ASSESSMENT OF ECOLOGICAL RISK ASSOCIATED WITH LEAD SHOT AT TRAP, SKEET & SPORTING CLAYS RANGES

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EXECUTIVE SUMMARY: ASSESSMENT OF ECOLOGICAL RISK ASSOCIATED WITH LEAD SHOT AT TRAP, SKEET & SPORTING CLAYS RANGES

This paper summarizes information related to assessing ecological effects of lead and lead shot pellets from shooting practice ranges in Massachusetts. The facilities in question include trap, skeet and sporting clays facilities, where shotgun shells with lead pellet loads are used, herein referred to as "shotgun practice ranges" (SPRs). Wildlife exposures, assessment, and management approaches that have been applied at lead shot sites throughout the country are summarized. It is intended that this document will be a useful reference for policy makers when decisions are made on whether and how ecological impacts from SPRs should be addressed. Risks associated with residual lead shot in hunting areas are not specifically addressed, although information contained in this document could be useful in assessing any area where lead shot is used.

The implications of applying the Massachusetts Contingency Plan (MCP) risk assessment guidance at lead shot sites are discussed. As of 2009, the MassDEP does not have a formal position on how SPRs should be handled under the MCP. The purpose of this discussion is to provide information that could be useful in management/policy decisions related to the level of regulation that may be warranted at SPRs that use lead shot. Specific risk management strategies and approaches are beyond the scope of this paper.

Lead shot is used at practice ranges for shooting trap, skeet and sporting clays. The spent shot becomes dispersed in the environment at or near SPRs. Spent lead shot at these facilities can be found either intact or as weathered particles or ionized salts. Lead contamination associated with lead shot is normally limited to the soil or sediment surface in the immediate vicinity of deposition. In depositional environments, such as many ponds or wetlands, lead shot may become buried by sediments over several years making it less available, and therefore less of a risk, to wildlife. Rainfall increases the likelihood that lead will be mobilized in the environment, either through dissolution or erosion.

The exposure pathway of greatest ecological concern at SPRs is ingestion of lead shot pellets from surface soil or sediment by birds and wildlife. This pathway is particularly hazardous to birds that ingest lead shot for grit as an aid in digestion. Incidental (accidental) ingestion of shot pellets by birds and wildlife preying on invertebrates and plants in soil or sediment where lead shot is dispersed may also pose a considerable risk of harm.

Acute effects of environmental lead have been documented at a number of sites. Most of these cases have been attributed to ingestion of spent lead shot by birds. Toxic effects of lead shot vary depending on shot size, the species consuming the lead, diet, and a variety of other variables. Previous studies have shown that ingesting as little as one lead shot pellet can be fatal to a bird.

A number of SPRs throughout the country have been cleaned up under federal jurisdiction. Lead shot ingestion probability models for birds and small mammals have been incorporated into a number of these risk assessments, and in several cases lead shot cleanup goals have been set in terms of shot pellet density (shot pellets/ft^2). The clean up goals based on lead shot density vary according to site conditions, but generally fall in the range of 3-13 shot pellets/ft^2. Concentrations of lead shot above this range have been thought to pose an ecological risk in those cases.

The densities of lead shot pellets present at SPR fall zones is likely to exceed the aforementioned 3-13 shot pellets/ft^2 benchmark by a wide margin. Further, it is likely that lead concentrations in soil, sediment or surface water in the vicinity of many SPRs could harm wildlife and/or wildlife habitat. Whether or not the MCP process is followed, assessments at SPRs should evaluate ecological risk from both lead shot and elevated concentrations of lead in soil, sediment, and surface water.

1.0 Introduction

This paper summarizes technical information relevant to characterizing and assessing outdoor trap, skeet and sporting clays clubs contaminated by lead and lead shot. For the purposes of this document, trap, skeet and sporting clays clubs will be referred to as "shotgun practice ranges" (SPRs). This paper reviews assessment methods employed at SPRs around the country, describes the findings from those investigations, and discusses the possible application of Massachusetts Contingency Plan (MCP) risk assessment methods at SPRs in Massachusetts.

The information presented in this document is intended for use in policy and management decisions related to assessing and mitigating potential ecological impacts from lead shot contamination at SPRs in Massachusetts. This paper is not a guide to conducting ecological risk assessments at SPRs, although the steps included in an ecological risk assessment are discussed to help the reader understand the tools and approaches available to assess risks posed by lead shot to the environment. Recommendations on specific assessment approaches and management strategies are not offered in this paper.

This paper focuses narrowly on evaluating and managing effects from lead shot, lead dust and dissolved lead dispersed in surface soil, sediment and surface water. It does not attempt to address the risks posed by munitions components (e.g., metals) other than lead. Further, it does not focus on other lead projectiles (e.g., bullets) which may pose an ecological risk if a) best management practices are not utilized and; b) fragments similar in size to lead shot pellets are generated.

The ecological risks from using lead shot for hunting on hunting ranges may also be significant, but risks and management issues associated with lead shot used for hunting are beyond the scope of this paper. The number of studies that address ecological risks specific to trap, skeet and sporting clays clubs is quite limited, however. For this reason, ecological studies of hunting ranges are cited in this paper because they provide examples of assessment approaches that may be applicable as well as indicators of risk at practice ranges.

This paper describes various approaches to assessing ecological risk and managing SPR sites contaminated with lead shot. The purpose is to provide information that could be useful in making management/policy decisions related to regulating lead shot sites in Massachusetts. Although most of the information collected in this paper is based on SPRs, this information may be applicable to non-SPR sites.

The main topics discussed in this paper include:

- Fate and transport of lead from lead shot in the environment
- Exposure pathways for wildlife at SPRs
- Effects of concern from wildlife exposure to lead

- Application of MCP guidance at lead shot sites
- Ecological risk assessment methods for lead shot applied nationally and in Massachusetts

2.0 General Problem Description

MassDEP is concerned about the potential ecological impacts of lead at SPRs. Lead concentrations at SPRs are often much higher than lead concentrations at waste sites regulated under Massachusetts General Law Chapter 21E and the Massachusetts Contingency Plan (MCP). Chapter 21E is the state hazardous waste site Superfund Law. Adverse effects on wildlife from exposure to lead shot have been widely reported in the literature.

Although moderate “background” levels of lead are ubiquitous in the environment, elevated concentrations can produce toxic effects in exposed organisms. Concentrations of lead in soil at SPRs can be 100 times greater than background levels. Background lead concentrations in soil from the scientific literature range from 10-30 milligrams of lead per kilogram (mg/kg) soil and from 10-110 mg/kg for sediment (Eisler, 1988). For risk assessments conducted under the MCP, MassDEP has identified a soil lead background concentration of 100 mg/kg. The recommended MassDEP sediment screening benchmark for lead is 130 mg/kg.

2.1 Lead Shot Physical Fate & Transport

Wind and rain are the primary factors that influence the transport of lead in the environment. Rainfall increases the likelihood that lead will be mobilized in the environment, either through dissolution or erosive sediment transport. The two forms of lead shot in the environment of concern in ecological risk assessment are intact (or nearly intact) lead shot and pulverized lead shot that has been degraded to particle sizes similar to soil fragments. Under certain environmental conditions, degraded portions of lead shot are more likely to become mobile than intact shot. The smaller particles are more susceptible to transport by erosion and runoff to surface water, and the higher surface area of smaller particles increases the rate of dissolution and leaching into the surrounding soil and surface water.

When exposed to moist air and/or water, lead oxidizes and forms a variety of weathering products that can include lead oxides, sulfates, phosphates, carbonates, and organic complexes (Interstate Technology & Regulatory Council [ITRC] 2005) as well as dissolved lead. The solubility of lead in water is dependent on solution pH, water hardness, and oxidation-reduction conditions. As water pH decreases, dissolved lead concentrations increase. Raising the water pH causes dissolved lead to precipitate out of solution, particularly between pH 7.5 and 9.5. Because lead is a metal that exhibits amphoterism (reacts with acids and bases), the lead solubility can actually go up at pH above 9.5 (Agency for Toxic Substances and Disease Registry [ATSDR] 2005). The rate of dissolution and the formation of precipitates are largely controlled by the site-specific water chemistry. In hard (i.e., mineral-rich) water, lead will precipitate out of solution into various oxides, sulfates, phosphates, and carbonates, thereby reducing its mobility. In Massachusetts’s surface water, however, hardness levels are generally low, so precipitation rates are likely to be low relative to those in harder waters.

Adsorption and ion exchange dynamics contribute to the retardation of lead migration in the environment. High clay and organic carbon typical of wetland environments in Massachusetts can retard the transport of lead in the dissolved phase through adsorptive processes, inhibiting lead’s transport to both surface water and groundwater. High organic carbon content can also induce reducing conditions favorable to the formation of lead sulfides, which are relatively insoluble and immobile as long as reducing conditions are maintained (ATSDR 2005).

Lead contamination associated with lead shot at SPRs is normally limited to the soil or sediment surface in the immediate vicinity. In review, the most significant forces affecting transport of lead in the environment include:

- Lead oxidizes when exposed to air and can dissolve when exposed to moist soil/sediment or acidic water (usually pH <6.5);
- Lead shot and lead particles can be moved by erosion;
- Lead associated with small soil particles can be moved by wind; and
- Dissolved lead can migrate through soils to groundwater under certain conditions.

2.2 Lead Shot Exposure/Ingestion

In general lead shot released at SPRs poses risks to fish and wildlife by three exposure pathways:

1. Wildlife (mostly birds) may consume lead shot;
2. Lead may make its way into the food chain by consumption of lead present in or on food items or via incidental ingestion of soil/dust by prey organisms; and
3. Wildlife may be exposed to lead contamination via direct contact (e.g., burrowing) and/or incidental ingestion of sediment, soil, or surface water contaminated with lead.

Current research indicates that the ingestion of shot by birds is the most significant ecological risk posed by lead shot. Consumption of one lead shot pellet can be fatal (Buerger et al. 1986). Because lead shot consumption is a major ecological concern, it has been more thoroughly investigated than the other lead exposure routes mentioned above and is addressed in the greatest detail in this paper.

2.2.1 Exposure to Lead Shot

2.2.1.1 Lead Shot Consumed as Grit

Lead shot that remains intact after being discharged poses a greater ecological concern to wildlife than other forms of lead because shot can be consumed by birds that use small gravel or grit in their gizzards to aid with digestion. Peddicord & LaKind concluded that as many as 20 bird species use grit particles ranging in size from 0.5 millimeters (mm) to 2.8 mm (Peddicord 2000). Shot sizes seven through nine, which are typically used at SPRs, fall within this range (Table 1).

Because lead shot can become eroded and soluble during digestion via grinding of food and grit in the low pH environment of the gizzard, the ingestion of a single shot can be fatal. Buerger et al. showed that 24% of birds treated with one #8 lead shot pellet died and the LD50 (single dose lethal to 50% of a test population) estimated from this experiment was approximately two #8 pellets (Buerger 1986). The toxicity of these lead particles is dependent on several variables such as diet and bird species (see Section 3.0).

For bird species that use grit particles in their gizzards, the grit particle size is usually greater than 0.5 mm in diameter. For purposes of ecological risk assessment at SPRs, the portion of lead shot that is broken into small fragments less than 0.5 mm is assumed to become part of the soil matrix.

Table 1: Comparison of Lead Shot and Soil Particle Sizes

Shot Size (1)	Pellet Diameter (2) (mm)	Equivalent Soil Particle Size (3)	Familiar Reference (4)
6 to T(5)	2.79 to 5.08	Fine Gravel	Peas, Rock Salt
7	2.54	Course Sand (2.00 to 4.75 mm)	Kosher Salt (1 to 4 mm)
7.5	2.41		
8	2.29		
8.5	2.16		
9	2.03		
--	--	Fine Sand (0.48 to 2.00mm)	Table Salt (0.5 mm)

(1) Pellet sizes 7 through 9 are typically used for Trap, Skeet and Sporting clays applications. Other pellet/particle sizes are shown for comparative purposes.
(2) Federal Cartridge Company 2006 Product Guide
(3) ASTM D 2487, Unified Soil Classification System
(4) Various sources in the public domain
(5) 5.08 mm shot is by convention designated by “T”

Factors that influence the ingestion of lead shot include: density of lead shot, feeding habits, sediment firmness, depth of water, pellet size, ice cover, season, and availability of alternative food sources. Bellrose and U.S. Fish and Wildlife Service (USFWS) staff at the Northern Prairie Wildlife Research Center recognized that certain species of birds are more likely to incidentally ingest lead shot (Bellrose 1959).

The propensity to incidentally ingest lead shot varies considerably by species (Figure 1). The bay diving ducks have the highest propensity to incidentally ingest lead shot. Data from studies pre-dating hunting bans indicate that from 12 to 28% of the grit ingested by diving birds was composed of lead shot (Bellrose 1959). Even within one species the variability appears to be quite high. Shot ingestion of Canada Geese (*Branta Canadensis*) varied considerably from 1.9 – 44.1%, depending on the state in which data were collected.

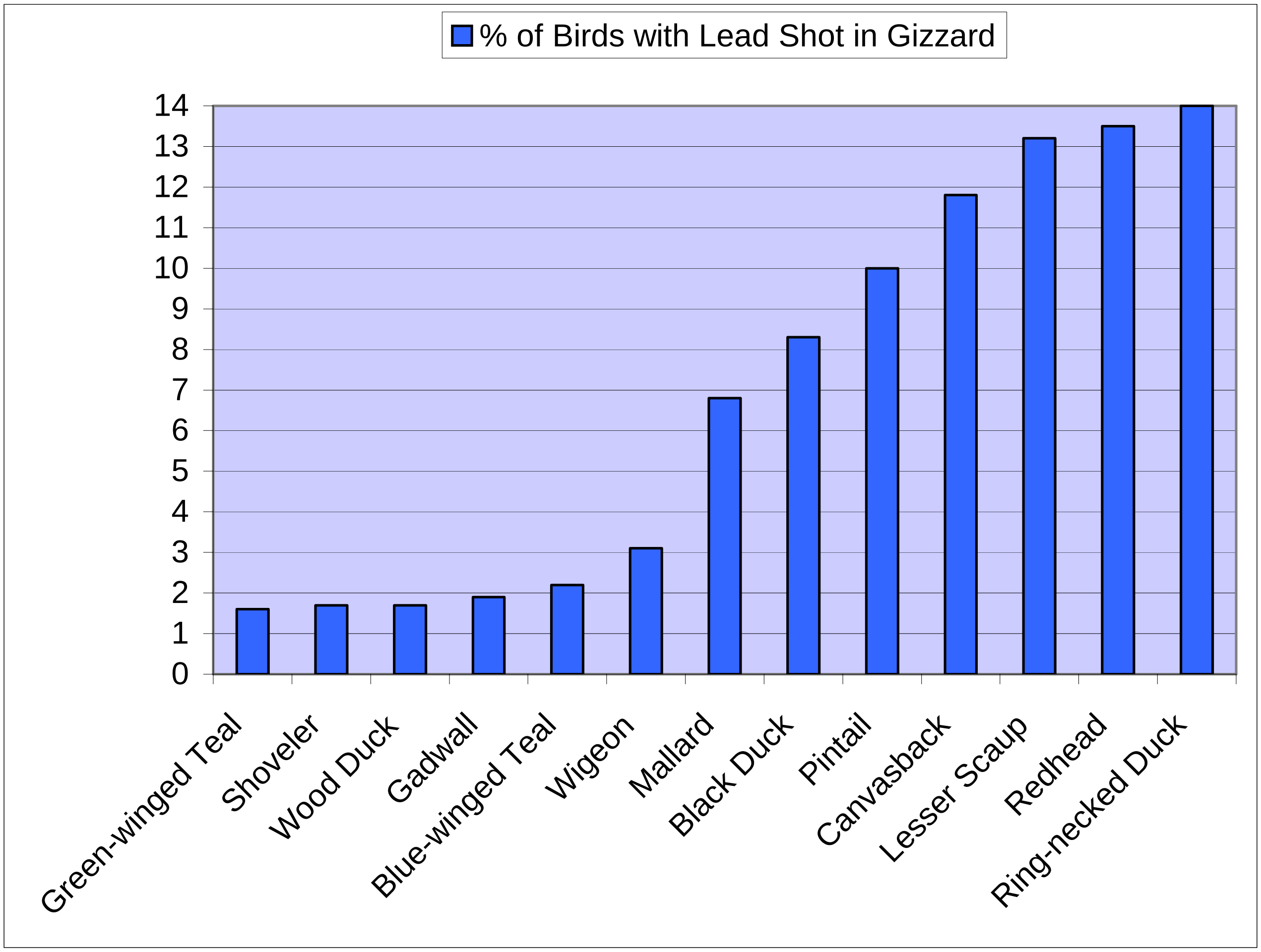

Figure 1: Percent of Waterfowl Gizzards Containing Lead Shot – (Data from Bellrose 1959). Data collected from 35,220 gizzards of various duck species collected in North America. All of these species have at least a portion of their life cycle in Massachusetts.

2.2.1.2 Reduction of Exposure by Sedimentation

Although lead shot will settle to the bottom of water bodies and subsequently be covered over by the accumulation of new sediment in many places, waterfowl can forage to as much as one foot below the sediment surface to acquire food items. The U.S. Geological Survey (USGS) studied blue-winged teal (*Anas discors*) and wood ducks (*Aix sponsa*) and found that their feeding on bottom mud and sediment was so intense in some areas that over a period of several weeks one foot of fine silt was removed from the bottom as ducks worked deeper and deeper to obtain food (USGS 2006).

Wetlands accumulate sediment at varying rates that fluctuate from year-to-year depending on wetland type and annual productivity. However, most wetlands accumulate between 1 and 10 mm of sediment per year. Many of the wetlands adjacent to SPRs may experience significant sedimentation rates that can eventually bury lead shot, limiting or eliminating exposures to ecological receptors.

Sedimentation rates can vary greatly from one habitat to another. Sedimentation rates for lakes range from 0.1 – 5 mm/yr (Callender 2000). In Nauset Marsh in Massachusetts, the sedimentation rate averaged 2.4 mm/year between 1921 and 1993 (Roman et al. 1997). The Wequetequock-Pawcatuck tidal marsh in Eastern Connecticut has had a sedimentation rate of 2.0-2.5 mm/year since 1938 (Warren and Niering 1993). In Narragansett Bay, the average sedimentation rate is 4.3 mm/yr in low marsh sites and 2.4 mm/yr in high marsh sites (Bricker-Urso et al. 1989). Sediment accumulation rates in San Francisco Bay ranged from 6.5 to 10 mm/year according to a U.S. Navy study (NAVFAC 2005).

Lead shot deposited onto solid ground (soil, firm bottom) is not likely to be accessed by wildlife much beyond the first few inches of the surface. If soil accumulates slowly, however, or if shot is continually deposited in an upland or aquatic environment, wildlife exposures are likely to continue.

2.2.2 Exposure to Soil, Sediment or Surface Water Contaminated by Lead

While direct ingestion of shot is likely to pose a greater risk than exposure to soil, sediment or surface water contaminated by lead, it is nevertheless very important to consider exposures to all contaminated media in risk assessments at lead shot sites. Management practices and remediation strategies to reduce exposure to shot may not eliminate all other significant exposures. Therefore risk management strategies should address both lead shot and environmental media contaminated by lead.

Lead exposures to fish, piscivorous birds, and herbivores are not commonly addressed in ecological risk assessments related to lead shot because the degree to which these organisms are exposed to dissolved or weathered lead is believed to be significantly less than the risks posed to birds or animals that might ingest lead shot. Because much of the lead in the environment is not readily soluble, exposure to lead contaminated surface water does not appear to be a common ecological pathway. Exposure to lead contamination in soil or sediment may be significant in some cases, but where lead shot is present it generally poses the greatest risk.

Dissolved lead is more toxic than total lead because it is more bioavailable. For all species, effects were most pronounced at elevated water temperatures and reduced pH, in comparatively soft waters, in younger life stages, and after long exposures (Eisler 1988). These conditions are not uncommon in Massachusetts, where hardness is typically lower than 25 milligrams per liter (mg/L) (as calcium) and many surface water bodies are at least slightly acidic.

Some metals, such as mercury, tend to biomagnify or increase in concentration as they move up the food chain. While inorganic lead does not tend to biomagnify (USEPA 2006), lead in soil can get onto food items via dust on prey items, or could be incidentally ingested with other food items. Lead shot and shot fragments may also be consumed incidentally by other birds or wildlife feeding on seeds, insects or other food items on or near the soil or sediment surface. Finally, in aquatic environments, lead in sediment can be incidentally ingested or taken up by benthic invertebrates subsequently preyed upon by fish, waterfowl or semi-aquatic wildlife.

Assessment of lead shot pellet counts per square foot should be coupled with assessment of soil lead concentrations because at most sites at least a portion of the lead shot will have degraded into small particles. This degraded or weathered lead could also pose ecological risks and should be considered in conjunction with lead shot pellet counts.

2.3 Effects of Concern

This section discusses effects of lead toxicity for various receptor groups. Lead adversely affects the survival, growth, reproduction, development and metabolism of many species under controlled conditions, but under natural conditions its effects may be substantially modified by physical, chemical, and biological variables. Lead is an accumulative metabolic poison that affects behavior, as well as the hematopoietic, vascular, nervous, renal, and reproductive systems (Eisler, 1988). In general, organolead compounds are more toxic than inorganic lead. Food chain biomagnification of lead is "negligible and immature organisms are most susceptible" (Eisler 1988).

Lead binds to proteins, particularly enzymes, and alters their biological function. Lead poisoning produces severe degenerative changes in the central nervous system (cerebral necrosis and death), in the peripheral nervous system (various forms of paralysis), in the blood and blood-forming tissues (anemia and impaired synthesis of hemoglobin), and in the kidney (Kendall et al. 1996). Lead has been shown to cause reproductive and immune system effects. Lead also affects liver and thyroid function and disease resistance (USEPA 2006). Effects for specific receptor groups are discussed below.

2.3.1 Plants

Toxicity to plants is limited by the low bioavailability of lead from soils (Eisler 1988). However, in low pH or low organic content soils, plants readily accumulate lead. Lead inhibits plant growth, reduces photosynthesis, and reduces mitosis and water absorption. Lead adversely affects algae growth in the aquatic environment.

2.3.2 Invertebrates

Lead exhibits significant toxicity to soil invertebrates and benthic invertebrates. Bioconcentration factors (BCFs) in invertebrates ranged from 1 to 650 depending on the species and concentration (Eisler 1988). Bioconcentration refers to the accumulation of chemicals in the tissue of a fish or other organism from water. Bioaccumulation refers to the accumulation of a chemical in the tissues of an organism to levels greater than levels in the environment.
Lead bioaccumulates in algae, macrophytes, and benthic organisms, but the inorganic forms of lead do not increase in concentration as they move up the food chain (USEPA 2006).

2.3.2 Fish

Fish exposed to high levels of lead exhibit a wide range of effects, including muscular and neurological degeneration and destruction, growth inhibition, mortality, reproductive problems, and paralysis (USEPA 2006).

2.3.3 Amphibians

There is limited toxicity information for lead and amphibians. Toxic effects include loss of sodium, reduced learning capability, and developmental problems (USEPA 2006).

2.3.4 Mammals

Lead poisoning in mammals can cause damage to the nervous system, kidneys, and liver, sterility, growth inhibition, developmental retardation, and effects to the blood (USEPA 2006).

2.3.5 Birds

Lead is a metabolic poison affecting a large number of biological functions, including survival, reproduction, growth, development, and behavior (DeFrancisco et al. 2003; Eisler 1988). Although acute effects of environmental lead have been documented at a number of sites, "most cases of acute effects from lead have been attributed to ingestion of spent lead shot" (Kendall et al. 1996).

2.3.6 Birds & Mammals – Lead Shot

Analysis of field and laboratory data indicates that the toxicity of lead shot ingested by birds is dependent on a number of variables (e.g., condition of the bird, climate, gender, age, and diet). Ingested lead shot can partially or completely dissolve in the acid environment of a bird's stomach. Among species, there are differences in stomach acidity, and the degree of physical abrasion that the lead shot undergoes in the gizzard.

The type of diet a bird is consuming contributes significantly to the toxicity of ingested lead shot. If a bird is consuming a soft diet (such as aquatic plants) that does not require much grinding by the gizzard, exposure to lead shot is generally lower (Kendall et al. 1996). If the diet is harder (such as grain or corn), then considerable grinding in the gizzard is required for digestion. If lead shot is present in the gizzard, then the grinding process can release significant amounts of lead, resulting in increased lead uptake and toxicity (Heusmann 2006). Diets higher in protein and calcium reduce the effects of lead poisoning and may reduce weight loss resulting from lead poisoning (Sanderson & Bellrose 1986).

Lead shot retention varies based on bird species, diet, body size, and season. When grit is readily available, birds ingest and eliminate considerable amounts of grit daily, whereas birds without ready access to grit tend to reduce grit elimination (Stafford and Best 1999). Hard food diets may increase grit consumption rate because the food needs more grinding to digest properly. Retention time may also be increased with hard food diets (Stafford and Best 1999). Nine of ten cowbirds (*Molothrus ater*) dosed with a single size 7.5 lead shot pellet and fed a natural diet excreted the shot within one day (Vyas 2001). In the house sparrow, most grit was excreted and replaced in five days (Gionfriddo and Best 1995; Best 1995). Gionfriddo and Best (1996) investigated avian grit use by examining the gizzard contents of 1440 birds collected from 12 states. Grit was present in 62 of 90 species and varied greatly in number and mean particle size. Mean grit size increased linearly with the log of bird body mass.

Animals without gizzards that incidentally ingest some soil with dietary items may occasionally ingest lead shot and this model has also been applied to them. Peddicord & LaKind (2000) conducted a bench-scale test to determine the bioavailability and absorption through the gut. Pellets were placed in solution of pH 2 or 6.5, approximating the stomach and small intestine pH levels, respectively, of mammals. Pellets were placed in each solution for up to 30 hours, the estimated retention time of a ruminant such as the white-tailed deer. By measuring dissolved lead, an estimate could be made of the exposure and uptake from a lead pellet in the gut. By estimating the number of lead pellets per gram of soil, and the amount of incidental soil ingested, an estimate can be made of the total lead dose to the animal from ingestion of soil contaminated with lead shot.

There are numerous studies in the scientific literature that document lethal and sublethal effects of ingestion of lead shot by birds in laboratory experiments. Longcore et al. (1974) found mortality rates in the mallard ducks ranged depending on shot size and number of shot ingested. Data from that study are summarized in Table 3.

Table 3: Lead Shot Doses Associated with Mortality

Single Oral Dose	Effects
1 No. 6 shot (1.0 g)	Mortality 9% in 20 days
1 No. 4 shot (1.6 g)	Mortality 19% in 20 days
2 No. 6 shot (2.0 g)	Mortality 23% in 20 days
4 No. 6 shot (4.0 g)	Mortality 36% in 20 days
6 No. 6 shot (6.0 g)	Mortality 50% in 20 days
8 No. 6 shot (8.0 g)	Mortality 100% in 20 days

Several different investigators have reported toxicity and mortality from ingesting one or two lead shot. A study of single oral dose of 2 shot (254 mg) in the black duck reported weight loss, emaciation, and mortality (Chasko et al. 1984). A single oral dose of one No. 8 shot (72 mg) administered to mourning doves resulted in 24% mortality in 4 weeks (Buerger et al. 1986). Three of ten cowbirds (*Molothrus ater*) dosed with a single size 7.5 lead shot died within one day (Vyas 2001).

3.0 Risk Assessment/Management Approaches

3.1 Massachusetts Contingency Plan (MCP) Approach

The Office of Research & Standards (ORS) attempted to identify ecological risk assessments on sites contaminated with lead shot in Massachusetts. ORS could not locate any ecological risk assessments conducted at hazardous waste sites in Massachusetts with lead concentrations comparable to concentrations found at SPRs. In fact, ORS could not locate any ecological risk assessments for SPRs that have been completed in accordance with MCP guidance. However, there are several lead shot-related sites in Massachusetts that are currently being evaluated and ORS is reviewing sampling data for these sites.

In the absence of any ecological risk assessments completed for SPRs under the MCP, this section will review the general assessment approach and types of information that ORS would apply at a SPR evaluated under the MCP. The MCP ecological risk assessment/risk management decision process is depicted in Figure 2 (end of document). The steps for an MCP ecological risk assessment include: (1) Background Comparison; (2) Stage I Environmental Screening; (3) Determination of Readily Apparent Harm; (4) Determination of an Imminent Hazard; (5) Stage II Environmental Risk Characterization; (6) Determination of Substantial Hazard; and (7) Applicable Standards. These steps may be appropriate to the evaluation of lead shot at SPRs and are presented in greater detail below.

3.1.1 MCP Approach: Comparison of Site Concentrations to Background Levels

For MCP purposes, if the concentrations of a contaminant of potential concern (COPC) at a site are consistent with background levels, no further evaluation or remediation is necessary. Evidence that site conditions are consistent with background concentrations demonstrates a condition of "no significant risk of harm" under the MCP and no further risk assessment work is needed. While portions of SPRs sites may be screened out as being consistent with background conditions, any areas within the shot fall zone will likely be above background lead soil or sediment concentrations and require further assessment.

Under the MCP, site concentrations may be compared to published (generic) background concentrations or to a site-specific data set. Site-specific background levels are always preferable to generic background levels. Generic lake and pond sediment and soil background levels are presented below.

Lake and pond sediment background lead levels:

- 144 mg/kg Sediment 95th Percentile (Pristine Ponds) MassDEP 1997
- 104 mg/kg Sediment 75th Percentile (Pristine Ponds) MassDEP 1997
- 56 mg/kg Sediment 50th Percentile (Pristine Ponds) MassDEP 1997

Background levels found in streams and rivers are likely to be lower, because rivers and streams are typically higher energy environments with larger grain sizes, lower organic carbon content, and lower concentrations of associated metals. No appropriate data sources for rivers and streams have been located to date.

Soil background lead levels:

- 100 mg/kg MassDEP Soil Background (90th Percentile) MassDEP 1996 & 2002

The 100 mg/kg background value is meant to be compared to all soil samples at the site. To be considered within background in Massachusetts, all soil lead samples must be below 100 mg/kg. Section 2.3 of the Guidance for Disposal Site Risk Characterization (MassDEP 1996) provides guidance on how to assess background conditions at disposal sites.

3.1.2 MCP Approach: Stage I Environmental Screening

Stage I screening is performed for each environmental medium. Screening benchmarks for various environmental media are presented below. When screening benchmarks are not exceeded, a condition of no significant risk is present and no further risk assessment work is needed.

3.1.2.1 Soil Screening

In the terrestrial environment, a site can be screened out for ecological risk if the area of contaminated soil represents less than two acres of habitat (MassDEP 1996). The reader is referred to the MassDEP guidance for more details. To date, MassDEP has not adopted soil-screening concentrations for terrestrial ecosystems.

3.1.2.2 Sediment Screening

MassDEP has published sediment-screening criteria for several Oil and/or Hazardous Materials (OHMs). The recommended MassDEP sediment screening benchmark for lead is 130 mg/kg. This is based on the probable effect concentration (PEC) from MacDonald et al. (2000) and was intended to identify a contaminant concentration above which harmful effects on sediment-dwelling organisms were expected to occur frequently.

In addition, MassDEP has proposed size-based criteria for screening sediment. In the aquatic environment, a site can be screened out for ecological risk if the area of sediment contamination is less than 1,000 square feet (MassDEP 2006a). There are some exceptions to the size-based screening criteria and the guidance documents should be consulted when performing this screening.

3.1.2.3 Surface Water Screening

MassDEP has adopted as screening values the lowest National Recommended Water Quality Criteria (NRWQC) published by U.S. EPA pursuant to the Clean Water Act. The published value for lead in water with a hardness of 100 mg/L is 2.5 ug/L (NRWQC).

3.1.2.4 Considering Rare and Endangered Species

Stage I must include consideration of the presence of endangered, threatened, and special concern species and areas of critical environmental concern. The Natural Heritage & Endangered Species Program of the Massachusetts Division of Fisheries and Wildlife has identified 12 bird species in Massachusetts that are considered endangered (i.e., in danger of extinction in Massachusetts) and 16 more that are either threatened or species of special concern. Species considered endangered include Sedge Wrens and Henslow's Sparrows. A complete listing of endangered bird species in Massachusetts can be found at http://www.mass.gov/dfwele/dfw/nhesp/nhrare.htm. If endangered, threatened, and special concern species are present at a site evaluated under the MCP, a Stage II environmental risk characterization must be completed (unless it has already been determined that there is readily apparent harm).

3.1.3 MCP Approach: Readily Apparent Harm

The MCP (310 CMR 40.0995(3)(b)) defines as Readily Apparent Harm: "Visible presence of oil, tar, or other non-aqueous phase hazardous material in soil within three feet of the ground surface over an area equal to or greater than two acres, or over an area equal to or greater than 1,000 square feet in sediment within one foot of the sediment surface." The readily apparent harm provision is aimed primarily at sediment and soil containing oil and tar, but the presence of lead shot is an essentially analogous condition; it is visible and known to be harmful. Most SPR shot fall zones are likely to have conditions that meet the definition of readily apparent harm. If MCP risk assessments are applied to lead shot sites, it may be appropriate to consider a shot density criterion for readily apparent harm in addition to the area criterion described above.

In addition to the presence of non-aqueous material described above, the existence of oil and/or hazardous material attributable to the disposal site in concentrations that exceed Massachusetts Surface Water Quality Standards is also a condition defined as readily apparent harm. The

Massachusetts Surface Water Quality Standard for lead is hardness-dependent and is based on the USEPA National Recommended Water Quality Criterion for lead (i.e., 2.5 ug/L).

If a condition of readily apparent harm exists in any environmental medium, then a condition of "no significant risk of harm" does not exist and a Stage II Environmental Risk Characterization is not required to make the determination for that medium. The next step would be evaluating remedial goals and alternatives for cleanup and their feasibility.

3.1.4 MCP Approach: Stage II Environmental Risk Characterization

As shown in Figure 2, if the definition of readily apparent harm is not met and if lead concentrations exceed the screening criteria and background levels, then a Stage II environmental risk characterization is required. The high levels of lead shot found at most SPRs are likely to result in a need for Stage II site-specific risk assessment under the MCP (analogous to a Method 3 human health risk characterization under the MCP or a baseline ecological risk assessment in the federal Superfund process). Stage II risk assessments conducted in areas with known rare and endangered species would likely require more stringent risk assumptions on the basis that the loss of a single individual can be significant.

The first step of a Stage II Environmental Risk Characterization is problem formulation, in which the assessment endpoints and the measures of effects are selected. Assessment endpoints typically represent various groups of environmental receptors (such as benthic invertebrates). Measurement endpoints are selected to evaluate effects to these receptors (such as sediment toxicity tests and benthic community surveys). Lead that has leached from lead shot into soil, sediment, or surface water can be evaluated by standard ecological risk assessment measures of effect in a weight of evidence approach. These measures of effect include comparison to benchmarks, sediment toxicity tests, sediment biological abundance and diversity surveys, food chain models and acid volatile sulfide/simultaneously extracted metals (AVS/SEM) measurements. These measures of effect are outlined below.

3.1.4.1 Benchmarks

Benchmarks are concentrations in soil, sediment, or surface water that have been published in the scientific and technical literature as being associated with low level effects or no level effects. They may be used in a Stage II Environmental Risk Characterization to evaluate risk from exposure to soil, sediment and surface water contaminated by lead. Benchmarks are specific to an environmental medium and are usually expressed in units of milligram lead per kilogram soil/sediment or microgram lead per liter of water. Commonly used comparison values are summarized below:

<u>Soil Benchmarks for Lead</u>

- 20 mg/kg — Eco-SSL for plants — USEPA 2005a
- 1700 mg/kg — Eco-SSL for Soil Invertebrates — USEPA 2005a
- 11 mg/kg — Eco-SSL for Birds — USEPA 2005a
- 56 mg/kg — Eco-SSL for Mammals — USEPA 2005a

Ecological Soil Screening Levels (EcoSSLs) are benchmarks developed by USEPA to be protective of specific receptor groups. The lead EcoSSL document contains a caveat that the levels "are derived for the inorganic forms of lead found in soils and are not derived for either organic lead compounds or metallic lead shot." If these lead sources are suspected to be present or are present, then a site-specific evaluation of risks associated with these forms of lead will be required outside the use of the EcoSSL values. The EcoSSLs were not meant to evaluate ingestion of lead shot by birds and mammals and may not be protective of this type of exposure. Birds are the most sensitive endpoint in the terrestrial environment, according to USEPA EcoSSLs. The EcoSSLs are concentrations above which further site assessment is needed. EcoSSLs are not be used as cleanup values without further evaluation.

<u>Sediment Benchmarks for Lead</u>

- 130 mg/kg — Probable Effect Concentration — MassDEP 2006b, based on McDonald et al., 2000
- 35.8 mg/kg — Threshold Effect Concentration — MacDonald et al. 2000

A set of benchmark concentrations often cited are those presented by McDonald et al. 2000. The probable effects concentrations (PECs) from this paper are "contaminant concentration above which harmful effects on sediment-dwelling organisms were expected to occur frequently." The threshold effects concentrations (TECs), were derived to represent a level below which harmful effects are not expected to occur. Sediment samples with lead concentrations between the TEC and PEC concentrations would be considered potentially toxic.

<u>Surface Water Benchmarks for Lead</u>

- 2.5 ug/L* — Criteria Continuous Concentration — USEPA NRWQC
- 0.5 ug/L** — Criteria Continuous Concentration — USEPA NRWQC
- 65 ug/L* — Criteria Maximum Concentration — USEPA NRWQC
- 14 ug/L** — Criteria Maximum Concentration — USEPA NRWQC

**Criterion based on hardness of 100 mg/L as measured in Calcium Carbonate*
***Criterion based on hardness of 25 mg/L as measured in Calcium Carbonate*

National recommended water quality standards (NRWQCs) are published by EPA pursuant to section 304(a) of the Clean Water Act and may be used as surface water benchmarks for Method 3 Risk Assessment under the MCP. The NRWQC values represent dissolved concentrations and are hardness-dependent. USEPA is actively working on the criteria for lead and they may change this value in the future. The use of these benchmarks to assess risk has some uncertainty because actual toxicity of lead may vary depending on certain physical and chemical conditions including water temperatures and pH.

As previously noted, under the MCP, the NRWQC (as a Massachusetts Surface Water Quality Standard) is used both as a screening criterion and as an applicable standard indicative of significant risk. A chemical concentration greater than a Massachusetts Surface Water Quality Standard is defined by the MCP as a condition of readily apparent harm.

There are no benchmarks specifically for amphibians but NRWQCs have been interpreted as an indication of risk to these organisms.

Groundwater Benchmarks for Lead

- 10 ug/L		Method 1 GW-3 Standard		MassDEP

The MassDEP Method 1 GW-3 groundwater standard of 10 ppb was derived to protect aquatic organisms where groundwater discharges to surface water.

3.1.4.2 Additional Measures of Effects from Lead Contamination

Additional measurements of effects that have been used for evaluating risk from lead contamination and lead shot are provided below for different types of plants and animals.

Plants
Plant toxicity tests have been used for a number of federal SPR ecological risk assessments (USFWS and USEPA 2004; USFWS 2004; USFWS 2002). Plant tests typically evaluate plant germination, growth and root elongation. In the aquatic environment, USEPA's National Recommended Water Quality Criteria can be used to evaluate the potential for effects to aquatic plants.

Benthic Invertebrates
Sediment toxicity tests involve collecting contaminated sediment in the field and exposing standard laboratory organisms in a controlled laboratory setting. Toxicity results are compared to laboratory controls (clean sediment) and reference area sediment. Results of toxicity tests are always considered in comparison to controls. ORS recommends that these tests be of a chronic duration and should generally evaluate survival, growth, and reproduction.

Biological abundance and diversity surveys are conducted by collecting sediment samples at the site and at a reference area that represents local conditions. Site and reference samples are compared using metrics for total abundance and species diversity of benthic organisms.

Acid Volatile Sulfide/Simultaneously Extracted Metals (AVS/SEM)
AVS/SEM is an indicator of toxicity of metals in sediment. There are a number of studies in the literature that document the sequestration of divalent metals (including lead) by sulfides in sediment on a 1:1 molar basis. There have also been a number of studies that have concluded that AVS/SEM analysis oversimplifies a complex environmental process of bioavailability. ORS believes that AVS/SEM is useful in a weight of evidence approach, but should not be used to overrule other stronger lines of evidence, such as sediment toxicity tests or benthic abundance and diversity surveys.

Soil Invertebrates
Soil invertebrates can be evaluated using the appropriate USEPA EcoSSL (2005) as a benchmark. In addition, terrestrial toxicity tests have been used at a number of federal SPRs ecological risk assessments (USFWS and USEPA 2004; USFWS 2004; USFWS 2002). A common terrestrial invertebrate toxicity test is the earthworm (*Eisenia foetida*) test. The earthworm test is a 28-day study that evaluates survival, growth, and bioaccumulation against exposure to a range of concentrations of a contaminant of concern.

Fish
The potential for toxicity to fish is typically evaluated by comparing surface water concentrations to USEPA's National Recommended Water Quality Criteria (NRWQC). See

Section 3.1.4.1 for benchmark values. Exceeding the NRWQC is, by definition, a condition of significant risk under the MCP. In addition to comparing to the NRWQC, surface water toxicity tests are often performed using a test species such as the fathead minnow.

Birds and Mammals
Food chain models are the measure of effects most often used to estimate exposure in the diet of birds and mammals. These models estimate any bioaccumulation in prey organisms and use standard assumptions to estimate dietary exposure in terms of average daily dose (mg/kg/day). The average daily dose is compared to a safe exposure level (in mg/kg/day) to characterize risk. Food chain models can be used to evaluate the potential for toxicity to birds and mammals in the terrestrial and aquatic food chains.

3.1.4.3 An Optional Approach for Assessing Lead Shot Exposure and Risk

The risk of ecological harm from lead shot has not been quantified in MCP risk assessments to date. If MassDEP decides to assess lead shot risks under the MCP, or to apply quantitative risk assessment under a different program, risk assessment procedures used by other agencies and other states may be applicable and informative. Assessing the risk posed by this exposure pathway requires an estimate of how much lead shot is likely to be ingested. Peddicord & LaKind (2000) developed an ingestion probability model to evaluate the ingestion of lead shot by birds and mammals. This model has been applied to birds more often than mammals because of the relative sensitivity of birds.

The Peddicord & LaKind model is based on certain assumptions and has some restrictions and limitations. This model was developed from the binomial probability formula and only models risk to those birds that consume grit to aid digestion. The model does not address lead toxicity, but the probability that a bird requiring grit will ingest a lead shot. Peddicord & LaKind (2000) made the environmentally conservative assumption that ingestion of one lead shot would be fatal. Currently the Peddicord & LaKind model is the only peer-reviewed model of its kind and has been used at a number of sites with lead shot contamination.

Like all models, the Peddicord & LaKind model requires careful application and the quality of the estimates generated by the model are only as good as the data going into the model. ORS has not done an exhaustive review of the mathematical suitability of this model and does not specifically recommend its use for ecological risk assessment. However, given the current lack of alternatives, the Peddicord & LaKind model can be a useful tool to assess lead shot exposure risks for birds.

While shot is generally considered an appropriate size for grit ingestion, bullet fragmentation may create irregularly shaped particles of various sizes and textures that may not be appropriate for grit ingestion. Therefore, this model is most appropriate for use at sites where shotgun pellets are the primary source of lead.

There are a number of assumptions in the lead shot ingestion model. In this model, ingestion of a single piece of lead shot is conservatively assumed to be fatal. The effects of lead shot pellet ingestion by birds vary with the type and amount of food, sex, age, and size of the bird and may or may not include death. Therefore, the calculated risk depends not on the clearly established, yet somewhat variable, toxicity of lead (depending on the exposure circumstances) but on the probability that a bird requiring grit will ingest a single lead shot pellet. Many birds (at least 20 species) use grit particles in the 2.8 to 0.5 mm size class and this has typically been used for ecological risk assessments. The model was developed to evaluate the possibility that a bird would ingest at least one lead shot pellet from the site during its lifetime and assumes that the shot ingestion is fatal.

The model estimates the probability of ingesting a lead particle and extrapolates effects from the individual to the population level. A 10% probability of a bird ingesting a lead shot pellet over its lifetime has been used as an acceptable risk (USFWS & USEPA 2004). This assumes that every bird that ingests lead shot will die, or 10% mortality from lead shot ingestion of a sub-population of birds at a site. USFWS and USEPA consider 10% lead shot mortality to be an acceptable population risk. Application of this 10% risk limit under any MassDEP regulatory program would require an explicit risk management determination that this risk management criterion is appropriate.

While the model developed by Peddicord & LaKind has been applied in a number of cases (see Section 3.2), at least one alternative model has been used to evaluate lead shot exposure. Battelle et al. (2004) developed a site-specific binomial probability model for the Alameda Naval Air Station. Exposure assumptions and estimations for diving ducks were incorporated into a site-specific probability model that was developed specifically for diving ducks (i.e., scaups and scoters) that forage in subtidal sediments of 10 feet or more below the water's surface. This model was developed from the binomial expansion formula. This model estimates the likelihood that a bird may ingest either grit or lead shot within the grit size range in a given number of attempts (or dives for grit). While the Peddicord & LaKind (2000) model was published in a peer-reviewed journal and has been used at a number of sites, the Battelle model was developed specifically for the Alameda site and has not been published in the scientific literature, nor has it been used at other sites with lead shot contamination.

ORS has not approved or adopted either of the probabilistic exposure models that have been used, nor have we evaluated all of the exposure inputs to the models. With or without probabilistic estimates of exposure, however, it is clear that when large quantities of lead shot are present on or near the surface of soil or sediment, some percentage of birds and mammals will ingest shot, and a percentage of those will die.

The number of shot per square foot screening method may be used to make a rough estimate of the potential ecological risk a site presents. However, assessment of lead shot counts per square foot must be coupled with assessment of soil lead concentrations because at most sites at least a portion of the lead shot will have degraded into small particles. This degraded or weathered lead also poses ecological risks and should be considered in conjunction with lead shot counts per square feet.

3.1.5 MCP Risk Management Considerations

Under the MCP, if the risk assessment does not demonstrate a condition of "no significant risk of harm to the environment" (i.e., there is significant risk of harm), then the feasibility of eliminating or reducing the risk must be evaluated. If cleanup to meet a condition of no significant risk is deemed not feasible, then a permanent solution (Class A or B Response Action Outcome or RAO) is not achievable. In such a case, a temporary solution is appropriate as long as the conditions outlined in the MCP are met.

The feasibility study must include consideration of damage to natural resources that would result from remediation. The environmental benefits of cleanup should be balanced against the environmental cost. Temporal considerations are a key component of "risk balancing" decisions. For example, short-term impairment of a wetland may or may not be considered a justifiable cost for removing persistent contamination that will pose significant risk for the long term depending in part on the magnitude of the impairment.

In addition to assessment of long-term risks, the MCP also requires assessment of shorter-term risks and comparison of site concentrations to certain standards. These requirements are summarized in the sections that follow.

3.1.5.1 MCP Determination of an Imminent Hazard

An Imminent Hazard is a hazard that would pose a significant risk of harm to the environment if it were present for even a short period of time. The following conditions constitute an Imminent Hazard to the environment (310 CMR 40.0955(3)):

- Evidence of stressed biota attributable to the release at the disposal site, including, without limitation, fish kills, or abiotic conditions; or
- A release to the environment of oil or hazardous material which produces immediate or acute adverse impacts to freshwater or saltwater fish populations.

As an example, stressed vegetation or a bird die-off at a lead shot site could indicate Imminent Hazard conditions.

3.1.5.2 MCP Determination of Substantial Hazard

Some SPRs may meet the definition of an Ecological Substantial Hazard (310 CMR 40.0956(2)). If a Substantial Hazard exists at a site, remedial measures are required.

There are a number of criteria for a Substantial Hazard, and this paper does not list all of them. However, the following criteria are most pertinent. A condition of no substantial hazard to the environment exists if steps have been taken to eliminate or mitigate any of the following conditions affecting an environmental resource at a site:

- Visible presence of oil, tar, or other non-aqueous phase hazardous material in soil within three feet of the ground surface over an area equal to or greater than two acres, or over an area equal to or greater than 1,000 square feet in sediment within one foot of the sediment surface;
- Continuing discharge of contaminated groundwater to surface water where surface water or sediment concentrations already pose a significant risk or exceed Massachusetts Surface Water Quality Standards.

3.1.5.3 MCP Applicable Standards

Under the MCP, a condition of no significant risk of harm to the environment can be demonstrated only if concentrations of OHM at or from the disposal site do not and are not likely to exceed any applicable or suitably analogous environmental standards which have been formally promulgated, including Massachusetts Water Quality Standards promulgated at 314 CMR 4.00. Applicable standards must be considered in addition to the conclusion of the risk assessment. A condition of no significant risk of harm to the environment can be demonstrated only if (1) the risk assessment demonstrates a condition of no significant risk and (2) site concentrations do not exceed applicable standards. For toxic substances, regardless of the risk assessment outcome, if an applicable standard is exceeded, there is significant risk by MCP definition.

There are no applicable standards to protect for ecological risk in soil and sediment, but as noted in the preceding paragraph, Massachusetts Surface Water Quality Standards are applicable standards under the MCP. USEPA National Recommended Water Quality Criteria are cited as Massachusetts Surface Water Quality Standards. The surface water standard for lead in Massachusetts corresponding to a hardness value of 20 mg/L (as calcium) is 0.5 µg/L. Massachusetts uses a lower hardness value because waters in Massachusetts tend to have lower hardness than the national average used in the federal standards (i.e., 120 mg/L calcium).

3.1.5.4 MCP Upper Concentration Limits

Most SPR shot fall zones are likely to have conditions that exceed the soil Upper Concentration Limit (UCL) for lead. UCLs in soil and groundwater are concentrations of OHM that, if exceeded under the conditions specified at 310 CMR 40.0996(2), indicate by definition the potential for significant risk of harm to public welfare and the environment under future conditions. The Upper concentration limits for lead are:

Soil:	3,000 mg/kg
Groundwater:	150 µg/L

3.1.5.5 MCP Approach Conclusions

The magnitude of contamination at lead shot sites tends to be significantly greater than contamination at non-lead shot sites. Put simply, at least a portion of every SPR assessed under standard MCP approaches will likely pose significant risk if lead shot is used at the SPR.

3.2 Approaches Used by Other States and the Federal Government

3.2.1 Risk Management Approaches

Ingestion probability models, such as Peddicord & LaKind, have been used at a number of SPR sites across the country to derive shot densities to guide assessment and clean up. This model assumed that ingestion of one lead shot would be fatal to birds. This is a conservative estimate. Buerger et al. showed that 24% of birds treated with one #8 lead shot pellet died and the LD50 estimated from this experiment was approximately two #8 pellets (Buerger 1986). A summary of Lead Shot Ingestion Probability Models can be found in Section 3.1.4.3.

<u>Risk Management Approaches Used at Sites with Lead Shot Contamination</u>

- 3 – 13 Shot/ft^2 Patuxent ERA US Fish & Wildlife
- 3 Shot/ft^2 Bryant Range-Fort Devens USEPA Region I
- 7 - 9 Shot/ft^2 Prime Hook ERA US Fish & Wildlife

These values were applied as remedial goals by other agencies under different regulations. They were taken from several federal assessments of SPRs. To date, MassDEP has not adopted screening criteria for lead shot. The means by which a two-dimensional remediation goal (shot/ft^2) has been applied to a volume of soil or sediment has not been documented for any of the sites that ORS has identified. The soil/sediment depth likely will be very shallow for grit ingestion and deeper for foraging for prey and will be species-dependant.

3.2.2 Federal Approaches

In 1976, the U.S. Fish & Wildlife Service (USFWS 1976) concluded that lead shot is the primary source of lead available to wild waterfowl. This determination was the impetus for the national ban on lead shot for waterfowl hunting in 1991. USFWS is concerned that spent shot at SPRs is having an impact on migratory birds in aquatic environments and is interested in furthering the cleanup of these sites (Munney 2006).

A number of SPRs have been cleaned up under federal jurisdiction. Most of these have either been on former military bases, or are properties being transferred to USFWS to serve as national wildlife refuges. USEPA and USFWS have both been actively involved in cleanups. A number of these cleanup efforts are described below.

Prime Hook, Milton, Delaware.
The ecological risk assessment for the Prime Hook National Wildlife Refuge Lead Shot Site in Milton, Delaware, used a variety of measures of effects (USFWS 2004). Lead was detected in surface soils up to 100,000 mg/kg and shot density was recorded up to 68,564 shot/ft^2.
To evaluate risk from lead contamination in soil, samples were collected from grid nodes spaced 30 meters apart and analyzed for metals and lead pellets.

The ecological risk assessment evaluated terrestrial plants (plant toxicity test), aquatic invertebrates (amphipod toxicity test), terrestrial invertebrates (earthworm toxicity and bioaccumulation test), and insectivorous birds (robin food chain model). There was reduced survival in the earthworm test and reduced growth in the plant test. The hazard quotients calculated with food chain accumulation models using insectivorous birds and mammals exceeded one, indicating risk. No Observed Adverse Effect Level (NOAEL) and the Lowest Observed Adverse Effect Level (LOAEL) values were developed from these studies for the receptors. A comparison of toxicity tests and food chain models indicated that 421 mg/kg lead was the lowest LOAEL. A comparison of NOAELs calculated from toxicity tests and food chain models indicated that 310 mg/kg was the highest NOAEL that was still less than the lowest LOAEL. Therefore, the targeted Preliminary Remedial Goal (PRG) for soil and sediment should be within the range (310-421 mg/kg) of these values to be protective. A risk management decision was made to use 421 mg/kg as the Preliminary Remediation Goal (PRG) in sediment and soil. Because the site may be dry for long periods of time, the PRGs were chosen to be protective of all species, without designating separate soil or sediment cleanup values.

To evaluate risk from ingestion of lead shot for omnivorous waterfowl (i.e., mallard), and omnivorous upland birds (i.e., dove), a lead shot ingestion probability model was used. The risk assessment applied the LaKind & Peddicord model discussed in Section 3.1.4.3. The results of probability models for lead shot ingestion indicated that birds were at risk. Based on the results of the studies, preliminary remediation goals (PRGs) were developed for the cleanup of lead contaminated soil, sediment, and lead shot. By accepting an ingestion probability of 0.1, a PRG for lead shot was established at between 7 and 9 lead shot pellets/ft^2 for the protection of waterfowl and upland birds.

Patuxent Research Refuge in Laurel, Maryland.
This risk assessment evaluated risk from exposure to lead contaminated soil for earthworms, the American robin, and the short-tailed shrew. The remedial goals for the site were expressed as the concentration modeled between the NOAEL and LOAEL for each receptor. The remedial goal for the site was chosen to be a value between the highest NOAEL (46 mg/kg) and the lowest LOAEL (260 mg/kg). The geometric mean between these values is 109 mg/kg and represents the Maximum Allowable Toxicant Concentration (MATC). Based on this, EPA proposed a site-wide cleanup level of 100 mg/kg at the Patuxent Research Refuge.

The risk assessment used the Peddicord & LaKind lead shot ingestion probability model using the mourning dove. Since the probability model indicated that the mourning dove was at risk, remedial goals were determined by calculating a number of lead shot per unit area that would result in an acceptable probability (less than 10% of birds) that lead shot would be ingested. The Patuxent risk assessment established a cleanup goal for particulate lead expressed as 3 to13 lead particles of 0.5 mm to 2.8 mm in size per square foot (USFWS and USEPA 2004).

Fort Devens, Massachusetts.
USEPA recently completed an ecological risk assessment and cleanup of the Bryant SPRs at Fort Devens, MA (2005). The range is now the property of USFWS as part of the Oxbow National Wildlife Refuge. The range was used for machine gun and pistol practice. Birds were considered exposed to lead when the liver had greater than or equal to 2 mg/kg lead.

As part of the Bryant Range ecological risk assessment, USEPA Region I canvassed other EPA regions for ecological risk assessments for lead (USEPA 2005) including the Patuxent Research Refuge in Laurel, MD (USFWS and USEPA 2004). USEPA Region I used the cleanup levels established at the Prime Hook Wildlife Refuge. The site was cleaned up by a removal action where concentration of lead in soil exceeded 100 mg/kg. This value is an approximation of the geometric mean of the NOAEL (46 mg/kg) and LOAEL (260 mg/kg).

Skeet Range, Alameda Naval Air Station, Alameda California.
Ecological risks to diving ducks were evaluated from lead shot in sediments at a skeet range located at the former Alameda Naval Air Station in San Francisco Bay, CA (Tri-Service Ecological Risk Assessment Workgroup 2004 &Battelle et al. 2004). The skeet range was in operation for 30-40 years until operations ceased in 1993. Lead sediment data were collected approximately 10 years after shooting ceased. Radiological studies indicated that approximately 5cm of sediment have accumulated on the sediment surface since range closure.

Lead shot at the Alameda skeet range were concentrated in depths of 10-15 feet of water. Therefore, diving ducks that feed in water of at least 10 feet were chosen for this site-specific risk assessment. Based on the distribution of lead shot and the behavior of waterfowl in the area, the screening level ecological risk assessment (SLERA) identified greater scaup and surf scoter as the species that have the greatest potential for uptake of lead shot through incidental ingestion of sediment-borne lead shot or grit. A site-specific probability model was used to estimate the likelihood that a bird might ingest either grit or lead shot at each attempt to acquire grit.

This risk assessment included a SLERA and a baseline ecological risk assessment (BERA). In the SLERA, a toxicity reference value (TRV) was derived. The SLERA and BERA focused on lead shot because lead sediment concentrations were similar to background in San Francisco Bay.

A literature search was done to identify the number of shot pellets likely to cause the death of a bird. The review of studies for waterfowl exposure to lead shot pellets found that mortality ranged from less than 2 pellets to as many as 16 pellets. Studies with higher pellet counts were associated with birds with high protein diets. The final SLERA identified one no.4 lead shot pellet as a conservative estimate of an effects level. This translates into 2 lead shot pellet of size 7 ½, which was used as the TRV or No Observed Adverse Effects Level (NOAEL) for the SLERA. The effect measure in this NOAEL development is death. There are likely many additional effects from lead exposure that this measurement does not include (e.g., reduced weight, wing droop). A Low Observed Adverse Effects Level (LOAEL) of three no.7 ½ lead shot pellets was also identified as the effects-based benchmark for the SLERA.

Studies reviewed support the theory that diets higher in protein and calcium (e.g., bivalves) reduce the effects of lead poisoning on birds. When studies on scaup or scoter could not be located, studies conducted on waterfowl species with diets similar to greater scaup and surf scoter (i.e., high in protein) were used to develop the TRV.

To estimate the likelihood of shot ingestion, exposure assumptions and estimations for diving ducks were incorporated into a binomial probability model. A site-specific probability model was developed specifically for diving ducks (i.e., scaups and scoters) that forage in subtidal sediments 10 feet or more below the water's surface. This model was developed from the binomial expansion formula and estimates the likelihood that a bird may ingest either grit or lead shot within the grit size range in a given number of attempts (or dives for grit).

A Monte Carlo program was used to obtain an exposure probability distribution. In Monte Carlo analyses, exposure values are randomly drawn from the range of values for each exposure parameter. This approach is repeated many times for all exposure parameters generating a distribution of results for the binomial probability model. The model results are then used to estimate risk to the scaup and scoter.

The binomial model was run under two separate sets of assumptions. In the first run of the model, presented in the SLERA, very conservative exposure assumptions were used to estimate exposure risks to diving ducks. In the BERA, more realistic exposure assumptions were used to estimate risks. Both the SLERA and the BERA are discussed in the section that follows.

Screening Level Ecological Risk Assessment (SLERA) binomial probability model:

The SLERA binomial model assumed diving ducks make approximately 510 dives per day and that diving duck feeding range consists entirely of the impacted skeet range (referred to as a 100% site use factor). The SLERA model also assumed that the blood lead retention time was 49 days. This is a conservative estimate of how long lead stays in waterfowl. The assumption is that if lead shot exposures occur beyond 49 days, then any previously consumed lead shot will have been excreted. Any additional lead ingestion that occurs within a 49-day period would represent cumulative lead exposure. The SLERA model assumed that 42% of dives made by scaup or scoter were used to collect grit. This is a conservative estimate based on the maximum percentage of shot found in the gizzard/stomach of surf scoter in a study conducted in British Columbia (42%).

The SLERA binomial probability model used conservative exposure assumptions based on research conducted on diving ducks and other waterfowl with a focus on species similar to the scaup and scoter. "The results of the screening level binomial probability modeling indicate that lead shot measured at the skeet range may pose a potential risk to benthic-feeding birds that use the site under conditions resulting in maximum exposure." (Battelle 2004)

Baseline Ecological Risk Assessment (BERA) binomial probability model:

Exposure parameters were refined in the BERA to address uncertainty associated with the exposure and risk in the SLERA and to calculate a more realistic estimate of risks posed to diving ducks. To aid in this refinement, a Monte Carlo analysis was conducted to evaluate the effects of uncertainty in input variable values for the binomial probability risk model and the sensitivity of the model to the input variables.

For exposure variables with limited uncertainty for diving ducks (e.g., foraging time/day), the 95% upper confidence limit of the mean was used in the BERA. Exposure variables with high uncertainty were refined in the BERA via Monte Carlo analysis. For example, sensitivity analysis confirmed that the most sensitive variable in the model for each simulation was foraging range. The SLERA used a foraging range exposure assumption of 100% and this was adjusted to 1% in the BERA, based on estimates of scaup and scoter use of the impacted habitat.

The BERA Monte Carlo analysis indicated that approximately 96% of the time, less than 1 in 1,000 birds foraging at the site would potentially be at risk (i.e., would consume 3 size 7 ½ shot. The BERA concludes "there is very limited potential for unacceptable risk from exposure to lead shot posed to the avian community that may use the site" (Battelle 2004). The model supported a conclusion of *de minimu*s risk and a recommendation of no further action at the site.

In addition to presenting the model results that predicted a low probability of shot ingestion at this site, the report also emphasized that the lead shot at this site was being buried by sediment deposition and concluded that exposure to waterfowl was insignificant.

<u>Inland Ranges, Fort Ord California</u>.
A study was conducted at the Inland Ranges at Fort Ord, California, to evaluate uptake of lead into plants, insects, lizards, and small mammals (TSERWG 2004). Samples were collected to represent background, low, medium and high spent bullet concentrations. At each location, soil, plant, insect, lizard and small mammal samples were collected. Lead was found up to 872 mg/kg in plants, up to 485 mg/kg in insects, up to 220 mg/kg in lizards, and up to 23.5 mg/kg in small mammals.

<u>Fort McClellan, Alabama</u>.
Two Fort McClellan, Alabama small range sites (from 5 to 45 acres in size) were evaluated for ingestion of lead pellets as grit (TSERWG 2000). The turkey and northern bobwhite quail were chosen as receptor species and the Peddicord & LaKind (2000) model was used. No information was available on cleanup levels. The former SPRs and training areas of this site are being dedicated as a national wildlife refuge.

<u>Nahant Marsh Superfund Site, Davenport Iowa.</u>
In 1995, U.S. Fish and Wildlife Service (USFWS) discovered hazardous levels of lead shot on 13 acres of a 78-acre property owned by the Scott County Sportsmen's Association in Davenport, IA (Nahant Marsh, adjacent to the Mississippi River). U.S. Environmental Protection Agency

(EPA) testing further revealed concentrations of over 500 lead pellets per square foot in the top six inches of soil.

USEPA Region 7 performed a cleanup at a 95-acre marsh that was based on risk to waterfowl. The screening-level risk assessment used a shot count of five pellets per square foot as a target risk level and cited as precedent a similar removal in a marsh in Region 5. EPA determined the lead cleanup would cost $2,000,000 (USEPA 2000; USFWS 2001). In order to ensure the cleanup, the EPA made a unique agreement with the City of Davenport and the Sportsmen's Association in which the EPA would be paid $86,000, the agreed upon purchase price, in exchange for the cleanup of the property. The only stipulation was that the property be sold and maintained as a natural habitat and used for educational purposes. This is the first time in the nation the EPA has used Superfund monies for conservation and education only. In 1999, the EPA completed sediment and soil cleanup at the marsh. The cleanup included excavation, treatment, and disposal of the two lead-contaminated areas of the site. EPA excavated 49,162 cubic yards of lead-contaminated sediment. The material was used as fill material for the cover of a closed landfill cell. EPA excavated 10,416 cubic yards of lead contaminated soil. All soil was used as daily cover at an existing landfill.

Blue Mountain Sportsmen's Center.
In New York State, the Westchester County New York Department of Parks and Recreation and Conservation funded an ecological risk assessment on the Blue Mountain Sportsmen's Center, a recreational outdoor shooting facility operated by Westchester County, New York, approximately 40 miles north of New York City (Peddicord & LaKind 2000). This work was conducted under a Resource Conservation and Recovery Act (RCRA) consent order with USEPA. This site was the first quantitative risk assessment of an SPR in the scientific peer-reviewed literature. The paper evaluated the risks of lead shot ingestion to birds. Ecological receptors included raptors, deer, foxes, birds and small mammals. The risk associated with the potential incidental ingestion of lead shot by mammals was estimated for the first time. Lead posed minimal risk to raptors, foxes, or deer. Lead in dietary items posed a small risk to individual birds. The only large risk was for small mammals and grit-ingesting birds within the shot fall zone at the trap and skeet range.

Discussion and Conclusions (Federal Approaches)
A substantial number of SPRs have been cleaned up under federal jurisdiction. The Alameda risk assessment concluded that based on depth and sedimentation rate, the ecological risks were minimal. All other sites that ORS identified concluded some level of ecological risk. There are several differences between the Alameda assessment and those that concluded a risk existed:

- A binomial probability model was developed for Alameda to evaluate shot ingestion by diving ducks. This model has not been published in a peer-reviewed journal and it has not been applied at other sites (unlike the Peddicord & LaKind (2000) model).
- Lead at Alameda had been deposited in water of deeper depth (10-15 feet) than other sites that were identified. Exposure was therefore only to diving ducks and not dabbling ducks.
- The sedimentation rate at Alameda (approximately 5 mm/year) was towards the high end of the range reported in the literature, which limited wildlife exposure (see Section 2.2.1).

Many of the federal cleanups have been part of military base closure processes. These cleanups typically follow the Comprehensive Environmental Response, Compensation and

Liability Act (CERCLA) risk assessment process using standard screening benchmarks and other sources of information typically used in ecological risk assessments. Lead shot ingestion probability models for birds and small mammals were usually incorporated into the risk assessment.

3.2.3 Approaches by Other States

Risk assessment and cleanup efforts have been limited in other states. Lack of funding and uncooperative responsible parties have been cited as impediments to the cleanup process. The State of New Hampshire is currently evaluating two SPRs. New Hampshire has expressed interest in teaming with Massachusetts to develop a strategy for cleaning up SPRs (Siegel 2006). The State of Washington is beginning a program to evaluate the risks of lead shot at SPRs (Sternberg 2006). The State of Ohio Environmental Protection Agency has expressed interest in the outcome of this white paper (Abraham 2007). Cleanup strategies have been pursued at different sites in a number of states and are discussed below.

<u>New Jersey</u>.
New Jersey is in the process of cleaning up several sites, including the Alfieri Site, which is a voluntary clean up consisting of two separate trap and skeet ranges in a 100-acre mature forested wetland area (Motter 2006). Lead levels exceed 100,000 mg/kg. Most of the contamination is within the top foot of a defined area correlating to the shot fall zone. They sieved many areas within the hottest zones and came up with only one intact shot pellet over the 100 acres. Therefore, separation of lead shot from soil and removal is not a cleanup alternative at the site. The responsible party conducted an ecological assessment of the area and came up with a risk reduction strategy weighing acres of mature forested wetland lost versus total mass of lead removed from the area. New Jersey Department of Environmental Protection and the responsible party eventually agreed that 93% removal of lead mass from the site was an acceptable level of risk reduction to avoid complete alteration of the forested wetland habitat.

<u>Long Island Sound, Connecticut</u>.
The Remington Arms Gun Club, operated by Remington Arms/Dupont contaminated the Housatonic River Estuary and Long Island Sound with lead shot. The Connecticut Department of Environmental Protection issued an order in 1985, which required investigation of lead contamination of sediments and associated aquatic wildlife at the site. Battelle performed an evaluation and cleanup of the trap and skeet shooting facility. Before remediation, lead concentrations in the shallow subtidal zone were as high as 12 percent, and lead pellets were commonly found on the beach. Prior to remediation, it was estimated that there was approximately 4.8 million pounds of total lead in sediments. Lead shot was not found further than approximately 500 feet from the shoreline. They developed a cleanup level for spent lead shot of less than one shot per liter of remediated sediment (Battelle 2006). The remedy was completed in 2001 and included the removal of lead shot from the intertidal and shallow subtidal environments. The responsible parties demonstrated that lead found in deeper waters was being buried naturally and therefore did not wash onto the beach or remain available to living marine organisms. The remedy included restoration of wetlands that were removed during remedial activities, preventing the ingestion of lead shot by black ducks and other species, minimizing impacts to the benthic community, and minimizing effects to oyster seed beds. Approximately 71,000 cubic yards of sediment/soil were removed between 2000 and 2001. Monitoring activities are in place at the site to detect transport of remaining lead shot and to evaluate the condition of the subtidal benthic community (NOAA 2007).

4.0 Conclusion

It is clear that most SPRs have lead contamination that will necessitate, at some time, an assessment of human and ecological risk similar to that required under the Commonwealth's MCP. SPRs have unique regulatory challenges. They involve routine activities (i.e., shooting at airborne targets) that by their nature deposit contaminants to the environment. While the enabling statute for the MCP, Ch. 21E, defines some activities that are exempt from the MCP, e.g., certain applications of pesticides, SPRs are not specifically exempted from the MCP.

This white paper provides a summary on the current state of knowledge on the potential ecological impacts from lead contamination from SPRs, and includes an overview of methodologies to assess ecological impacts. It is intended that this document will be a useful reference for policy makers when decisions are made on whether and how ecological impacts from SPRs should be addressed.

Ecological risk assessments reviewed for this paper indicate that bird consumption of lead shot poses the greatest ecological concern from lead shot. Consumption of a single lead shot has been reported in some cases to be fatal to birds. However, the toxicity of lead shot can be mitigated somewhat by variables such as diet, shot size, and bird species.

A number of SPRs have been cleaned up under federal jurisdiction. These cleanups typically follow the CERCLA risk assessment process using standard screening benchmarks and other sources of information typically used in ecological risk assessments. Lead shot ingestion probability models for birds or small mammals were usually incorporated into these risk assessments. The ecological risk assessment for the Prime Hook National Wildlife Refuge lead shot site in Delaware developed a preliminary remediation goal for lead shot at between 7 and 9 lead shot pellets/ft^2 for the protection of waterfowl and upland birds.

ORS is unaware of any MCP sites in Massachusetts that have gross lead contamination at the concentrations comparable to those commonly present at firing ranges where an ecological risk assessment was conducted. Levels of lead at SPRs are much higher than routinely seen at MCP sites and are often in a different form (i.e., pellets/shot) than seen at MCP sites.

Conditions at firing ranges are likely to meet the definition of Readily Apparent Harm or to warrant a Stage II ecological risk characterization under the MCP. Risk levels have been identified from a number of sources. The USEPA EcoSSL for soil invertebrates is 1700 mg/kg. The recommended MassDEP sediment screening benchmark for lead is 130 mg/kg and identifies a contaminant concentration above which harmful effects on sediment-dwelling organisms were expected to occur frequently. Concentrations in sediment and soil at firing ranges are likely to exceed these risk-based concentrations in the shot drop zone by a wide margin.

Although there are no specific methods within the MCP for assessing lead shot impacts (versus lead in sediment or soil), non-MCP ecological risk assessments have used a density of shot per square foot to determine adverse ecological impacts from lead shot based on the probability of birds eating shot. The lead shot density clean up goal varies based on site conditions. For the risk assessments reviewed for this paper, lead shot clean up goals ranged from 3-13 shot/ft^2. Concentrations of lead shot above this screening level are thought to pose an ecological risk. While there is uncertainty inherent in the exposure models, and the exact frequency of effects at a particular location cannot be predicted, it is also clear that where lead shot is present at or near the soil or sediment surface, some percentage of the birds and wildlife in the area will consume the shot, some will likely experience adverse effects and some will die. There are no studies that specifically identify increased bird death adjacent to SPRs, but there are many documented cases of dead birds with lead shot in their digestive systems.

Finally, assessment of lead shot counts per square foot should always be coupled with assessment of soil and/or sediment lead concentrations because at most sites at least a portion of the lead shot will have degraded into fractions resembling soil particles. Although consumption of lead shot by birds and wildlife are expected to pose the greatest risk, exposure to lead associated with soil and sediment at SPRs can also be significant.

5.0 Possible Next Steps

This white paper has focused on the risk characterization portion of the MCP. Risk assessment is used in the MCP to determine whether a remedial response action is necessary and, if so, to determine whether a condition of no significant risk of harm to human health, safety, public welfare, and the environment exists or has been achieved at a site. Site risk characterization is a decision tool for making remedial decisions in a manner that is both protective of public health and the environment and consistent from site to site. A risk characterization must be performed at each site seeking a Response Action Outcome (RAO) because determining whether a condition of "no Significant Risk" exists is a basic requirement of an RAO.

Risk management decisions are made as part of RAOs. RAOs are the end-points of all response actions conducted under the MCP, and the documentation that the disposal site has reached an end-point is the RAO. RAOs represent the risk management stage of the site cleanup process. RAOs are divided into three main categories (A, B, and C) and several subcategories to distinguish between the different types of endpoints which
may be reached for a given site. The level of cleanup is a risk management decision, and is reflected by the RAO category. For example, an A-1 RAO is only given for a site that is cleaned up to background. On the other end of the risk management spectrum, a Class C RAO is given when it is not feasible to eliminate risk (but substantial hazards have been eliminated).

As of 2008, the MassDEP does not have a formal position on how SPRs should be handled under the MCP. On a case-specific basis, MassDEP has addressed closed SPRs where the planned reuse of the land created unacceptable exposure pathways or active SPRs with exposure or potential migration issues that warranted near term attention. For the most part, the focus at these SPRs has addressed some combination of human exposure pathways, surface water quality impacts, and wetlands filling issues. The full range of ecological issues that would be assessed under an ecological risk assessment consistent with the MCP have not been addressed in these cases.

<u>Further Research on Risk Management Decisions</u>.
One next step would be to evaluate risk management options for the identified ecological risks at SPRs. Research could be conducted on risk management decision-making at previous range assessments and cleanups. This research could include technical and economic feasibility aspects of certain ecological risk reduction strategies. Some of this information may be extracted from existing best management practice literature. This effort could help guide the future decision-making used to define feasible risk management strategies that are based on the integration of ecological risk information and feasible remediation strategies.

Developing Generic Risk-Based Cleanup Levels.

ORS has identified cleanup levels for a number of ecological receptors at different lead shot sites across the country. MassDEP could develop generic cleanup standards to manage lead shot sites in Massachusetts. One potential approach would be to use food chain models and a lead shot ingestion model (e.g., Peddicord & LaKind 2000) with generic assumptions to derive standards. This could be done for sediment, wetland, and upland habitats. MassDEP could analyze the results for use as generic cleanup levels to aid in risk management decisions. Another approach that could be used is to parallel the process applied in USEPA Region I. At the Bryant Range the geometric mean of the NOAEL (46 mg/kg) and LOAEL (260 mg/kg) was calculated (109 mg/kg) and an approximation of the geometric mean was used as a clean up value (100 mg/kg). Regardless of the approach chosen, both the lead shot and lead associated with soil and sediment should be considered when developing cleanup levels.

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Figure 2. MCP Ecological Risk Assessment Decision Diagram for Lead Shot