Introduction

The purpose of this project was to gather information about the distribution and fate of lead bullets and shot at the National Forest Service's Blacksburg shooting range. This information will provide a baseline for the development of best management practices for this range. It is important to note that although the patterns of lead behavior and distribution found at the Blacksburg range may occur at other ranges, each range has a unique combination of usage, geological setting, soil type, and climate so generalization of our findings to other sites should be done with great caution.

Lead toxicity in humans has long been recognized and clinically confirmed. Consequently, action has been taken, primarily since the 1970's, to stem several of the major pathways by which lead was brought into human contact - drinking water, gasoline, paint. In addition, regulations were imposed to promote effective recycling of automotive batteries. Wildlife impacts were documented, primarily in waterfowl, and subsequently led to a general ban on the use of lead shot in waterfowl hunting and the banning of small lead fishing sinkers in two states.

Despite these actions, there remains one major flux of lead into the environment - recreational shooting. This is, by far, the greatest use of lead dispersed into the general environment and today accounts for most of the more than 52,000 metric tons of lead manufactured into ammunition. The bulk of this lead is discharged at formal and informal recreational shooting ranges where there can be intense accumulations of lead. Lead is the focus of this project, but it is important to note that there are other metals associated with the lead bullets and shot; these include arsenic and antimony, widely used as hardening agents, and copper, aluminum, iron, and zinc, used in various casings. The general public has been made aware of the dangers and threats of lead in the environment and has seen the extensive efforts made to eliminate or clean up lead from various materials and sites (including military ranges). At the same time, little has been said about the public shooting ranges, which probably represent the most lead-loaded areas in the country. The public has begun to ask the question, "what danger, if any, do these sites present to humans and wildlife?" There have already been efforts to clean up some ranges, but most have had little, or no, attention. Furthermore, many of these efforts have concentrated only on the larger and more visible particles, such as whole bullets and casings, which are probably much more aesthetic than chemical contaminants.

The study area is a public shooting range operated by the U.S. Forest Service in the Jefferson National Forest adjacent to Route 621, approximately one-quarter mile (800 meters) north of Route 460 in Montgomery County, Virginia; Latitude 37° 18'N, Longitude 80° 26'30"W (Figure 1). The shooting range includes two separate shooting
areas - (i) shotgun range (ii) rifle range (Figure 2). The shotgun range is a lightly grass covered slightly upward sloping field approximately 80 meters in length and 75 meters in width. The rifle range contains sparse grass and slopes slightly upward from the shooting stands to the backstop area; it has been cut into the east side of a forested ridge. The cut into the ridge provides a backstop of shaley material which is about 2 meters in height but which then grades upward another 2 to 4 meters before encountering the standing forest which continues upward at about a 15 degree slope. The trees in the area above the back stop are 10 to 40 centimeters in diameter. The Forest Service has estimated that there are currently 1 to 3 million rounds expended per year at the Blacksburg Range (W. Compton, pers. comm. 1998).

Figure 1. General location map of the shooting range, which is located in the George Washington and Jefferson National Forests in Montgomery County in southwestern Virginia, approximately 5 km west of Blacksburg.

Figure 2. Simple plan map of the Blacksburg shooting range showing the rifle range (rectangular area at the top) and the shotgun range (triangular area at the right). The southeastern face of Gap Mountain rises upward more than 200 meters in elevation behind the back stop area of the rifle range. This map has been simplified from a large and more detailed map prepared by the U.S. Forest Service.
Methods

Both the rifle and shotgun ranges were sampled to determine the distribution of metallic lead in and around the developed range area. The samples consisted of soil material recovered from a carefully measured area of the land surface. The shot was separated from the soil by panning and the bullets were recovered by sieving through a 0.25-inch wire mesh.

Samples of ground and surface water were collected and filtered through 0.45 µm filters and then analyzed for lead by graphite furnace AA. Lead was extracted from soil samples using a sequential extraction method that is designed to release successively more tightly bound lead with each extraction step. The lead concentration in the extraction solutions was analyzed by graphite furnace AA.

Details of these methods are given in the publications that describe each of the studies. These publications are listed in the Appendix and a copy of each is attached to this report.

Major Findings

Shot and bullet distribution

We have documented that over the period 1993-2000 about 11.1 metric tons of lead shot accumulated over a 220x300 m ($66,000 \text{ m}^2$) area on the shotgun range. More than 85% of this lead is scattered into the forested area that surrounds the approximately 60x60-m cleared area that is maintained by mowing and routine cleaning. This lead is irregularly distributed over this area. There are maxima in lead shot concentration at distances of ~28, ~80, and ~180 m from the shooters box. A significant amount of fine particulate (< 1 mm) lead metal is present from the shooters box to a distance of about 50 m.

From 1993-2001 about 10 metric tons of lead have accumulated on the ~120 m long x 60 m wide rifle range. The bullets are irregularly distributed with highest amounts associated with small, ~20 cm-high ridges that run perpendicular to the shooting lanes. Much of the lead is buried in the backstop at a distance of ~105 to 120 meters from the shooters boxes. There is an unknown quantity of lead bullets in the forest up slope from the rifle range. Because rifle bullets carry much further than shot, some bullets could be present in the trees and soils near the ridge top. Although some bullets show evidence of fragmentation on impact, there is relatively little particulate lead on this range.

Inspection of the trees at the edge and back of both ranges showed that they all contain a significant amount of imbedded lead. The amount of lead imbedded in these trees declines very rapidly away from the shooting range as the most exposed trees shield the more distant ones from impacts.

Shot and bullet corrosion

A major concern regarding the lead shot and bullets distributed on these ranges is that the lead will corrode, become water soluble, and migrate with the ground or surface waters. Microscope observations of bullets from this site show clear evidence of lead corrosion. There is also solid evidence, in the form of white coatings on the shot and bullets, that much of the lead released by the corrosion process is rapidly reprecipitated as hydrocerrusite, $\text{Pb}_3(\text{CO}_3)_2(\text{OH})_2$, which has a solubility minimum between pH 9 and 11. Note that the pH in the immediate vicinity of a corroding bullet surface is somewhat
higher than soil water pH because the corrosion process consumes hydrogen ions. It appears that the build up of the hydrocerrusite coatings somewhat reduces the rate of hydrogen ion migration to the lead metal and thus reduces the overall corrosion rate.

Some shot samples taken from the duff in the forested area showed brown coatings along with the cream-colored hydrocerrusite. These may consist of a mixture of humic acids and lead humates. The stability and solubility of lead humate is not well known.

Examining polished sections of shot and bullets using reflected light microscopy showed that they all contain zones that are enriched in arsenic±antimony. These hardeners are added to reduce the malleability of the shot and bullets. We did not investigate the corrosion rates or mobility of these elements, however our microscope observations suggest that they corrode at a much lower rate than the lead.

Lead mobility

The solubility of hydrocerrusite increases very rapidly with declining pH so that at a pH of around 7 solutions in equilibrium with hydrocerrusite contain hundreds of parts per billion dissolved lead. This is consistent with the lead concentrations found in samples of surface waters taken from the rifle range during a rain event. Such high dissolved lead concentrations in water discharged to streams could pose a problem. However, lead ions are readily incorporated into iron and manganese oxides and carbonate minerals in the soil so that samples of runoff taken at the edge of the rifle range and beyond showed relatively low dissolved lead concentrations. This lack of dissolved lead mobility was confirmed by our study of soil samples taken from the shotgun range. These samples showed that most of the lead is present in iron and manganese oxides and carbonate minerals in the top few centimeters of the soil. There is no evidence that soluble lead is being carried deeper than that by infiltrating rain water. Thus, it appears that the major mode of lead transport off of the ranges is by erosion of lead-containing soil particles.

Appendix: Publications

Note that the Scheetz and Rimstidt manuscript is being revised and will soon be returned to Applied Geochemistry for publication and the Craig et al manuscript about bullet distribution on the rifle range is in preparation with the goal of submitting it in early 2006.

Copies of publications are attached and the files are identified by the code listed in square brackets at the end of each reference.

Journal Articles

Scheetz, C.D. and J.D. Rimstidt (in revision) Dissolution, transport, and fate of lead on shooting ranges. *Applied Geochemistry.* [Scms]


**Theses**


**Published Abstracts**


Rimstidt J. D. (2001) Lead distribution patterns on shooting ranges:


