derive from the clay targets used on the trap and skeet range [3]. There are sufficient toxicological data to establish that these COC, depending on environmental conditions and concentrations, may pose some potential risk to ecological receptors and humans [5–12]. Samples of soil, sediment, and surface water and air were collected and analyzed for COC [13]. Concentrations (95% upper confidence limit on the mean) of selected COC are presented in Table 2.

ECOLOGICAL RISK ASSESSMENT

Introduction

The Center contains diverse wetland and terrestrial habitats. Wetland habitats include freshwater marshes, bogs, and wooded areas with a small brook and a few interspersed pools. Terrestrial habitats include old-field growth and mixed coniferous and deciduous woodlands, with black and red oak, eastern hemlock, red maple, and black gum common. The primary source and release mechanisms for contaminants are the shooting of lead bullets and shot at the various ranges and the breaking of clay targets on the trap and skeet range. The stream and marsh sediments and surficial soil are secondary sources since they contain the spent bullets, shot, and target fragments. Although the particulate lead, other metals, and PAHs in soil and sediment may pose a potential risk to ecological receptors, various secondary release mechanisms may alter the distribution and bioavailability of contaminants. Metals and PAHs can dissolve in rainwater and dew and wash into surface water. Transformation processes could release metals, including oxides of lead, and/or PAH to soil and sediment. Contaminants may be taken up by vegetation or lower-trophic-level animals,

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Table 1. Five metals and 16 polycyclic aromatic hydrocarbons (PAHs) identified as contaminants of concern (COC) in the ecological and human health risk assessment

Metals	PAHs		
Lead	Acenaphthene	Benzo[*b*]fluoranthene	Fluoranthene
Arsenic	Acenapththylene	Benzo[*k*]fluoranthene	Fluorene
Antimony	Anthracene	Benzo[*g,h,i*]perylene	Indeno[*1,2,3-cd*]pyrene
Copper	Benzo[*a*]anthracene	Chrysene	Naphthalene
Zinc	Benzo[*a*]pyrene	Dibenzo[*a,h*]anthracene	Phenanthrene
			Pyrene

which may then be consumed by animals feeding at higher trophic levels. In the risk context, the biota feeding at lower trophic levels represent an environmental medium like water, sediment, and soil because they are consumed by predators and are a biological resource to be protected in their own right. Because of concern about the potential implications of direct ingestion of lead shot, it is treated as a distinct environmental medium for exposure assessment.

Once the contaminants are distributed through the environmental media, risk depends on available pathways for contaminants to reach receptors. In this ecological risk assessment, which focuses on terrestrial receptors of concern, ingestion is the only pathway from contaminated media to receptors that was considered quantitatively. Preliminary investigations showed that other pathways were either insignificant because of factors such as exceedingly low Henry's law constants (e.g., metals via inhalation) or essentially unquantifiable because of a lack of sufficient information for modeling purposes (e.g., dermal exposure). Estimation of the fate of contaminants associated with dust was not attempted because the uncertainties in such an estimation were considered substantial in relation to the likely magnitude of such exposure. However, since dust will settle over time and become incorporated into the surface media, this exposure was considered indirectly in evaluation of other media (e.g., estimates of soil ingestion). In such cases, lack of quantitative treatment adds some small, nonconservative degree of uncertainty to conclusions, but not of a magnitude considered sufficient to affect the utility of conclusions for risk management purposes.

Animals feeding at higher trophic levels may eat contaminated vegetation or animals that feed at lower trophic levels. Surface water containing contaminants is consumed by most receptors. Contaminated soil may be ingested by receptors, either incidentally as it clings to vegetative portions or roots of plants being ingested, via grooming activities, overtly by animals seeking minerals, or along with grit ingested for processing food (e.g., some birds). Lead shot may be ingested incidentally by herbivores nibbling vegetation to the ground surface, and some birds may ingest lead shot along with other grit for grinding food in their gizzard.

Table 2. Exposure point concentrations (95% upper confidence limit) of chemicals of concern in soil, sediment, and surface water at the Blue Mountain Sportsman's Center

Chemical	Soil, mg/kg	Sediment, mg/kg	Surface water, mg/L
Acenaphthene	0.268	0.25[a]	9.0×10^{-4} [a]
Acenaphthylene	0.0127	0.32[a]	1.15×10^{-3} [a]
Anthracene	0.10[a]	0.09[a]	5.0×10^{-4} [a]
Antimony	173.3	9329	7.04×10^{-3}
Arsenic	13.6	259	1.0×10^{-3}
Benzo[*a*]anthracene	0.349	0.02[a]	5.0×10^{-4} [a]
Benzo[*a*]pyrene	0.457	0.029[a]	5.0×10^{-4} [a]
Benzo[*b*]fluoranthene	0.378	0.04[a]	5.0×10^{-4} [a]
Benzo[*g,h,i*]perylene	0.11[a]	0.011[a]	5.0×10^{-4} [a]
Benzo[*k*]fluoranthene	0.342	0.013[a]	5.0×10^{-4} [a]
Chrysene	0.36	0.021[a]	5.0×10^{-4} [a]
Copper	90.3	164	1.4×10^{-1}
Dibenzo[*a,h*]anthracene	0.084[a]	0.0048[a]	5.0×10^{-4} [a]
Fluoranthene	0.467	0.029[a]	5.0×10^{-4} [a]
Fluorene	0.048[a]	0.029[a]	5.0×10^{-4} [a]
Indeno[*1,2,3-cd*]pyrene	0.162	0.017[a]	5.0×10^{-4} [a]
Lead	856.9	7051	49.1
Naphthalene	0.0949	0.25[a]	9.0×10^{-4} [a]
Phenanthrene	0.24[a]	0.09[a]	5.0×10^{-4} [a]
Pyrene	0.465	0.038[a]	5.0×10^{-4} [a]
Zinc	99.4[a]	118	2.33×10^{-2}

[a] When the 95% upper confidence limit is higher than the maximum detected value, the maximum detected value is used [37].

Receptors of concern

To characterize the site-specific ecological risk presented by contaminants at the Center, a comprehensive list was constructed of all the receptors potentially in the study area that could be reasonably evaluated for risk management purposes [14]. Species-specific habitats were assessed to determine whether particular species could occur in the study area, and a small list of representative receptors of concern (ROC) was identified. These receptors encompass a range of habitats and taxa and serve as representative species on which to focus quantitative assessment. Each species was identified as a surrogate for a particular feeding guild so that species not explicitly modeled are represented by other members within the same guild. In that manner, although only a few individual species were explicitly modeled, a very broad range of potential receptors was considered. The ROC and rationales for their selection, consistent with the ecological risk assessment guidance [14], are as follows.

*White-tailed deer (*Odocoileus virginianus*).* The white-tailed deer is common at the Center and is an important game animal. It is the only vegetarian ROC and thus represents the primary consumers or herbivorous feeding guilds in the food web. The species is also evaluated in the human health risk assessment because of the potential for illegal hunting and consumption of deer from the Center.

*Ruffed grouse (*Bonasa umbellus*).* The ruffed grouse is a popular game bird that has been observed at the Center. Its diet is largely vegetable matter, but it eats insects and other invertebrates and thus is classified as an omnivore. It feeds primarily on the ground and represents several guilds of ground-feeding birds that have the potential to ingest lead shot at the trap and skeet range.

*American robin (*Turdus migratorius*).* The American robin forages and probably nests at the Center. It is omnivorous and frequently feeds on the ground. It may be exposed to contaminants through the food web and through potential ingestion of lead shot or contaminated soils in addition to dietary exposures. The robin represents the invertebrate-consuming feeding guild that may be exposed to contaminants associated with abiotic solids.

*Eastern phoebe (*Sayornis phoebe*).* The eastern phoebe was observed at the Center during this study. The phoebe eats mainly flying insects and other invertebrates and takes little food from the ground. Because the phoebe feeds largely in flight and probably does not ingest grit, it represents the invertebrate-consuming feeding guild not exposed to abiotic solids-related contaminants, in contrast to the American robin.

*Red-tailed hawk (*Buteo jamaicensis*).* This raptor is one of the most widespread and common hawks and has been identified at the Center. It feeds on a variety of mammals and birds, but its predominant prey is rodents. Its position at the top of the ecological food web makes it an appropriate representative of many raptorial species and guild.

*Red fox (*Vulpes fulva*).* The red fox occurs commonly in the area and is a carnivore feeding at several levels in the food web. Its diet is diverse, including rabbits, other rodents, insects, and occasionally berries and fruit. Its feeding habits make it vulnerable to contaminants that may accumulate in terrestrial food webs. The fox is a representative of carnivorous and omnivorous mammal feeding guilds at the site.

Mice and rabbits (various species). Small omnivorous and herbivorous mammals such as mice and rabbits are important prey for carnivorous receptors, such as the red-tailed hawk and red fox. Because they represent both dietary items for higher trophic level consumers and because of their value as representatives of important feeding guilds at the site, these species were included as ROC.

Risk characterization

A contaminant toxicity reference value (TRV) is the highest exposure level for an ecological receptor that is likely to be without appreciable risk of deleterious effects. The TRVs for this risk assessment were developed on an oral or dietary intake dose basis from toxicological literature. When toxicity data were lacking for some receptors (e.g., red fox), a sensitive toxicological endpoint was identified for different taxa (e.g., dog) in the same or a related feeding guild and extrapolated to represent the receptor, and therefore the guild, of interest.

In developing TRVs, uncertainty factors (UFs) were set at their most plausible values reflecting the relationship between experimental response and the risk under consideration. A UF is applied to a toxicological endpoint (dose) to correct for identified sources of uncertainty. The UFs were based on values suggested by the literature and the toxicological databases for the contaminants of concern. Best professional judgment was used in application of UFs in deriving TRVs, considering many aspects of the technical soundness, ecological relevance, and biological applicability of the endpoint(s) being considered. Consistent UF values were generally used for a few common extrapolations. For instance, a factor of five was used to account for intertaxon variability, a value that appears realistic based on studies of UFs [15]. A UF of 10 was used to extrapolate from lowest observed adverse effect level to no observed adverse effect level endpoints and from subchronic to chronic endpoints. A UF of 100 was used to extrapolate from single oral doses and acute LD50s to chronic NOAELs [16]. These UFs appear to lead to reasonable estimation of risks based on values found in the literature [17].

The most scientifically sound data point (based on replication, documentation, experimental conditions and relevancy, peer review, and so on) found for each COC was selected for calculation of TRVs for each ROC. Whenever possible, the toxicity endpoint used as a TRV was a NOAEL for chronic or subchronic exposures. Since the true effect level is higher by an unknown amount than the NOAEL, the NOAEL may result in overestimation of risk and is thus protective. When more than one NOAEL was available for a particular animal, the lowest NOAEL for a serious effect (e.g., decreased reproductive success) was chosen.

Development of TRVs for terrestrial animals for the Center was based largely on toxicity of chemicals to laboratory animals, primarily rats and mice. Important sources of data for TRV derivation included the Agency for Toxic Substances and Disease Registry series of toxicological profiles and the Contaminant Hazard Reviews series published by the U.S. Fish and Wildlife Service, which provided toxicity data for birds and mammals not included in Agency for Toxic Substances and Disease Registry.

The TRVs for each COC were established for specific receptors when sufficient data existed and for receptor categories when this was not possible. The ROC or ROC categories for which TRVs were developed are small mammals (rabbits and mice), medium mammals (red fox), mammals (white-tailed deer), ground-feeding and passerine birds (robin, grouse, and eastern phoebe), and raptors (red-tailed hawk).

Exposure assessment

The temporal and spatial components of exposure must be integrated to adequately assess the risk presented by site contaminants. To accomplish this, exposure factors used in the diet–dose risk modeling for the Center ROC include home range, body weight and site-apportioned water ingestion rate, food ingestion rate, and feeding fractions. Because the Center does not appear to have features unique in their attractiveness within the home range of any ROC, the spatial and temporal components of exposure were apportioned as simple fractions of potential foraging ranges accounted for by the site.

In addition to exposure from environmental media and diet, lead shot may be ingested by some receptors, such as birds that take in grit or mammals that may incidentally ingest soil along with food. These varied pathways necessitated development of three separate exposure models for estimation of ecological risk: shot ingestion by birds, shot ingestion by mammals, and ingestion of environmental media and water by birds and mammals. The role of dust in exposure was not considered directly. However, since dust settles over time and adheres to or becomes incorporated in other media, dust was included in evaluation of these media in the third exposure model for estimation of ecological risk.

Shot ingestion by birds

One of the concerns at the Center was that birds that ingest grit for the gizzard could be vulnerable to lead shot ingestion. The effects of lead shot ingestion by birds vary with the type and amount of food, sex, age, and size of bird and may or may not include death [18]. This evaluation did not delve into the variables that determine the toxicological effects of ingested lead shot. Instead, it made the environmentally protective assumption that lead shot ingestion would be adverse and could include death. Therefore, the calculated risk depends not on the clearly established, albeit variable, toxicity of lead but rather on the probability that a bird requiring grit will ingest a lead shot.

The probability of shot ingestion by a bird was assumed to be a function of the rate of uptake and retention of grit in the gizzard, the daily and annual residence time onsite, the fraction of the available grit-sized particles that is lead shot, and the portion of the foraging range that contains lead shot. Because many birds (20 species) that use grit retain particles in the 2.8 to 0.5mm size class [18–24], only that size range was evaluated. The following equations were developed to calculate the probability (P_t, ranging from 0 to 1) that a bird will ingest at least one lead shot from the site in a lifetime. These equations do not address the secondary ingestion of shot in the prey of raptors. This possibility is discussed in the interpretation of the results for the red-tailed hawk and other raptors.

$$P = S \cdot P_s + (1 - S)P_o \quad (1)$$

$$N = Y(D_e/D_p) \quad (2)$$

$$P_t = 1 - (1 - P)^N \quad (3)$$

where

P = Probability that a single selected particle will be a lead shot

P_s = Fraction of grit-sized particles onsite that is lead shot

P_o = Fraction of grit-sized particles offsite that is lead shot

P_t = Probability that a bird will ingest at least one lead shot in a lifetime

S = Fraction of foraging time that a bird spends on site

N = Number of particles selected and retained in the gizzard in a lifetime

Y = Number of years a bird lives

D_e = Number of days per year that a bird forages in the area

D_p = Retention time for a shot in the gizzard (days)

The proportion of grit-sized particles that are shot particles in the soil within the shotfall zone at the trap and skeet range was determined as follows. Individual soil samples from the shotfall zone were weighed, composited, and dried at 105°C for 1.5 h. Each composite was passed through a 4.0-mm sieve to remove large particulates and was then passed through 2.8-, 2.36-, 2.0-, 1.4-, 1.0-, and 0.5-mm sieves. The fractions retained on each screen and in the bottom pan were weighed. Material less dense than lead was removed from each fraction by flushing with water. Material removed and material retained from each fraction was dried and weighed. Next, the volume of each fraction was determined by displacement of water. A maximum of 50 lead particles from each size fraction were counted and weighed. A maximum of 50 nonlead grit particles from each size fraction were counted and weighed.

The fraction of grit-sized particles as an average at the trap and skeet range was determined by calculating the average mass of a given size class of particle (lead or nonlead) and comparing this to the observed density of the sample to determine the relative contribution of the sample weight from each type of particle. Because of concerns about possible inaccuracies in measurement of the small volumes of particles in the smaller size classes, the last two steps were replaced with estimated values. The mean density of nonlead particles was estimated to be 1.79 gm/cm^3 as a mean of measurements from all size classes. Density of lead shot was determined to be 11.08 gm/cm^3 based on manufacturer's information regarding size and mass of pellets. These estimates were considered reasonable because of the direct relevance of the sources on which they are based. Since a sample that contains no lead would then be expected to have a density of 1.79 gm/cm^3 and one that is entirely lead would be expected to have a density of 11.08 gm/cm^3, the actual proportion of grit-sized particles that is lead can be determined as follows:

$$F = (\text{sample density} - \text{grit density})/(\text{lead density} - \text{grit density})$$

where F is the fraction of lead particles.

The total number of particles in each size class was calculated by assuming that each particle was a sphere with a diameter equal to the median size of the class and determining the number of such spheres that would be present in a sample of the volume that was measured. This allowed calculation of the total number of particles present in the size class. The estimated fraction of particles in the 2.8- to 0.5-mm size classes that is lead was 0.14 (14%) in the shotfall zone. This value was used in grit ingestion modeling, as it pertains to the size range of grit particles that are commonly utilized by 20 species of grit-ingesting birds occurring at the Center or representative of species occurring there [19].

The number of lead particles per unit mass of soil for modeling mammalian ingestion of particulate lead was determined by summing the calculated number of lead particles in all size classes and dividing by the total mass of soil sieved. This value was estimated to be 0.78 lead particles per gram of soil in the shotfall zone at the trap and skeet range.

Shot ingestion by mammals

Animals without gizzards that incidentally ingest some soil with dietary items may occasionally ingest particulate lead. A large proportion of the soil ingested by mammals is dust on dietary items [21]. However, for this assessment all soil (including dust on vegetation) consumed from the trap and skeet range was assumed to contain lead pellets in the proportions (number of pellets per gram of soil) actually measured in the shotfall zone. The concentration of pellets in the receptor's diet was adjusted to reflect the fraction of the receptor's foraging range accounted for by the trap and skeet range. For example, deer foraging range is 200 ha, and the trap and skeet range is 7.48 ha; therefore, the number of pellets in the soil component of the deer's diet is 7.48 ha/200 ha × 0.78 pellets per gram of soil.

Because information was not available from the literature, a bench-scale experiment was conducted to estimate the dose resulting from the ingestion of lead shot by mammals. Several different quantities of lead pellets were placed in solutions of pH 2 or pH 6.5, approximating the stomach and small-intestine pH levels, respectively, of mammals [25]. Pellets were placed in each pH solution for up to 30 h, the estimated retention time in the stomach and small intestine of a 75-kg ruminant mammal such as white-tailed deer [25]. Dissolved lead concentrations were measured through time. Regressions were derived for the relationships between gut retention time and dissolved lead and between number of pellets ingested and dissolved lead to determine the mass of lead released per pellet after a given period of time. From these data, the mass of lead received from a pellet during pellet retention in the gut was divided by organism body weight to estimate the dose (mg/k body weight) from an ingested pellet.

The number of pellets ingested by mammalian receptors was calculated from the average number of pellets in soils within the foraging range and the rate of soil consumption as follows:

$$P_i = P_a \cdot R_s \tag{4}$$

where

P_i = Number of pellets ingested per day

P_a = Average number of pellets in foraging range soils (# pellets/kg dry soil)

R_s = Rate of soil ingestion (kg/kg bw/day)

The total dose to a receptor is the dose from ingesting a single pellet times the number of pellets ingested, added to the dose obtained from environmental media and diet. Risks from environmental media and diet were calculated as described in the following section assuming no pellet ingestion. Risks were also calculated assuming pellet ingestion in order to estimate the incremental risk from incidental ingestion.

Exposure via environmental media and water

Ingestion is the primary pathway of contaminant uptake at the Center. All ROC modeled in this assessment were assumed to ingest water directly or incidentally as the receptor feeds on other food items. Water ingestion rates (WI, in liters/day) were calculated as follows using equations from Calder and Braun [26]:

$$\text{Birds WI} = 0.059\ M^{0.67} \qquad \text{Mammals WI} = 0.099\ M^{0.90}$$

where

M = organism mass in kg

The food ingestion rate (FR, in g/kg body weight) is the amount of food an animal consumes in a given time and is based on the following equations from Nagy [27]:

$$\text{all birds FR} = (0.648\ M^{0.651})/M$$

$$\text{passerines FR} = (0.398\ M^{0.850})/M$$

$$\text{mammals FR} = (0.235\ M^{0.882})/M$$

where

M = organism mass in kilograms

Another exposure factor in the risk model is the animal's dietary apportioning (relative quantities of various items in the diet). An animal's encounter with contaminants is influenced by its food preferences. Organisms may ingest other ROC at lower trophic levels as well as soil and sediment. Dietary fractions are the percentage of each food source consumed by a receptor and represent the transfer of energy, food, and potentially contaminants. Food items and feeding fractions for Center receptors were obtained from [22–24,26–33].

A food web for the Center was constructed from the feeding fractions and trophic hierarchies of the ROC to simulate the potential uptake of contaminants from the sources to receptors. Ecological exposures were modeled by calculating the dietary dose for each receptor (the mass of contaminant per unit time received from its food and incidental ingestion of abiotic media and lead shot). Dose is a function of which dietary items a receptor consumes, the concentrations of contaminants in the items, and the rate at which the items are consumed. The calculation is expressed mathematically as follows:

$$D_{ik} = R_k \cdot \sum_{j=1} Fr_{kj} \cdot Cf_{ij} \tag{5}$$

where

D_{ik} = Dose of contaminant i to the kth consumer, in mg contaminant per kg organism wet weight per day

R_k = Feeding rate in kg (wet weight) food per kg (wet weight) organism per day

Fr_{kj} = Fraction of consumer k's diet that is food source j

Cf_{ij} = Concentration of compound i in food source, including soil and water

n = Number of food sources

Mathematical adjustments were made for portion of time spent on site (size of foraging range relative to size of the Center or a particular area of the Center). Assimilation efficiency (ability of a consumer to extract a contaminant from ingested media) was set to 1.0. This was based on the assumption that the efficiencies with which organisms on site extract contaminants from their food are likely similar to those used in derivation of TRVs; therefore, doses obtained from dietary items should be similar at the site and in literature studies for the same feeding rate.

Because concentrations of COC in all food were not available for exposure assessment, assumptions were made regarding the concentrations in some food items. The COC concentrations in plants at the Center were used to represent tissue concentrations of insects. COC concentrations in mice at the Center were used to represent tissue concentrations of rabbits, which were not analyzed. Although red-tail hawk and red fox occasionally prey on birds, it was assumed that 100% of their diet was mammals, as tissue data were available only for small mammals. Because the insects of interest feed primarily on vegetation or other insects that feed on vegetation and because contaminants such as lead are not expected to biomagnify in terrestrial systems [34], these assumptions are not expected to bias the modeling results, although they contribute to uncertainty.

The food web model was run through 500 iterations for each receptor with values derived stochastically for some parameters on each iteration. Dietary fractions were assumed to center around the value derived from literature sources but were assigned triangular distributions. The upper and lower limits of these distributions were assumed to be ±25% of the mean. This was performed for each dietary item for each ROC, and the resultant values were normalized to sum to 100%. Consumption rates were handled in a similar manner. Contaminant concentrations were assigned lognormal distributions based on the data, and these distributions were randomly sampled on each iteration. At the conclusion of the iterations, mean doses and standard errors were calculated for each receptor.

The dose estimate produced by the exposure modeling was added to the dose potentially received from shot passing through the gut of receptors without gizzards, so that the estimated total dose could be compared to a TRV.

Interpretation of results

The hazard quotient (HQ) method was used to evaluate the potential risk of the modeled doses. This requires generating

Table 3. Hazard quotients for lead for receptors of concern (ROC) at the Blue Mountain Sportsman's Center. Other than lead, antimony (Sb) in the robin was the only HQ > 1

ROC	Off site	On site (not including shot ingestion)	On site (including shot ingestion)
Red-tailed hawk	<1	<1	<1
White-tailed deer	<1	<1	<1
Red fox	<1	<1	3
Eastern phoebe	<1	26	26
American robin	2	37	37
	Sb < 1	Sb = 2	Sb = 2
Rabbit	<1	2	47
Mouse	<1	3	1,445
Ruffed grouse	<1	15	3,939

the ratio of the actual dose received to the TRV, such that values greater than 1 reflect an exceedence of the TRV by the modeled dose and thus potential risk, and values less than 1 reflect lack of risk. The HQs were developed for each receptor at the Center.

Hazard quotients were calculated for each ROC–COC pair, with receptors evaluated under three conditions: off site, on site considering all exposure routes except shot ingestion, and on site including the predicted shot ingestion. The HQ for lead is shown in Table 3 for all ROC; the only COC other than lead with a HQ greater than 1.0 was antimony in the American robin.

No risks to any ROC from any COC were identified off site. As this is consistent with expectations for the remote and undeveloped area, it lends confidence to the model. With the possible exception of antimony in robins, lead was the only COC that posed increased risk to any ROC on site. The ROC fell into four groups with regard to risk at the Center.

Minimal risk

Red-tailed hawk and other raptors. No risks to the red-tailed hawk were identified at the Center (HQ < 1 off site and on site, including the shot ingestion exposure route). Because hawks and other raptors are not known to ingest grit as part of their diet [23], the probability of incidental direct ingestion of lead shot by red-tailed hawks and other raptors from the shotfall zone at the trap and skeet range is essentially zero. The probability of raptors occasionally secondarily ingesting shot that had been ingested by prey seized from the shotfall zone would be expected to be low because the shotfall zone is a very small portion of the foraging area, and prey from there is likely to be a very small portion of the diet; only a portion of the prey organisms from the shotfall zone would contain shot when captured; only a portion of any shot in prey organisms would be ingested by predators; and the effects of ingested lead shot vary with the type and amount of food, sex, age, size of the predator, and other factors. Even if individual raptors were to occasionally secondarily ingest shot, little risk to raptor populations in the area would be expected because so few individuals comprising such a small proportion of the breeding population could possibly be exposed from an area as small as the trap and skeet range.

The risk assessment indicated that lead and other COC at the Center pose minimal risk to hawks and other raptors.

White-tailed deer. The risk assessment indicated that lead and other COC at the Center pose minimal risk to white-tailed deer. The HQ was <1 off site and on site, including the shot ingestion exposure route. This indicates that the potential for incidental ingestion of lead shot poses little actual risk to white-tailed deer.

Red fox. No risks to red fox were identified off site or on the ranges via exposure routes other than ingestion of lead shot (HQ < 1), indicating that dietary contribution of lead to these organisms was minimal. Incidental secondary ingestion of lead shot contained in prey seized from the shotfall zone at the trap and skeet range may pose slight risk to individual red foxes (HQ = 3). However, this probability would be expected to be low and of little ecological consequence for the reasons discussed previously for the red-tailed hawk and other raptors.

Risk from diet; minimal risk from shot ingestion

Eastern phoebe. The only risks to eastern phoebe were identified in association with on-site lead exposure via diet (HQ = 26). The HQ was the same when incidental ingestion of lead shot was considered, indicating that this is not an important exposure pathway for eastern phoebe. The eastern phoebe, a member of the flycatcher family (Tyrannidae), catches flying insects in the air [22] and thus is not expected to ingest grit or to incidentally ingest shot. Although the HQ of 26 indicates individual phoebes at the site may be at risk from lead in the diet, little risk to the local population is considered likely. The small proportion of the total range of the local population represented by the site, and thus the small proportion of the total activity of the local population spent at the site, makes the potential for population-level impacts slight.

American robin. This analysis suggests a minor potential for risk to robins in association with exposure to lead off site (HQ = 2). The HQ for on-site lead exposure via diet was much higher (HQ = 37), indicating that the dietary contribution of lead to robins may be important at the Center. The HQ was the same when incidental ingestion of lead shot was considered, indicating that this is not an important exposure pathway for robins because they do not ingest grit [19] and thus are unlikely to ingest shot. No risks to robins were identified for any other COC except antimony. The off-site HQ was <1, while the risk to robins on site was the same (HQ = 2) via diet and via diet plus shot ingestion. Since the HQ for antimony only slightly exceeds 1 in both cases, there is only a slight potential for adverse effects on robins due to antimony exposure via diet. Although individual robins at the site may be at risk from lead in the diet, little risk to the local population is considered likely. The small proportion of the total range of the local population represented by the site, and thus the small proportion of the total activity of the local population spent at the site, makes the potential for population-level impacts slight.

Minimal risk from diet; risk from shot ingestion

Rabbit. The only dietary risks to rabbits were associated with on-site lead exposure (HQ = 2). The calculated risk to rabbits that incidentally ingest lead shot (HQ = 47) from the shotfall zone at the trap and skeet range indicated that this may be an important exposure pathway for rabbits. Although they may do so, there is no direct evidence of rabbits actually ingesting lead shot. A large proportion of incidentally ingested soil is typically dust on dietary items and dirt consumed during grooming activities [23], which means there is little possibility of lead shot being contained in a large proportion of incidentally ingested soil. Therefore, the likelihood of rabbits ingesting lead shot is low, although a rabbit would be at risk if it were to do so. Even if individual rabbit(s) were to ingest shot at the trap and skeet range, little risk to the local population is considered likely for the reasons discussed previously for the eastern phoebe.

Mouse. The only dietary risks to mice were identified in association with on-site lead exposure (HQ = 3). The calculated risk was high (HQ = 1,445) to mice that incidentally ingest lead shot from the shotfall zone at the trap and skeet range. There is no direct evidence of mice actually ingesting lead shot, and the likelihood of their doing so is small for the reasons discussed previously for rabbits. However, a mouse that ingested shot would be at risk. Even if individual mice were to ingest shot at the trap and skeet range, little risk to the local population is considered likely for the reasons discussed previously for the eastern phoebe and rabbits.

Risk from diet and shot ingestion

Ruffed grouse. Risks to ruffed grouse were identified in association with exposure to lead on site. The HQ of 15 when shot ingestion was not considered indicates considerable dietary contribution of lead to grouse. For a ruffed grouse whose foraging range includes the entire shotfall zone at the trap and skeet range, the probability of ingesting a pellet during a lifetime at the site was 1.0. The HQ of 3,939 due to incidental ingestion of lead shot indicated that this is a major exposure route for lead to individual ruffed grouse whose foraging ranges encompass the shotfall zone at the trap and skeet range. This is considered a worst-case estimate of risk to ruffed grouse because it is based on the maximum life span of nearly 11 years observed for banded birds in the wild [22], while the average life span is approx. two years [20]. This level of ingestion of lead shot by individual grouse within the shotfall zone at the trap and skeet range is not expected to pose unacceptable risk to ruffed grouse populations in the area. The average population density of ruffed grouse inhabiting northern mixed forests in New York State ranges from 3.3 to 7.4 grouse per 100 acres [20]. Therefore, only two to four ruffed grouse would be expected to occur on the entire Center of approx. 50 acres. Fewer than two ruffed grouse would be expected on the approx. 18.5-acre shotfall zone at the trap and skeet range. Thus, the maximum seasonal mortality of ruffed grouse due to lead shot ingestion would be on the order of two grouse and would not be expected to pose unacceptable risks to ruffed grouse populations in the area. The annual ruffed grouse survival rate is estimated as 47% for adult males.

HUMAN HEALTH RISK ASSESSMENT

In addition to evaluating ecological impacts, risks to human health from activities at the Center were assessed. The purpose of the assessment was to determine whether there was a potential human health risk associated with the COC in the soil, surface water, sediments, air, and deer. Several groups of individuals were considered, including Center customers, Center employees performing maintenance and range officer duties, and trespassers (adults and children) on the Center's grounds. The assessment followed the traditional four steps: hazard identification, dose–response assessment, exposure assessment, and risk characterization.

Hazard identification

The five metals and 16 PAHs evaluated in the ecological risk assessment were also selected for estimation of human health risk. The PAHs were separated into the seven carcinogenic and nine noncarcinogenic PAHs. Structural similarity was used to derive toxicological values for similar compounds for which there was insufficient toxicity information. For each toxicological group, the compound with the strongest composite of strength (or weight) of scientific evidence for cause-and-effect relationship, severity of effect (e.g., irreversible, most adverse), and potency (most potent surrogates have selection priority as a conservative measure in the absence of chemical-specific information on other potential surrogates) was selected as representative of other compounds in the same group. Among the carcinogens, benzo[*a*]pyrene has the most relevant toxicity information and is one of the more potent PAH carcinogens; the relative toxic potency of each of the other six carcinogens (benzo[*a*]anthracene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, chrysene, dibenzo[*a*,*h*]anthracene, and indeno[*1*,*2*,*3*-*cd*]pyrene) was based on the cancer potency of benzo[*a*]pyrene. Five noncarcinogenic PAHs (pyrene, acenaphthene, anthracene, fluoranthene, and fluorene) had data suitable to estimate their respective toxic potencies. Four noncarcinogenic PAHs (acenaphthylene, benzo[*g*,*h*,*I*]perylene, naphthalene, and phenanthrene) did not have data suitable for estimating their toxic potencies.

DOSE–RESPONSE ASSESSMENT

Dose–response assessment is the determination of a chemical's concentration at which toxicity does or does not occur based on the quantitative relationship between increasing a chemical's dose and the resulting increase in an adverse toxic response. Based on the ability of a chemical to cause cancer or adverse health effects other than cancer, two types of toxic potency concentrations are utilized (Table 4).

Cancer potency factors (CPF) for the carcinogenic effects of a chemical. The U.S. Environmental Protection Agency CPFs for arsenic and benzo[*a*]pyrene were used in this assessment. For each of the carcinogenic PAHs that lack adequate and directly applicable dose–response information, a CPF relative to benzo[*a*]pyrene was assigned based on cancer studies in mice where PAHs were applied to the skin. Accordingly, each PAH's CPF was a modification of the CPF for benzo[*a*]pyrene.

Oral reference doses and inhalation reference concentrations for a chemical's adverse health effects other than cancer. Oral reference doses were available for antimony, arsenic, zinc, acenaphthene, anthracene, fluoranthene, fluorene, and pyrene. A toxic potency concentration was estimated for copper.

Toxic potency concentrations are not established for lead. A blood lead level of 10 μg/dL has been identified as a level at which toxic effects in humans can be manifested (e.g., elevated blood pressure). This blood lead level has been used in this context within this risk assessment, as a level of concern for lead toxicity. The Integrated Exposure/Uptake/Biokinetic (IEUBK) Model [35] and the O'Flaherty [36] model were used to estimate blood lead concentrations resulting from exposure to environmental sources.

ASSESSMENT OF HUMAN EXPOSURE

The purpose of an exposure assessment is to determine the populations that may potentially be exposed to site-related chemicals, the pathways by which exposure may occur, and the magnitude, frequency, and duration of these potential human exposures. The exposure assessment involved (1) identification of populations of interest (Center customers, Center

Table 4. Toxicity values utilized in the human health risk evaluation

Chemical	Toxic potency factors for noncancer health effects (mg/kg/d) (chronic)			Cancer potency factor (mg/kg/d)		
	Oral	Dermal	Inhalation	Oral	Dermal	Inhalation
Acenaphthene	0.06	0.06	0.003	NA	NA	NA
Acenaphthylene	NA[a]	NA	NA	NA	NA	NA
Anthracene	0.3	0.3	0.02	NA	NA	NA
Antimony	0.0004	0.0004	0.00004	NA	NA	NA
Arsenic	0.0009	0.01	0.0009	1.8	1.8	15
Benzo[*a*]anthracene	NA	NA	NA	0.04[b]	NA	NA
Benzo[*a*]pyrene	NA	NA	NA	7.3	NA	NA
Benzo[*b*]fluoranthene	NA	NA	NA	0.2[b]	NA	NA
Benzo[*k*]fluoranthene	NA	NA	NA	0.02	NA	NA
Benzo[*g,h,i*]perylene	NA	NA	NA	NA	NA	NA
Chrysene	NA	NA	NA	0.002[b]	NA	NA
Copper	0.003	0.00003	0.0018	NA	NA	NA
Dibenzo[*a,h*]anthracene	NA	NA	NA	4[b]	NA	NA
Fluoranthene	0.04	0.04	0.002	NA	NA	NA
Fluorene	0.04	0.04	0.002	NA	NA	NA
Indeno[*1,2,3-cd*]pyrene	NA	NA	NA	0.04[b]	NA	NA
Lead	NA	NA	NA	NA	NA	NA
Naphthalene	NA	NA	NA	NA	NA	NA
Phenanthrene	NA	NA	NA	NA	NA	NA
Pyrene	0.03	0.03	0.002	NA	NA	NA
Zinc	0.3	0.3	0.09	NA	NA	NA

[a] NA = not applicable because toxic potency concentration could not be derived and/or the route of exposure under which the NA is placed does not apply to this chemical.
[b] Cancer potency factor based on cancer potency factor for benzo[*a*]pyrene.

employees, and trespassers), (2) identification of exposure pathways, (3) identification of relevant exposure scenarios, (4) estimation of exposure point concentrations, (5) identification of the values to be assigned to each exposure parameter in each exposure scenario (e.g., ingestion rates; inhalation rates; body weights; exposure times, frequencies, and durations; rates of absorption of chemical into the body; and skin surface area), and (5) quantification of the actual exposure.

Potential receptor populations

This assessment is limited to on-site exposures at the Center and assumes that future land use would continue to be as an outdoor shooting range. Center customers (adults), Center employees, and trespassers (adults and children) were identified as the populations with the potential for exposure to chemicals of concern at the Center based on visits to the site, interviews with site personnel, and a review of previous investigations of the site [13]. Although a public shooting range, the Center grounds are tightly controlled because of the nature of the use of the Center. People entering the Center grounds for purposes other than shooting are defined as trespassers for the purposes of this assessment.

Activities and practices of identified populations were characterized in order to assess the likelihood and extent of their exposure. Exposure was assessed with respect to current authorized and unauthorized activities at the Center. Exposure pathways considered to represent plausible, complete pathways of potential exposure to chemical constituents in soil, sediment, surface water, air, or deer are summarized in the following. The role of dust in exposure was not considered directly. However, since dust settles over time and adheres to or becomes incorporated in other media, dust was included in evaluation of these media (e.g., estimates of soil ingestion). Specific exposure information (e.g., exposure times, clothing) was obtained from R. Seacord as unpublished data unless stated otherwise.

Center customers. Customers were assumed to shoot at the Center for an average of 10 years, shooting can occur in any weather, and the maximum length of time for recreational firing on a given day is approx. 4 h. Children under the age of 12 are not permitted on the range. It is assumed that customers do not come into contact with surface water or sediment. The potential exposure pathway for Center customers is incidental ingestion of soil, via hand-to-mouth activities, in the area of the Center used by customers.

Center employees. Employees perform a variety of maintenance activities, including grass and weed cutting. Maintenance employees work a 5-d week, 7-h shift. All workers wear long pants, shirts, and shoes. Extended exposure to surface water may occur when employees cut *Phragmites* on the large bore range. This activity occurs over several days, for 2 to 3 h per day. Protective clothing, including hip boots, is worn. The potential exposure pathways for Center employees are air and incidental ingestion of soil, sediment, or water in the area of the Center by employees engaged in maintenance and range officer activities.

Trespassers. No information on trespasser activities was available from the Center; professional judgment was used in the selection of exposure parameters. The Center grounds are posted with English/Spanish signs stating ‘‘Posted—Keep out’’ and ‘‘Danger—This area may be dangerous to your health due to the presence of lead. Unauthorized personnel keep out.’’ In addition, no legal hunting/fishing occurs on the Center's grounds. However, there were no secure fences on the periphery of the property, and the property appears to be accessible to adults and children. Therefore, it is reasonable to assume that unauthorized activities (e.g., hiking, playing, hunting) occur on the Center's grounds. The following assumptions are made: Trespassers are on the Center's grounds 10 times per year for 1 h per event (children) and 8 h per event (adults). Children may play in the stream during trespassing events. Hunters are assumed to take and consume one deer per year from the grounds. Based on observations from site visits, it is assumed that the stream running through the site does not support a fishery adequate to encourage onsite fishing. The potential exposure pathways for trespassers are incidental ingestion of soil and surface water at the Center by adult and child trespassers engaged in poaching, hiking, and playing; incidental ingestion of sediment at the Center by child trespassers engaged in playing in the stream; and ingestion of deer taken from the Center grounds by adult trespassers engaged in unauthorized hunting.

Estimating exposure point concentrations

Soil, sediment, and unfiltered water samples were collected at the Center and analyzed for COC [13]. A value of one-half the detection limit was utilized for ''nondetect'' values. These concentrations were then used to determine the 95% upper confidence limit on the mean, or 95 UCLM, according to U.S. EPA methodology [37]. Concentrations of selected COC are included in Table 2.

Breathing zone samples were collected from personal monitors attached to Center customers and range officers during shooting at each of the Center's ranges. Sampling occurred over a 7-h period on 11 June 1994. Samples from personal monitors, as well as a sample of background air, were analyzed for each of the chemicals of concern. Air concentrations of copper, lead, naphthalene, and phenanthrene were elevated above background at some of the ranges [13]. The air concentration for four of the chemicals of concern were as follows: copper, 32 $\mu g/m^3$; lead, 14.6, 36, and 258 $\mu g/m^3$; naphthalene, 2.6 $\mu g/m^3$; and phenanthrene, 0.07 and 0.16 $\mu g/m^3$.

No data on concentrations of metals (antimony, arsenic, copper, lead, and zinc) in deer were available; these values were calculated based on the assumption that deer tissue has the same concentration as principal exposure media [34], that is, bioconcentration factor equal to 1.0, where the exposure media concentration is equal to $\Sigma Fr_{kj} \times Cf_{ij}$ (from Eqn. 1). Predicted concentrations on a fresh-weight basis in deer whose home range includes the Center are antimony, 0.06 mg/kg; copper, 0. 89 mg/kg; lead, 2.58 mg/kg; zinc, 5.69 mg/kg; and arsenic, 0.045 mg/kg. (The predicted arsenic concentration in deer whose home range does not include the Center is 0.044 mg/kg.)

Dose estimation

The last step in the exposure assessment is the estimation of intake and resulting dose for each of the pathways considered in the assessment. The extent of potential intake received through the various pathways is dependent on an individual's location and behavior. It is not possible to predict accurately the level of exposure for specific individuals because of uncertainties in both their current and future activity patterns and incomplete knowledge of certain exposure variables (e.g., frequency of trespassing at the Center, duration of employment at the Center). Therefore, it is necessary to make a series of simplifying assumptions about potential exposure that are believed to be conservatively high to derive an estimate of potential human exposure.

The adult populations modeled in this assessment are typically represented by using default values for the average male adult [38]. The generic equation to calculate dose is as follows:

$$\text{(L)ADD} = \frac{C \times IF \times EF \times ED \times AF}{BW \times AT} \tag{6}$$

where

(L)ADD = (Lifetime) Average daily dose (mg/kg-day)

C = Concentration in a specific medium (mg/L or mg/kg)

IF = Intake factor (product of variables including inhalation rate ingestion rate, etc.)

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

AF = Absorption factor (unitless)

BW = Body weight (kg)

AT = Averaging time (days)

Estimating intakes and blood levels for lead

The 10-μg/dL total blood lead level is employed in this risk assessment as a comparative estimate of the blood level above which toxic effects may be evidenced in adults and children. The IEUBK Model (version LEAD99D) is used in this assessment for estimating blood lead levels at the Center.

Since the IEUBK model was not designed for episodic exposures such as those that might be experienced by populations at the Center, a more recently developed physiologically based model [36] of lead kinetics was used to estimate the blood lead levels of adults and children experiencing episodic exposures. (For a more complete description of the advantages, uncertainties, and limitations associated with the different blood lead models, see [39].)

Characterization of the nature and magnitude of human risks

Risk characterization is the final step of the human health risk assessment process. In this step, the toxic potency concentrations (oral reference doses) and carcinogenic toxicity potency factors were used in conjunction with the estimated chemical dose for the modeled populations to quantitatively estimate carcinogenic health risks and health risks other than cancer associated with exposure to soil, sediment, surface water, and deer based on the exposure estimates for Center customers, Center employees, and adult and child trespassers.

Chronic noncarcinogenic risk. Chronic noncarcinogenic risks were estimated for Center customers, Center employees, and adult trespassers on Center grounds. Exposure and resulting risk from incidental ingestion of soil, sediment, and surface water; inhalation of COC released during firing; and ingestion of deer were assessed. All the HQs were within an acceptable range (<1, ranging from 3×10^{-8} to 2×10^{-1}), except for effects associated with Center customers inhaling copper during firing (HQ = 7). Therefore, on the basis of standards accepted in the scientific community, it is assumed that adverse effects would not occur from exposure to any of the COC under the specified conditions of exposure, except for effects associated with Center customers inhaling copper during firing. Risk estimates associated with Center customers shooting are related to the voluntary activity of shooting and are not associated with in-place contamination at the Center.

Subchronic noncarcinogenic risk. Subchronic noncarcinogenic risks were estimated for Center employees and child trespassers at the Center. Exposure and resulting risk from incidental ingestion of soil, sediment, and surface water were assessed. The HQs were less than 1 for all exposure scenarios (from 9×10^{-9} to 4×10^{-1}). Therefore, it is reasonable to assume that adverse effects would not occur from exposure to any of these COC under the specified conditions of exposure.

Cancer risk. Cancer risks were estimated for Center customers, Center employees, and trespassers on Center grounds. Exposure and resulting risk from incidental ingestion of soil, sediment, and surface water; inhalation of chemicals released during firing; and ingestion of deer were assessed. Cancer risks for the different exposure scenarios ranged from 1×10^{-11} to 2×10^{-5}. Cancer risks associated with the following pathways and chemicals were between 1×10^{-6} and 2×10^{-5}: Center employees exposed to arsenic through ingestion of soil (2×10^{-6}), child trespassers with access to the entire site exposed to arsenic through ingestion of sediment (2×10^{-6}), and adult trespassers exposed to arsenic through ingestion of deer meat (2×10^{-6}). For known or suspected carcinogens, acceptable exposure levels are generally concentration levels that represent an excess upper bound lifetime cancer risk to an individual of between 10^{-4} and 10^{-6}. Exposures to carcinogens resulted in risks within or below this risk range.

Risks associated with lead

Adults. Two models were used to estimate adult blood lead levels corresponding to exposure to lead in media at the Center: the IEUBK model and a physiologically based model by O'Flaherty [36]. Based on the IEUBK model, elevated blood levels (above 10 μg/dL) were estimated for Center customers inhaling lead during firing at the Small Bore Range (14.0 μg/dL). It should be noted that the risks due to inhalation during firing are related to operation of the Center and not to in-place chemicals.

The O'Flaherty model was run for Center customers (exposed for six consecutive Saturdays to lead in soil and air during firing), Center employees (exposed to lead in soil for three 5-d workweeks and in surface water and sediment during one week of mowing *Phragmites*), and adult trespassers (exposed to lead in soil and surface water for three consecutive Saturdays). For the Center customer, the model shows blood lead levels increasing with each visit to the Center, with peaks of approx. 11 μg/dL but appearing to level off at approx. 10 μg/dL over the six consecutive weeks. For Center employees, the model shows blood lead levels increasing with the workweek involving exposure to soil, sediment, and surface water and then decreasing when exposure is only to soil. A maximum blood lead level of 25 μg/dL is estimated, appearing to level off at approx. 5 μg/dL once the exposure is to soil only. For the adult trespasser, the model shows blood lead levels increasing with each visit to the Center, with peaks below 10 μg/dL. After 100 d of no exposure at the Center, the model estimates that blood lead levels would return to pre-exposure levels.

The results of the two models taken together indicate elevated blood lead levels (above 10 μg/dL) for Center customers shooting on the small-bore range (IEUBK) and Center employees ingesting sediment and surface water (O'Flaherty). This peak estimated blood lead level is below the American Council of Governmental Industrial Hygienists—Biological Exposure Index of 50 μg/dL (ACGIH; Cincinnati, OH, USA). Because historical blood lead levels of Center employees are available, the modeled blood lead levels for the employees may be compared with observed blood lead levels. In 1992, blood samples were drawn from five Center employees and analyzed for blood lead levels. The employees' activities included maintenance, range officer duty, and office work. The duration of employment ranged from approx. 6 to 11 years (B. Samuels, unpublished data). Blood lead levels of the five employees ranged from less than 5 μg/dL to 7 μg/dL, all below the level of concern [40].

Therefore, even though the O'Flaherty model [36] predicts a short-term blood lead level above 10 μg/dL for workers cutting *Phragmites*, the estimate of chronic blood lead levels in Center employees (IEUBK Model [35]) of less than 10 μg/dL appears to be confirmed by observed blood lead levels in Center employees.

Children. Two models were used to estimate child blood lead levels corresponding to exposure to lead in media soil, sediment, and surface water at the Center: LEAD99D and the model of O'Flaherty. Based on LEAD99D, children exposed to lead in soil, sediment, and surface water, under the exposure scenarios described in this paper, would be expected to have mean blood lead levels of 8 μg/dL, with approx. 30% of the exposed children's blood lead levels above the level of concern of 10 μg/dL. If incidental ingestion of sediment at the Center does not occur and water and soil remain at current lead concentrations, children's blood lead levels would be reduced slightly: Blood lead level mean was estimated to be 7 μg/dL, with approx. 25% of the children exceeding the level of concern. If the average soil concentration on site was to remain at current lead concentrations but no exposure to surface water or sediment was to occur, children's blood lead levels would be reduced significantly: Blood lead level mean under this scenario was estimated to be 3 μg/dL, with fewer than 1% of the children exceeding the level of concern.

The mean blood lead level in children as estimated with the O'Flaherty model is in close agreement with the LEAD99D Model: Blood lead levels vary between 5 and 11 μg/dL. The results of the two models taken together indicate elevated blood lead levels for approx. 30% of children ingesting soil, sediment, and surface water (LEAD99D) and approx. 25% of children ingesting soil and surface water (LEAD99D). Thus, sediment and surface water appear to make the greatest contribution to elevated blood lead levels in children trespassing at the Center.

The previous blood lead level estimates are based on the assumption that children may trespass over the entire Center grounds. It may be more realistic to assume that children would remain near the Center boundary adjacent to a school and approx. one-half mile from the ranges. Children have not been reported in the areas of the Center near the ranges that have bullets or shot on the ground. Estimated blood lead levels based on the more realistic assumption of exposure to sediment, soil, and water at the portion of the Center grounds adjacent to the school are mean blood level of approx. 2 μg/dL, with less than 1% of children exceeding the level of concern (LEAD99D).

SUMMARY AND CONCLUSIONS

This paper, describing an ecological and human health risk assessment of an outdoor firing range, is the first on the subject in the published literature. The evaluation was based on environmentally conservative assumptions that purposely result in a tendency to overestimate risk. This approach provides reasonable assurance that less adverse effects will actually occur in the field than are indicated by the calculated risks.

Risks at the population level were minimal to all ecological receptors at the Center from all contaminants of concern (except lead) acting through all exposure pathways. Lead at the Center posed no increased risk to hawks and other raptors, foxes, or deer. Lead in dietary items posed a risk to individual grit-ingesting birds (ruffed grouse) and a small risk to individual birds that do not ingest grit (phoebe and robins). Individual grit-ingesting birds (ruffed grouse) were also at risk from the incidental ingestion of lead shot within the shotfall zone at the trap and skeet range. Lead in dietary items posed no more than a minor potential for risk to individual small mammals (rabbits and mice). If a small mammal were to ingest lead shot, it would be at risk, but there is no direct evidence of these animals actually ingesting shot, and the likelihood of their doing so is considered small. Risks associated with lead at the Center may occur at the level of individual organisms. Risks are not expected at the population, community, or ecosystem level since density-dependent compensation mechanisms would likely offset any site-related loss of individuals that might occur.

For humans exposed to COC at the Center, the results of this analysis indicate that adverse noncancer effects would not occur from exposure to any of the COC under the specified conditions of exposure, except for potential effects associated with Center customers inhaling copper during firing. Risk estimates associated with Center customers shooting are related to the voluntary activity of shooting and are not associated with in-place contamination at the Center. Cancer risks for the different exposure scenarios ranged from 1×10^{-11} to 2×10^{-5}. For known or suspected carcinogens, acceptable exposure levels are generally concentration levels that represent an excess upper bound lifetime cancer risk to an individual of between 10^{-4} and 10^{-6}. Exposures to carcinogens resulted in risks within or below this risk range.

Analyses of adult blood lead levels from exposure to lead in media at the Center were performed. Elevated blood levels (above 10 μg/dL) were estimated for Center customers inhaling lead during firing at the small bore range (14.0 μg/dL). It should be noted that the risks due to inhalation during firing are related to operation of the Center and not to in-place chemicals.

This analysis also indicates elevated blood lead levels (above 10 μg/dL) for Center customers shooting on the small-bore range and Center employees ingesting sediment and surface water. Because historical blood lead levels of Center employees are available, the modeled blood lead levels for the employees may be compared with observed blood lead levels. Blood lead levels of the five employees ranged from less than 5 to 7 μg/dL, all below the level of concern.

Children exposed to lead in soil, sediment, and surface water, under the exposure scenarios described in this paper, would be expected to have mean blood lead levels of 8 μg/dL, with approx. 30% of the exposed children's blood lead levels above the level of concern of 10 μg/dL. The results of the analysis indicate elevated blood lead levels (above 10 μg/dL) for approx. 30% of children ingesting soil, sediment, and surface water and approx. 25% of children ingesting soil and surface water. Thus, sediment and surface water appear to make the greatest contribution to elevated blood lead levels in children trespassing at the Center.

The above blood lead level estimates are based on the assumption that children may trespass over the entire Center grounds. It may be more realistic to assume that children would remain near the Center boundary adjacent to a school and approximately one-half mile from the ranges. Estimated blood lead levels based on the more realistic assumption of exposure to sediment, soil, and water at the portion of the Center grounds adjacent to the school are mean blood level of approx. 2 μg/dL, with less than 1% of children exceeding the level of concern.

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