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Sponsored By Naval Facilities Engineering Command

ENVIRONMENTAL EFFECTS OF SMALL ARMS RANGES

ABSTRACT This study focuses on contaminant releases from outdoor small arms ranges. Ranges for larger weapons such as artillery, cannons, mortars, and howitzers, as well as skeet and trap shooting areas, and indoor ranges are excluded from this study. This report attempts to locate and evaluate information in the following general subject areas: contaminant concentrations normally present at sites, normal background levels of identified contaminants, toxicity information on identified contaminants, regulatory controls and considerations, and identification and classification of small arms ranges that are controlled by the Navy.

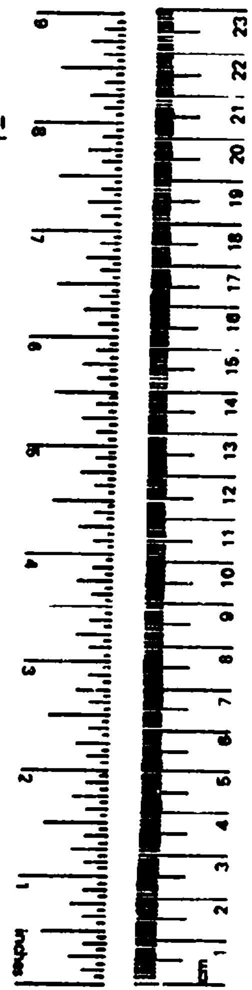
NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043-5003

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

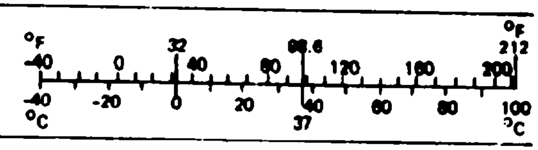
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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This study focuses on contaminant releases from outdoor small arms ranges. Ranges for larger weapons such as artillery, cannons, mortars, and howitzers, as well as skeet and trap shooting areas, and indoor ranges are excluded from this study. This report attempts to locate and evaluate information in the following general subject areas: contaminant concentrations normally present at sites, normal background levels of identified contaminants, toxicity information on identified contaminants, regulatory controls and considerations, and identification and classification of small arms ranges that are controlled by the Navy.

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EXECUTIVE SUMMARY

This report is part of a series of reports assessing environmental contamination at outdoor small arms ranges, identifying associated health risks, and evaluating and selecting control alternatives. The final product of this effort will be a technology transfer package specifying technologies to recover, recycle, and treat contaminated soil and control nonpoint source pollution at abandoned, current, and future ranges. Indoor ranges and skeet ranges are not addressed in this report.

This report consists of a literature search of data and studies of environmental contamination at small arms ranges; geochemical equilibria modeling to determine the fate of lead, copper, and zinc in the environment; and a survey to gather information on the Navy's small arms ranges.

Soils in the impact and target berms have been found to have elevated levels of metals including lead, copper, and zinc, causing the soils to be classified as hazardous waste. Of these, lead is the only metal regulated by the Resource Conservation and Recovery Act. Elevated levels of metals have also been found in the soils and vegetation in large areas behind and adjacent to the target and impact berms. Though these levels are below hazardous waste levels, storm-water runoff from these areas can transport the metals to nearby water-courses and be classified as nonpoint sources of pollution.

Geochemical equilibria modeling of lead, copper, and zinc in three different groundwater compositions shows that the solubility of these metals increases with decreasing pH values. The modeling and current data indicate that groundwater contamination should only be a problem at sites where the soil pH is below 7 and groundwater is less than 10 feet deep.

A total of 34 responses were received to a survey requesting information on the size and number of ranges, and current environmental practices at ranges at 65 Naval bases. There are 245 active ranges at 89 bases and a minimum of 56 abandoned ranges. The average annual mass of lead accumulated in a single berm is estimated to be 7,000 pounds. The average berm is 18 feet tall, 42 feet wide, and 132 feet long.

More information and data on the extent of environmental contamination at small arms ranges can be found in the following Naval Civil Engineering Laboratory selected reports:

Memorandum to files, Characterization of Metals in Soil and Vegetation of a Small Arms Impact Berm, NAVAMPHIBASE Little Creek, Leslie Karr, et al., June 1990.

TN-1823, A Biogeochemical Analysis of Metal Contamination at a Small Arms Firing Range, Leslie Karr, et al., Marine Corps Combat Development Command (MCCDC), Quantico, Virginia.

An assessment report for a small arms range at Camp Pendleton is being prepared.

The result of the findings included in this report will be used to aid in the selection of systems to prevent runoff from ranges and technologies to recover, recycle, and treat contaminated soil. The selection process and its results will be discussed in the next report of the series. After that, the selected technologies will be bench-scale tested and a design for field demonstration will be prepared. Results of these studies will be included in demonstration evaluation reports. Successfully demonstrated technologies will be transferred to Navy use in User Data Packages.

For further program information, please contact Mr. Jeff Heath, Code L71, Naval Civil Engineering Laboratory, Port Hueneme, CA, at AUTOVON 551-1657 or commercial 805-982-1657.

CONTENTS

INTRODUCTION

The Navy and Marine Corps control approximately 245 active outdoor small arms ranges and an estimated 56 abandoned ranges. Because of the inevitable build-up of bullets in the target and impact berms, these ranges are potential source areas for metals contamination. If left unattended, this source of contamination may be dispersed into the environment along various pathways including surface water runoff, groundwater migration, and airborne dust migration.

Typically, small arms ranges consist of a firing line, target line, target berm (on rifle ranges only), and impact berm. The distance from the firing line to the target line is normally 100 to 300 feet for pistol ranges and up to 2,000 feet for rifle ranges. Impact berms vary in height from 5 feet to as high as 50 feet. Figures 1 and 2 show typical configurations for pistol and rifle ranges.

Lead contamination levels along the face of small arms range berms typically are in the range of approximately 1 percent by weight with concentrations reaching 30 percent for some isolated samples. Ricochet problems often result from the build-up of large bullet fragments. Currently practiced solutions for the ricochet problem are: (1) removing and replacing the berm with clean soil, (2) adding a clean layer of soil to the face of the berm, (3) removing large projectiles by screening and returning the soil to the berm, and (4) abandoning the berm. Initial test results indicate that berms are often surrounded by a halo of lead contamination in surface soils and plants.

SCOPE

This study focuses on outdoor small arms ranges. Small arms are pistols, rifles, and machine guns with calibers of 0.6 inches (15 mm) or less. Ranges for larger weapons such as artillery, cannons, mortars, and howitzers, as well as skeet and trap shooting areas, and indoor ranges are excluded from this study.

This report provides baseline information that will be used to: (1) assist in selecting technologies and developing technologies for routine Navy use, (2) assist in development of design improvements for new ranges, and (3) identify additional information and techniques that will be needed to implement these efforts. Specifically, this report attempts to locate and evaluate information in the following general subject areas:

1. Contaminant concentrations normally present at sites.

2. Normal background levels of identified contaminants.

3. Toxicity information on identified contaminants.

4. Regulatory controls and considerations.

5. Identification and classification of small arms ranges that are controlled by the Navy.

APPROACH

The approach taken in this study includes conducting a literature search of relevant published data and studies; determining the fate of lead, copper, and zinc in groundwater through geochemical equilibria modeling; and conducting a survey of small arms ranges located at Naval bases.

Literature Search

Information on the potential for nonpoint source pollution from Navy small arms ranges was obtained by conducting a computerized literature search and by surveying various organizations and facilities that were familiar with either lead in the environment or the use of small arms.

The data bases that were consulted included National Technical Information Services (NTIS), Chemical Abstracts (CA), Water Resources Abstracts, Pollution Abstracts, and the Defense Technical Information Center (DTIC). The keywords used to access information were:

• Lead	• Shotgun	• Stabilization
• Shot	• Range	• Fixation
• Pistol	• Pollution	• Recovery
• Handgun	• Fate	• Contamination
• Sidearm	• Environment	• Groundwater
• Rifle	• Transport	• Soil

Information on the fate of spent shot in soil was solicited by phone from various organizations including the following:

- Lead Coalition
- Lead Industries Association
- National Rifle Association

- Sport Arms and Ammunition Association in Connecticut
- Bureau of Mines
- Amateur Trap Shooting Association
- International Lead Zinc Research Organization.

Information on the potential for pollution from small arms ranges was requested from the following governmental and military agencies:

- U.S. Environmental Protection Agency (EPA) in Cincinnati, Ohio
- Minnesota Pollution Control Agency
- Army Corps of Engineers
- National Guard facility at Camp Grayling Michigan
- Civil Engineering Environmental Group at Tyndall Air Force Base
- U.S. Army Toxic and Hazardous Waste Management (USATHAMA) group
- Numerous Navy bases

Information on bullet casings was solicited from the Copper Development Association.

Survey

A written survey was sent to 65 of the 89 Naval and Marine bases believed to have outdoor small arms ranges. The survey and was used to evaluate the potential for nonpoint source pollution from Navy small arms ranges. Appendix A contains a copy of the survey. A mailing list (Appendix B) was created using the list of Naval small arms firing ranges found in Karr, et al. (1990) and cross-referencing it to the Naval publication OPNAVPO9B2105(87) which lists addresses for the bases.

The written survey was developed to obtain more detailed responses about the potential for nonpoint source pollution from the ranges. Factors that were considered important in understanding the potential for nonpoint source pollution included the following:

- Amount and type of bullets used
- Amount and type of soil polluted

- Current practices for handling berm soil
- Closeness and quality of ground and surface waters.

Geochemical Equilibria Modeling

The mobility of lead, copper, and zinc in an aqueous environment (surface waters and groundwaters) is dependent on the aqueous solubility of the metal ions. To understand the potential nonpoint source pollution of impact berms, a geochemical model, SOLMINEQ.88 (Kharaka, et al., 1988), was used to study the solubility of lead, copper, and zinc in various groundwaters of typical geological terrains. The computer program can be used to model speciation, saturation, solubility, and dissolution/precipitation of metal ions at subsurface temperatures (0 to 250°C) and pressures (1 to 1,000 bars). A thermodynamic data base of 260 inorganic and 80 organic aqueous species and 220 minerals is included in the program.

BACKGROUND INFORMATION AND DATA

Literature Search and Case Studies

Literature Search and Phone Inquiries. A limited amount of information was generated by the computerized literature search. The Copper Development Association searched its files for information on casings; however, limited information was found. Information was obtained from a computer search on the transformation of lead pellets in soil and the bioaccumulation of lead in wildlife as the result of soil polluted with metallic lead pellets. Specific information on lead pollution at small arms ranges consists primarily of recent studies conducted by the Navy (Karr, et al., 1990 and Karr, 1990) at two Naval bases, Marine Corps Combat Development Center (MCCDC) Quantico and Naval Amphibious Base Little Creek, and a study made by Battelle (Battelle Ocean Sciences, 1987) on skeet ranges. A study (Jorgensen and Willems, 1987) conducted in Sweden on shotgun pellets provided some insights on the fate of lead in the environment.

Responses to the phone inquiries led to information on two additional case studies. In the first case study, both Patrick Reagan of the Lead Coalition and Shelly Siewert of the Minnesota Pollution Control Board mentioned that elevated lead levels were found in the milk of cows that had grazed on pasture land that was adjacent to the White Bear Run Gun Club in Ramsey County, Minnesota. Results of the milk analyses were unavailable. As a result of this incident, the gun club has disbanded. The second case study was mentioned by Craig Boreiko with the International Lead Zinc Research Organization. He stated that a firing range in Stockholm, Sweden, had been converted into a park; however, he was not familiar with any written reports about the project. In discussions with Patrick Reagan concerning the fate of spent shot in soil, several pertinent characteristics about lead mobility were mentioned; namely, (1) lead tends to remain in the upper surface layers, (2) lead is bound to the organic content in the soil, and (3) lead is amphoteric, meaning that it is mobile at both low and high pHs.

Wayne Sisk with USATHAMA indicated that the Army has not yet conducted a study on this subject.

Chemical Composition of Small Arms Ammunition. A typical round of ammunition consists of a bullet or ball, a cartridge case that contains the propellant, and a cap consisting of an ignition system. Bullets are either solid or filled and come with or without an outer metal jacket. Jacketed bullets are used for antipersonnel and armour piercing roles, while filled bullets consist mainly of tracer or incendiary materials. The bullet or ball is usually made of a lead alloy consisting of copper and sometimes tin, with up to 15 percent antimony added for hardness (Ross, 1980). Table 1 presents the various grades of lead alloy used in bullets that are acceptable to the U.S. Military (Federoff and Sheffield, 1975). The unjacketed or "bare" ball is used in shotgun shells, .22 caliber rifle ammunition and in many revolver cartridges.

Metal jacketed bullets are used in high-velocity and automatic weapons such as M16 rifles and M60 machine guns. The outer metal jacket is usually either copper-plated or covered with a thin layer of gilding metal. There are various grades of gilding metals having copper and zinc as the major components (Table 2). Jacketed bullets have been shown to reduce the amount of airborne lead particulates (Juhasz, 1977), but the bullet may shatter upon impact, exposing the lead core. Metals of significant mass fraction in a bullet are lead, copper, zinc, and antimony. Of these, lead is the only metal that is regulated as a Resource Conservation and Recovery Act (RCRA) "characteristic waste," as determined using the Toxicity Characteristic Leaching Procedure (TCLP) test.

Filled bullets (i.e., tracer munitions) are used to provide an effective means of determining the direction of fire for rapid firing of small arms. When used in machine guns, filled bullets are belted in a predetermined sequence. Tracers are generally made up of chemical compounds of strontium and magnesium. Typical chemical compositions of igniters and tracers for small arms are given in Table 3.

In addition to the bullet, the ignition system primer may be a possible source of metals contamination. Commercial primer compounds for small arms ammunition are generally mixtures of lead styphane and barium nitrate (Table 4). Barium is a RCRA metal, similar to lead, but is regulated at much higher levels. A study on lead contamination from various primers (Juhasz, 1977) showed that the use of nonlead primers with jacketed bullets reduced airborne lead particulates from a pistol from levels of about 402 µg/round to about 23 µg/round. Airborne lead particulates from nonjacketed bullets fired from a pistol can be present in concentrations as high as 3,380 µg/round. Consequently, airborne particulates can contribute to pollution in the area adjacent to the firing line.

Toxicity of Lead, Copper, and Zinc.

Lead Occurrence in the Environment. Lead is ubiquitous in nature, being a natural constituent of the earth's crust. Lead is commonly used in ammunition, batteries, solder, radiation shielding, and cable sheaths. Its use in paints and as an octane additive in gasoline has decreased. In addition to occurring naturally in soil, lead concentrations may be increased by atmospheric pollutants from smelters, motor vehicles, and other sources. Landspreading of sewage sludge may also increase the lead levels in treated areas.

Lead content in soil averages approximately 16 parts per million (ppm) with the normal range being 10 to 37 ppm and a 99.7 percent upper limit of 121 ppm (Davis and Wixson, 1986). Lead levels in surface waters average approximately 3 µg/L with a few streams exceeding 50 µg/L. Groundwater lead levels that occur naturally are usually in the 1 to 10 µg/L range, but may exceed 100 µg/L in some areas. Normal lead levels in various media are given in Table 5.

Accumulation by Plants and Animals and Ecotoxicology. Lead in soil is generally unavailable to plants and is frequently strongly fixed to the organic fraction of the soil. Lead has been found in many plant species (e.g., at levels of 2 to 5 mg/kg in leaves), but it is not an essential element. High lead levels have been reported to be tolerated by many plant species, while other species have shown retarded growth. Accumulation in plants can occur by adsorption through roots and leaves with little translocation within the plant. Compared with soil concentrations, lead concentrations in plants are low (Carrier, 1977). Translocation of lead from the foliage surface into the plant may occur, but the rate is very slow even under conditions of elevated lead solubility, low pH, and long exposure time.

Lead is not an essential element in animals. Ingestion of plant foliage contaminated by atmospheric deposition of lead and inhalation of lead may contribute significantly to the total body burdens, primarily in the bones and kidneys of wildlife and livestock. Lead poisoning in livestock and other grazing animals has been reported. Lead is poorly absorbed through the intestine, but retention time in the body is long. Susceptibility to lead may be affected by the type of lead compound, acidity of the general intestinal tract, animal species, and life stage or age. Young cattle have been reported to be especially susceptible to lead poisoning (Wilkes, 1977). Lead may bioaccumulate from herbivorous to carnivorous trophic levels, and earthworms may accumulate levels that may be toxic to birds.

Lead may be accumulated by fish and other aquatic animals through the body surface or via the food chain. Accumulations occur primarily in the calcareous tissues. Toxicity varies with species and generally increases with decreasing hardness. Chronic exposure to elevated concentrations may result in deformities in fish, with frequency varying with concentrations and hardness. Experiments have shown that acute toxicity of rainbow trout occur at about 1,170 µg/L and 471,000 µg/L in freshwater of 28 and 353 mg/L hardness as $CaCO_3$, respectively (Davies, 1976). Chronic toxicities of rainbow trout were found to be 31.7 µg/L and 7.6 µg/L in freshwater of similar hardness (Davies, 1976).

Effects on Humans. The principal route of exposure to lead for humans is via food and beverages. The normal daily intake of lead for an adult averages about 0.75 mg/day. The lead content of food is quite variable, and there are no absolutely lead-free food items. Municipal water supplies also contain traces of lead; the daily human intake of lead from water is usually about 10 µg/day (Doull, et al., 1986). The primary drinking water standard for lead is 50 µg/L.

Other less common sources of ingested lead are lead-based paint in older dwellings, lead in atmospheric deposition from vehicle exhaust and industrial emissions, hand-to-mouth activities of children in polluted environments, and dust brought home on clothes of industrial workers. Adults absorb 5 to 15 percent of the lead ingested and retain less than 5 percent of that absorbed (Doull, et al., 1986). Small children may absorb approximately 40 percent of the ingested lead and retain about 30 percent of that absorbed. Another source of lead is inhaled particulates. In the average urban environment, intake of respired lead is about one-half that of ingestion. Lead levels in blood vary with age and sex. Children under 7 years of age have higher levels of lead than older children, and men have higher levels than women. Lead levels in blood in adult men average about 15 to 18 μg/dL, while adult women average about 10 to 12 μg/dL (Doull, et al., 1986). The acceptable level of lead in blood is less than 25 μg/dL.

The most serious effects of lead are those related to the central nervous system (CNS), although other effects such as kidney dysfunction may occur in individuals exposed to high concentrations. Effects on the CNS are manifested as disorders of the brain and nervous system. Low-level lead toxicity is associated with levels in the blood of 30 to 50 μg/dL. These levels may cause hyperactivity, decreased attention span, and impairment of mental function (Doull, et al., 1986).

Ingestion of high levels of lead may result in lack of muscular coordination, stupor, coma, or convulsions. In early stages of acute lead poisoning, kidney dysfunction may be reversible. However, after years of elevated exposure, permanent kidney damage may occur (Doull, et al., 1986). Lead-induced anemia may occur from reduced life span and numbers of red blood cells. Also, alteration of enzyme activity in the blood may occur. Blood lead levels above 40 μg/dL cause anemia in children and above 50 μg/dL can cause anemia in adults. Some effects on blood synthesis have been noted at lead levels of 20 to 25 μg/dL in children and at 25 to 35 μg/dL in adults blood (Doull, et al., 1986).

Severe lead toxicity is known to cause sterility, abortion, and infant mortality and illness. Some studies (Doull, et al., 1986) indicate that a reduced response in the immune system may occur. In experimental animals, high doses of lead have resulted in cancer in the kidneys (Carson, et al., 1986).

Copper Occurrence in the Environment. Copper is ubiquitous in the earth's crust and is present as the metal and as cupric (+1) and cuprous (+2) species. Copper occurs primarily as sulfides and oxides in the ores. Metallic copper is prepared from ores by smelting and refining. These processes are the largest source of atmospheric emissions of copper (Demayo, et al., 1982). About one-half of all copper produced is used as a conductor in electrical equipment; it is also used in alloys, plumbing, and in the manufacture of various goods.

Copper content in soil averages approximately 30 ppm with the normal range being 2 ppm to 250 ppm. Copper levels in surface waters average 3 μg/L with a normal range of 0.05 μg/L to 12 μg/L.

Uptake and Effects in Plants, Animals, and Humans. Copper is an essential element for normal growth of both plants and animals, but can be harmful in excess. Copper compounds are often used in various pesticides for control of insects, algae, and fungi.

Oral ingestion is the major source of copper in humans and wildlife. Inhalation is an insignificant source of copper except for a few instances of occupational exposure. Shellfish, liver, kidney, nuts, and dried legumes are food sources high in copper. The estimated copper requirement is about 0.03 mg/day per kilogram of weight for an adult and about 0.08 mg/day/kg of weight for a child. This translates to an average daily requirement of about 1 to 3 mg per person (Demayo, et al., 1982). The average daily intake is about 2 to 4 mg per person (Doull, et al., 1986).

Copper is actively absorbed by the stomach and intestines and stored in the brain, liver, kidney, and heart. Approximately 40 to 70 percent of the ingested copper is retained (Demayo, et al., 1982). Acute ingestion of copper causes gastric disorders, jaundice, liver damage, and anemia. Chronic copper toxicity is very rare in humans and few chronic effects have been reported in humans and animals, except for sheep which are particularly sensitive to copper. Dietary intakes above 15 mg/day may produce observable effects in humans.

Acute copper toxicity is considered high for invertebrates and moderate for vertebrates. Concentrations in nonaquatic organisms range from 2 to 4 mg/kg with accumulation occurring primarily in the liver of higher organisms and in the blood of annelids and insects.

Aquatic Toxicity. Copper toxicity to aquatic organisms varies with species of plant or animal and depends on factors such as pH, complexing agents, other metals present, and the species of copper. Toxicity generally increases with decreasing pH, hardness, and organic content; toxicity is also greater for the cupric than for the cuprous species. Copper is reported to bioaccumulate in algae and oysters, but does not accumulate in the edible portion of fish tissue (Demayo, et al., 1982).

Copper toxicity levels in rainbow trout are 22.4 µg/L for a water hardness of 32 mg/L as $CaCO_3$, and 82.2 µg/L for a water hardness of 371 mg/L as $CaCO_3$ (Howarth and Sprague, 1978). Chronic toxicity levels for rainbow trout range from 11.4 to 31.7 µg/L for a hardness of 45.4 mg/L as $CaCO_3$ (McKim, et al., 1978).

In the case of saltwater animals, acute sensitivities range from 5.8 µg/L for the blue mussel to 600 µg/L for the green crab. Oysters can bioaccumulate up to 28,200 times when exposed continuously to 50 µg/L for 140 days as compared to the control, and become bluish-green, apparently without significant mortality. The bay scallop, however, does not survive under long-term exposures of saltwater with 5 µg/L of lead (U.S. EPA, 1984). The water quality criteria for both fresh water and seawater concerning copper are given in Table 5.

Zinc Occurrence in the Environment. Zinc is seldom found as a free metal in nature, but it does occur as the sulfide, oxide, or carbonate. Zinc is the fourth most widely used metal in the world (Cammarota, et al., 1980). The principal uses of zinc are in metallurgy, mainly as a constituent of brass and bronze, or for galvanizing and as a white pigment (zinc oxide) in paint and rubber. Zinc is present in most foodstuffs as well as in water and air. Zinc is divalent and also amphoteric. Complexes of zinc with common ligands in surface water are soluble in neutral and acidic solutions, so that zinc is easily transported in most natural waters and is fairly mobile.

Zinc content in soil averages approximately 90 ppm with the normal range being 1 ppm to 900 ppm. Lead levels in surface waters average approximately 15 µg/L.

Uptake and Effects. Zinc is a nutritionally essential element and is not carcinogenic. Seafoods, meat, whole grains, dairy products, nuts, and legumes are high in zinc content. A deficiency in zinc can result in severe health consequences. The National

Academy of Science recommends that adults should have an intake of 15 mg of zinc per day, and pregnant women should have an intake of 20 mg/day (Sittig, 1980). In humans, zinc ingestion for therapeutic purposes has produced no clinical symptoms at daily intakes of 150 mg/day for as long as 6 months (Greeves and Sillen, 1970). Food poisoning (Sittig, 1980) was observed with ingestion of a meal containing about 1,000 ppm of zinc and among people who ingested fluids containing zinc at a concentration of 2,200 ppm. However, evidence of hematologic and renal toxicity was not observed in individuals ingesting as much as 12 grams of elemental zinc over a 2-day period.

The current zinc standard for drinking water is 5 mg/L based on organoleptic effects (i.e., the bitter taste caused by zinc present at this level). Zinc compounds are not particularly toxic to nonaquatic organisms unless ingested in significant quantities. Earthworms have been demonstrated to accumulate up to 670 ppm of zinc from soil and may be capable of supplying potentially lethal concentrations of zinc to predators such as birds and small mammals (Gish and Christensen, 1973). Toxic levels in predator organisms range from 50 to 500 ppm wet weight.

The toxicity of zinc in an aquatic environment is influenced by chemical parameters such as pH, hardness, and the presence of other ions such as calcium and magnesium, which vary among species. These factors either influence the availability of zinc or inhibit the sorption or binding of available zinc by biological tissues. For example, in one study (Sinley, et al., 1974) the acute toxicities of juvenile rainbow trout were 1,210 µg/L and 430 µg/L in freshwater with a hardness of 330 mg/L and 25 mg/L as $CaCO_3$, respectively. Chronic toxicity of rainbow trout was shown to be 227 µg/L in water with a hardness of 26 mg/L as $CaCO_3$. In marine waters, acute toxicity was found in bivalve larvae at 141 µg/L and for a species of polychaetes chronic toxicity at 220 µg/L (Wilkes, 1977). The proposed EPA water quality criteria for both acute and chronic toxicity are 120 and 110 µg/L, respectively, in freshwater (100 mg/L hardness), and 95 and 86 µg/L for marine environments. Other information on the levels of zinc in various media is presented in Table 5.

Case Studies.

NAB Little Creek. Karr, et al. (1990) studied an impact berm at the Naval Amphibious Base (NAB), Little Creek, Virginia. Soil samples from the A horizon (1- to 2-inch depth) and B horizon (4- to 6-inch depth) and vegetation samples were collected primarily from the face berm and top of the berm and analyzed for total elemental lead, zinc, and copper. Soil obtained from bullet pockets on the berm and in the vicinity of the impact berm was sieved to 80 mesh (0.177 mm) prior to analysis. Leaves from trees near the impact berm were cut from heights ranging from 1 foot to 7 feet aboveground, depending on species. Leaf litter beneath two trees was also analyzed.

The concentrations of lead, copper and zinc from the samples are summarized in Table 6. Lead concentrations are greatly elevated in both the A and B horizon soil samples and the vegetation. Copper concentrations are also elevated in the A and B horizon soil samples, but are still within the range found in naturally occurring soils. Copper was only slightly elevated in the vegetation. Zinc results are inconclusive as it is believed the control sample was contaminated from other sources of lead. Zinc levels are within the range of naturally occurring soils.

MCCDC Quantico. In a similar study at MCCDC Quantico (Karr, 1990), elevated levels of lead, copper, and zinc were found in the impact berm soils, in soils up to 250 feet behind the impact berm, and in soils in the drainage ditch leading from the berm. Vegetation samples at these locations also showed elevated levels of these metals. Lead levels in bullet pockets in the berm were as high as 23,200 ppm. The results of the soil sampling of the impact berm are included in Table 6. Two sampling transects were performed to assess the extent of nonpoint source pollution in storm-water runoff from the impact berm and surrounding area. The first sampling transect started at the top of the impact berm and extended down the back slope and to a distance of 250 feet behind the berm. The other transect extended from the front toe of the impact berm and for a distance of about 250 feet along a drainage ditch leading away from the berm. Lead, copper, and zinc concentrations in the soils of the A and B horizons and in vegetation at the sampling points in the transects were all elevated above background levels. The lead concentrations as reported by Karr, et al. (1990) are summarized in Figures 1 and 2.

The lead concentrations on the downslope of the A and B horizons (Figure 3) were about one to two orders of magnitude higher than the lead concentrations in the background soils. The lack of a uniform decrease in lead concentrations away from the berm and elevated lead concentration (258 ppm) as far as 270 feet away from the berm suggest that contaminated sediments and possibly fine lead particulates from the berm were transported by runoff. Also, lead levels in the vegetation along this sampling transect were significantly higher than the mean background lead concentration in uncontaminated plants. A rapid decrease in the soil lead concentrations for the backslope transect up to about 100 feet away from the berm (Figure 4) probably indicates low sediment transport downstream by runoff and some overshoot. The soils for the backslope and downslope sampling transects are moderately acidic (pHs 5.6 and 4.69, respectively), and are conducive to solubilization of lead. Similar results were found for copper and zinc in the soil and vegetation at the site.

In an environmental assessment study also conducted at MCCDC Quantico in 1988 (Wm. F. Freeman Associates, 1988), a leachable lead content as high as 18.6 mg/L was observed for a soil sample taken from the bullet pockets of an impact berm. This leachate concentration exceeds the TCLP level of 5 mg/L for lead. Soils with this lead level in the TCLP leachate will be classified as hazardous. Leachable lead levels taken from the toe of the berm and sediments from the side slope of the drainage swale were also relatively elevated at 0.75 mg/L and 0.44 mg/L, respectively. The lead concentrations in soils away from the berm suggest that lead is being transported with surface runoff.

Remington Gun Club. The effects of lead pollution on wildlife from a trap and skeet facility, Remington Gun Club in Stratford, Connecticut, were investigated by Battelle (Battelle Ocean Sciences, 1987). In this facility, the lead shot was discharged into the cove area of the Long Island Sound. Approximately 3 million pounds of lead have been fired into the cove since the club's founding.

Lead levels in the blood of black ducks nesting around the facility were higher than normal, suggesting that lead shot in the sediments was ingested by the ducks. Blue mussels around the shooting range had tissue lead levels significantly greater than those in nearby background areas. Although lead shot pollution from a trap and skeet facility would be more diffused in comparison with a small arms range, similar threats to health and the environment can be assumed.

Aging of Lead in Soils. An article by Jorgensen and Willems (1987) describes the fate of lead shot in soils. Lead pellets collected from the ranges showed slight corrosion and were partially covered by a crust of a white, grey, or brown material. Analyses of the outer crust using x-ray fluorescence, diffractometry, and infrared spectrometry indicate that the crusts were generally hydrocerussite ($Pb_3(CO_3)_2(OH)_2$) with smaller fractions of $PbCO_3$ and $PbSO_4$. Increasing amounts of $PbSO_4$ were found in soils with lower pH values.

Summary of Case Studies. In summary, the various case studies showed instances where soils from target and impact berms were contaminated with high levels of lead and failed the TCLP test, leading to a hazardous waste classification. The fairly high lead, copper, and zinc concentrations in the areas surrounding the berms and in the storm-water runoff channel from the berms indicated that storm-water runoff from small arms ranges may contribute to nonpoint source pollution of receiving waters. Stray bullets and airborne particulates from nonjacketed bullets may also add to this dispersed or "halo" effect of lead, copper, and zinc contamination around the berms. Significant levels of lead and copper in the vegetation around the berm also suggested possible lead and copper accumulation in wildlife present in the vicinity of the small arms ranges.

Regulatory Considerations

How small arms ranges are regulated under various Federal, State, and local laws and regulations is a nebulous subject. This is due to the lack of clear guidance on how to classify this operation and the right of States under several Federal Laws to impose stricter standards.

The following is a summary of the regulations that may apply to small arms ranges. We have attempted to identify the minimum and maximum levels of regulations that may be imposed as of the date of this publication. It is highly recommended that environmental legal counsel be sought for determining how the regulations impact small arms ranges at specific facilities before initiating any permitting, reporting, mitigation, cleanup, or closure activities.

Federal Hazardous Waste Regulations. The Resource Conservation and Recovery Act (RCRA) requires that all wastes destined for land disposal be evaluated for their potential hazard to the environment. Wastes are deemed hazardous if they: (1) appear on an extensive EPA list, or (2) show a hazardous waste characteristic, which is determined by testing.

The first question one must answer in determining if soil contaminated by lead projectiles is a solid or hazardous waste is whether the soil is a waste. At currently operating small arms ranges, bullets containing lead are shot at a target and eventually fall to the ground. There is strong argument that bullets fired during target practice are not discarded material which falls within the regulatory definition of "solid waste," but instead are a recyclable material. Bullets and fragments would be expected to land on the ground. Hence, the "ordinary use" of bullets includes placement on land. Moreover, it is possible that the user has not abandoned or discarded the bullets, but rather intends to recycle them at some time in the future. Therefore, the bullets may not be considered a solid waste or a hazardous waste in certain cases. The preamble to the EPA's corrective action proposed rules, and several other EPA documents, contain the above discussion of the definition of waste at impact ranges.

In addition, a U.S. District Court decision (Barcello vs. Brown, 478 F. Supp. 646, 688-869 - D. Puerto Rico, 1979) has suggested that materials resulting from uniquely military activities engaged in by no other parties fall outside the definition of solid waste. This argument can be applied to small arms ranges implying that the bullets in the soil are not a solid or hazardous waste.

Contaminated soil from small arms ranges is classified as a waste if it is removed and hauled to a disposal site. Also, in some areas, the State regulatory agencies have adopted a stricter stance and have listed currently operating small arms ranges as a Solid Waste Management Unit (SWMU) as defined by RCRA. As such, the contaminated soil is considered a waste.

The second question that needs to be answered is whether the soil is hazardous. Soils containing lead shot are not included in the EPA hazardous lists, but they may fall into the category of "characteristic wastes." The four types of hazardous waste characteristics are reactivity, ignitability, corrosivity, and toxicity, with toxicity pertaining to lead-contaminated soils. The toxicity characteristic is estimated by the amount of toxic contaminant that is solubilized from the solid being tested into an aqueous leaching medium, using a prescribed leaching methodology. Lead is one of the regulated metals and, as indicated above, is one of the principal contaminants in small arms practice ranges. The Extraction Procedure Toxicity Characteristics (EPTC)) leaching methodology was introduced by the EPA in 1980 to assess the toxicity of the wastes destined for land disposal. A new test method, the Toxicity Characteristic Leaching Procedure (TCLP), was officially presented in the January 1986 Land Disposal Restrictions, which proposed to establish treatment standards before wastes could be disposed of on land. Since then, TCLP has been modified several times and is now the accepted procedure for determining whether a waste is hazardous or nonhazardous, and also for determining whether appropriate treatment standards have been met.

TCLP uses an acetic acid or buffered sodium acetate solution in a 20:1 leachate:waste ratio. The threshold concentration for lead in the TCLP extract is 5 mg/L. Below that level a waste is considered nonhazardous; above that level the waste shows "toxicity characteristic" and is therefore defined as hazardous. Theoretically, a soil with a total lead concentration lower than 100 mg/kg cannot exceed the TCLP threshold because of the 20:1 dilution factor during leaching. As discussed earlier in this report, lead content in soil averages about 16 mg/L.

Lead-contaminated soil from small arms practice ranges may vary widely in total lead content because of the highly heterogeneous distribution of shot in the soil. Total lead concentrations ranging up to several percent or more may not be unusual for the soil directly behind the targets. However, RCRA regulates these soils by the TCLP-soluble level content, not the total lead content.

While it is possible for a soil containing percentages of lead to pass the TCLP, it is also possible that such a material will fail the TCLP. In the chemical environment of this test, lower soil pHs will be associated with higher lead extractabilities, as a first rule of thumb.

The physicochemical form of the lead (e.g., weathered lead salts such as oxyhydroxides or carbonates as opposed to elemental lead) is also an important variable.

Therefore, it is likely that a significant percentage of soils at small arms ranges are hazardous. Hazardous soils are expected at and immediately around the bullet pockets in the impact berms.

At some operating small arms ranges, lead bullets build up in the soil in the impact berm to a point where a ricochet hazard exists. Typically, when this occurs, the soil from the berm is either removed for disposal or sieved to remove the bullets and returned to the berm.

If the soil containing lead bullets is removed for disposal and not recycled, it is probably a harzardous waste and must be handled as such under RCRA. The reason behind this is that the soil is a waste because it is removed from the berm and discarded. As a ricochet hazard exists, it is probable that there are at least several percentages of lead in the soil. Testing using the TCLP procedure would reveal if the lead in the soil exceeds the hazardous limit of 5 mg/L, classifying the soil as a hazardous waste.

Contaminated soils classified as hazardous wastes require pretreatment prior to disposal to meet the Land Disposal Restrictions, possibly even for disposal in a subpart B regulated landfill. Stabilization/solidification is the BDAT (Best Developed and Available Technology) for disposal of metal-contaminated soils. A treatment permit under RCRA may be needed.

If the soil is sieved to remove bullets, the soil and bullets may not be considered hazardous waste. As mentioned earlier in this report, the intent here is not to dispose of the soil or bullets, but to recycle or reuse them. The covered bullets would need to be recycled and the soil returned (recycled) to the impact berm. Sieving to recover most of the lead bullets and fragments may or may not result in a residual soil that can be classified as nonhazardous, depending upon a number of factors such as the amount or chemical form of the lead remaining in the soil after sieving. If the bullets and fragments are not recycled or the soil not returned to the berm, the contaminated soil could be classified as a hazardous waste and regulated as such under RCRA. Also, if the berm has been listed as a SWMU, a RCRA treatment permit may be required to perform the sieving.

A small arms range that is listed as a SWMU and is being closed down may need to be mitigated under the site closure provisions of RCRA. A closure plan may need to be developed and permits obtained for treatment of the contaminated soil or its on-site disposal.

Finally, there has been little action in this area so there is little specific guidance or precedent. The preceding is a discussion of some possible outcomes under the current RCRA regulations. Legal counsel should be sought to determine appropriate actions at a specific site. Figure 5 is a flow chart to aid in determining RCRA criteria.

State Hazardous Waste Regulations. The State of California regulates hazardous wastes on the basis of the total concentration and the California WET (Waste Extraction Test), which uses a citrate solution, a 10:1 leachate waste ratio, and a 48-hour extraction period as opposed to an 18-hour period in the TCLP. Therefore, the test is usually more severe than the TCLP, sometimes by several orders of magnitude, resulting in a waste classification referred to as "California-only" wastes (i.e., wastes that fail WET but pass TCLP). Such wastes are regulated as hazardous only in the State of California but are not considered EPA or RCRA wastes.

In addition to lead, substances containing copper and zinc are regulated under California's hazardous wastes laws. Consequently, it is likely that a larger proportion of contaminated soils from small arms ranges in California will be regulated as hazardous waste than in other states.

Also, as discussed above under the Federal Hazardous Waste Regulations section, the States may have stricter definitions of what qualifies as a waste and may classify contaminated soil as hazardous waste in more instances.

Federal CERCLA Regulations. The Comprehensive Environmental Compensation and Liability Act (CERCLA) requires the reporting and mitigation of releases of certain contaminants to the environment. Small arms ranges could come under the provisions of CERCLA in several instances.

Unused or previously closed small arms ranges may be identified under the Navy's Installation Restoration Program as abandoned sites. If the site poses a risk to human health or the environment, a Remedial Investigation/Feasibility Study (RI/FS) may be performed to determine the extent of contamination and quantify the risk, if any, posed by the site. Any mitigation or cleanup would be performed under CERCLA provisions. This means that, at some sites, no permits would be needed for on-site treatment. Some State and local agencies may have additional requirements so that RCRA treatment permits and other permits may be required to perform the cleanup. Again, as there have been no small arms ranges cleaned up under the Installation Restoration program, legal counsel should be sought to determine how to proceed.

Current operating sites may also be covered under CERCLA. Contaminated soil transported in storm-water runoff could be considered a spill or release under CERCLA. If a reportable quantity of the contaminant left the site, the release would need to be reported under CERCLA. For both lead and copper, the reportable quantity is one (1) pound per event. Note that in this instance, CERCLA only requires reporting. Cleanup or mitigation of the release, if required, would probably be pursued under RCRA or the Clean Water Act.

Prior to closing an operating small arms range, consideration should be given to cleaning up the soil. This action would most likely be considered recycling or covered under RCRA, as discussed previously in this report. If the range is closed without any cleanup, further action would probably be covered under CERCLA.

Clean Water Act Regulations. The Enactment of Section 319 of the Water Quality Act of 1987 created specific provisions for the control of nonpoint source pollution. With this act, the States now have additional support and direction for comprehensive implementation of nonpoint source pollution controls. This Act gives the States responsibility, as well as flexibility, to design and implement nonpoint source pollution programs as a part of an overall State water quality cleanup strategy. As mandated by the Act, the States are required to submit to the EPA a State Assessment Report and a State Management Program within 18 months of enactment. The State Assessment Report identifies water bodies that cannot attain water quality goals without additional nonpoint source pollution controls, sources of nonpoint source pollution for each watershed, and categories of controls including best management practices for nonpoint source pollution control. The State Management Program summarizes how the State will accomplish its nonpoint source pollution goals.

Storm-water runoff from the berms and surrounding areas may contain elevated levels of lead, copper, zinc, and other heavy metals, and increase nonpoint source pollution of receiving waters. Due to erosion of the berms from bullet impacts, increased levels of sediment and nutrients such as nitrogen may be found in the storm-water runoff from the target and impact berms. As the States implement their nonpoint source pollution programs, controls may need to be added to small arms ranges to control pollutants in storm-water runoff.

Storm-water discharges from small arms ranges may need National Pollutant Discharge Elimination System (NPDES) permits. Amendments to 40 CFR Parts 122, 123, 124, which became effective on December 17, 1990, require that NPDES permit applications be submitted for storm-water discharges associated with industrial activities and storm-water discharges from large and medium separate storm sewer systems. As this regulation is currently being implemented, it is unclear if a small arms range is classified as an industrial activity. For example, NPDES permit applications are required for facilities involved in the recycling of materials. We previously discussed that under RCRA, the impact berms at small arms ranges could be considered recycling activities; a NPDES permit application may be required using this same reasoning. Further, under section 122.26 (a)(v) of the December 17, 1990 amendments, the EPA or a State may also require permit applications for discharges that contribute to a violation of water quality criteria. Using this criteria, the EPA or State may require a NPDES permit application on a case by case basis.

Some small arms ranges in coastal areas may not have capture berms and may allow bullets to fall into the adjacent body of water. As this could be considered a discharge of a solid waste directly into a surface water, a NPDES permit may be required.

Due to the newness of this regulation and the different interpretations each State may use, legal counsel should be sought to determine if a NPDES permit application is needed for a specific small arms range.

Geochemical Modeling of Lead, Copper, and Zinc Mobility

The mobility or solubility of metals in natural waters is determined by the chemical characteristics of the water, mainly the pH, redox potential (Eh), and the concentrations of complex-forming ligands (carbonates, sulfate, organic acids, etc.). Solubilities of lead, copper, and zinc in natural groundwaters of different complex-forming ligands and pH are discussed below with reference to groundwater compositions found in three types of geological formations: basaltic, sand and gravel, and limestone. These rocks types were chosen to represent a variety of geological terrains that may be found at Naval bases around the country.

Typical chemical characteristics for these waters are shown in Table 7. We have categorized chemical constituents in water as "low" for concentrations that are less than 100 mg/L, "moderate" for concentrations between 100 and 250 mg/L, and "high" for concentrations that are above 250 mg/L. Groundwater from basaltic terrain can be categorized as having low sulfate and moderate carbonate content. Groundwater from sand/gravel can be categorized as having moderate levels of sulfates and carbonates. Groundwater from limestone terrain tends to have high carbonates but moderate levels of sulfate. To construct the solubility diagram, the various sulfate and carbonate concentrations presented in Table 7 were used, but with pH as a variable from 4 to 10. In one of the scenarios, organic matter (i.e., fulvic acid) was assumed to be present to illustrate the impact of dissolved organic matter on metal solubility. In the case of zinc, the impact of silicates on zinc solubility is also discussed.

Lead. Lead can occur in three oxidation states: elemental, divalent, and tetravalent. Divalent lead is the dominant species within the range of Eh-pH conditions of natural waters (Figure 6), while tetravalent lead exists only in extremely oxidizing conditions that are not usually found in the environment. Figure 6 also shows that lead is rather insoluble under most Eh-pH conditions found in natural waters except for low pH. Depending upon the pH and the concentrations of anions (sulfate and carbonate), a lead sulfate, lead carbonate, or lead sulfide phase generally controls the total solubility of dissolved lead in the system.

The solubility of lead in the three selected groundwaters is shown in Figure 7. Lead is very insoluble above a pH of 7, and there is not much difference in the solubility of lead between the different groundwater types. Below pH 7, the presence of sulfate at moderate levels (~100 mg/L) increases the solubility of lead when the concentration of carbonate also is at moderate levels (~100 to 200 mg/L). For moderate concentrations of sulfate, the solubility of lead is lower for higher carbonate concentrations; but at about pH 4, the solubility of lead is comparable with moderate concentrations of carbonate. The solubility of lead at low pH is shown to be higher for groundwater with a low concentration of sulfate and a moderate concentration of carbonate. This result suggests that liming the target berms to increase pH and alkalinity may retard dissolution of lead into surface runoff and groundwater.

The effect of dissolved organic matter, represented by fulvic acid, is to increase the solubility of lead in the pH range of 4 to 6. Figure 7 shows this effect at a fulvic acid concentration of 10 mg/L, typical of shallow groundwaters and soil pore size.

In addition to carbonate and sulfate solid phases, lead phosphates may also control the solubility of lead in some environments. The solubility of lead phosphates, however, is lower than that of carbonates or sulfates. On the contrary, lead oxide is much more soluble than most other lead compounds or native lead. The solubility product (log Ksp) of lead phosphate is -44.3, while that of lead oxide is 12.7 (see Table 8). Consequently, the concentration of lead in leachates will be higher where lead oxide, and not native lead, is being leached. However, in an aquatic environment, the equilibrium concentration of dissolved lead in the soil solution will be controlled by the least soluble lead compound that is stable in that environment. From the solubility product information in Table 8, the sulfate, carbonate, and sulfide forms of lead as well as the mixed carbonate-hydroxide form, hydrocerussite, $Pb_3(CO_3)_2(OH)_2$, could be expected to form as an alteration product of elemental lead in various chemical environments. Therefore, depending on the lead compounds that form on the surface of the bullets, the leaching characteristics of lead in abandoned ranges will be different from the leaching characteristics of "fresh" bullets in active ranges.

Copper. The dominant oxidation states of copper are monovalent (cuprous) and divalent (cupric). Copper in both of these forms occurs in natural waters (Figure 8). Within the stability field of divalent copper, cupric carbonate or cupric oxide, depending upon the pH, exerts control over the solubility of copper. The solubility of copper in the three selected groundwaters is below 0.1 mg/L at pH values greater than 8 (Figure 9). In the pH range of 6 to 7, the solubility of copper is below 6 mg/L, and the variations in sulfate concentrations do not have a significant effect. However, organic matter increases copper solubility in a manner similar to lead. At pH below 6, copper may be relatively soluble (and mobile) in oxidized, shallow groundwaters.

Zinc. Zinc occurs in the natural environment exclusively in the divalent oxidation state. The solubility of zinc in groundwater is likely to be controlled by a zinc-silicate phase ($ZnSiO_3$ or Zn_2SiO_4, willemite) or a Zn-Fe-oxide ($ZnFe_2O_4$, franklinite). The hydroxide and carbonate phases are not likely to exert a solubility control because dissolved silica is present in most natural waters. The solubility of zinc in the three groundwater types is shown in Figure 10. Below pH 5, silica is very soluble, even in the presence of relatively high dissolved zinc (SiO_2 = 49 mg/L). At pH >5, the solubility of zinc decreases rapidly and is lower than 1 mg/L at pH 6 and higher. Because of insufficient data, no calculations are shown for the effect of organic complexing on the solubility of zinc. However, organic complexing of zinc is expected to be similar to that of copper and, therefore, will probably have a minor effect on the solubility of zinc at higher pH values.

Summary of Geochemical Modeling. Because of the low solubility of lead in water and its tendency to be trapped by organic matter in the soil, it is doubtful that lead could pose a significant threat to groundwater at most sites. Sites where groundwater is shallow (less than about 10 feet deep), the soils are sandy, and the soil pH is less than 7, may contain elevated levels of lead in the groundwater.

Similarly, copper and zinc solubilities drop greatly with increasing pH. Also, the drinking water standards for these metals are less restrictive. Copper is not a threat at sites where the soil pH is greater than 7 and zinc is not a threat at sites where the soil pH is greater than 6.

SURVEY RESULTS

The Navy Facilities Assets Data Base (NFADB) maintained by the Facilities Support Office (FACSO) in Port Hueneme, California, lists 89 naval bases having a total of 245 outdoor small arms ranges.

Sixty-five of the 89 naval bases were selected to receive a survey to collect data on: (1) small arms ranges, and (2) the potential for nonpoint source pollution from the ranges. From these 65 surveys, 37 responses have been received to date. The following is a compilation and analysis of some of the information contained in these surveys.

Thirty of the bases that responded to the survey currently have one or more active ranges. Three of the bases that responded have only abandoned ranges and three others have no ranges. Indoor ranges and skeet and shotgun ranges were not included in the analysis of the survey data. These ranges pose a different set of environmental concerns, such as indoor air pollution. Thus, 52 percent of the bases surveyed responded positively to the survey, which represents about 38 percent of the total number of bases listed in Karr, et al. (1990) (Figure 11) and about 32 percent of the total number of naval ranges.

Certain types of generalizations are difficult because much of the data are site-specific. For example, berm soil type varies from 90 percent clay at certain sites to 100 percent sand at other sites; therefore, there is not a typical soil type used in the construction of all berms. Similarly, proximity of surface water and groundwater to the berm varies greatly from site to site.

Two common practices were noted. First, spent casings are almost always collected and removed from the range. Second, lead is the primary chemical constituent in the bullet (and also the most toxic) and, therefore, the metal of greatest interest when evaluating the potential for nonpoint source pollution from responses.

Two naval bases indicated that their small arms ranges do not have impact berms to stop the bullets. Instead, the bullets drop onto a designated area adjacent to the small arms range. At Marine Corps Recruiting Depot (MCRD) Parris Island, South Carolina, bullets collect on a marshy area next to the range. At Camp Smith Training Facility, Ewa Beach, Hawaii, the seafront adjacent to the small arms range collects the spent bullets. Metal pollution from these two bases may be more dispersed than at ranges with impact berms and the level of threat to health and the environment may also be different.

The responses to individual questions are discussed below. A blank copy of the survey is included in Appendix A and Appendix B presents the mailing list. Please note that the surveys were screened for reasonableness of the responses and for potential erroneous responses on the part of the person completing the questionnaire. In many cases, questionable data were clarified over the telephone. When this was not possible, any highly suspect data were eliminated from the evaluations below.

Question 2: Number of Active Sites

Most of the sites surveyed (26 out of 30) have one or two active small arms ranges (Figure 12). The total number of active ranges for the 30 responses was 79. The high was 30 ranges (Figure 12), at Marine Corps Air-Ground Combat Center (MCAGCC) Twenty-Nine Palms, California. This assessment is echoed in the NFADB where the majority of activities have one or two ranges, while a few large Marine Corps training bases have over 20 ranges each.

Question 3: Number of Years in Service

The number of years of service for a small arms range varies from a few years to as long as 73 years. The frequency of responses based on a 10-year interval histogram (Figure 13) shows that the majority of the ranges (21 of the 31 responses) have been in service less than 30 years. The average number of years of service is approximately 27 years.

Question 4: Number of Abandoned Ranges

Of the 34 responses, there were a total of 18 abandoned ranges, including three bases that indicated they have only abandoned ranges and no active ranges. This number of abandoned ranges represents about 23 percent of the total number of active ranges (79) in this survey. Extrapolating this result to the 245 ranges listed in the NFADB yields approximately 56 abandoned small arms ranges at all of the naval installations.

Question 5: Lifetime of Ranges

Of the 35 activities that responded to this question, seven indicated that their ranges had an "indefinite" lifetime, 14 did not know the life span, and 13 gave a specific time period. Of the 13 that stated specific periods, the average lifetime of a small arms range is about 31 years.

Question 6: Number of Targets per Site

Figure 14 illustrates the number of targets per site. Each grouping in the histogram is in increments of five. There was a cluster of responses having 5 to 20 targets per site with several outliers having 40 or more targets per site. These clusters confirm field observations that there are two typical types of ranges: small pistol ranges with an average of 15 targets per range as shown in Figure 1, and larger rifle ranges with 50 or more targets per range as shown in Figure 2. The average is 17 targets per range.

Question 7: Number of Rounds per Year

The data on the number of rounds shot per year were computed to the average mass of lead accumulating per year in an impact berm. The mass of each type of bullet used is given in Table 9. The average coomposition of bullets was assumed to be 70 percent lead, 20 percent copper, 5 percent antimony, and 5 percent zinc.

The mass of lead generated per year is given in Figure 15a, with group intervals in increments of 1,000 kg/year. Fifteen of the total responses indicated lead masses of less than 2,000 kg/year. Three responses indicated that the mass of lead generated was more than 9,000 kg/year. The mean value is 3,190 kg/year. Sample size for this question is 30. For all 245 ranges reported in the NFADB, the mass of lead discharged into the environment at all naval bases is 780,000 kg/year (860 tons).

The mass of copper generated per year is given in Figure 15b with a histogram interval of 100 kg/year. The mean mass is 354 kg/year. For all 245 ranges, the mass of copper discharged into the environment at all naval bases is 87,000 kg/year (95 tons).

Question 8: Chemical Composition of the Bullet

Of the 34 responses, 27 respondents answered this question. Nineteen of the respondents indicated that lead was the major metallic component in the ammunition used, with a relative lead composition greater than 90 percent (see Figure 16a). Of the 19 respondents, two (from NAS Pensacola, Florida, and NAVSTA Panama Canal) indicated that the ammunition used for their small arms was mainly made of copper in proportions as high as 90 percent. Upon questioning, they indicated that 90 percent of their ammunition used consisted of copper-jacketed bullets. Copper seems to be used more extensively as an outer sheath material than steel (Figures 16b and 16c).

Question 9: Spent Casings

Thirty-two respondents indicated that spent casings from ammunition were collected and disposed of or recycled (Figure 17). Only two respondents indicated that the casings were not collected. Of the 32 positive responses, 22 indicated that the spent casings were sold to a metal recycler, and nine indicated that they were disposed of (see Figure 17, insert). Of the 22 respondents that indicated the spent casings were sold to a metal recycler, 10 indicated that the material was turned over to the Defense Reutilization Marketing Office (DRMO) and recycled. The nine respondents that indicated that the metal casings were disposed of did not state the mode of disposal.

Question 10: Type of Soil

There were 31 responses to this question. The data are plotted in Figure 18. Some respondents placed a check mark by the type of soil rather than indicating a percentage. When a single check mark was indicated, we assumed that the soil consisted of 100 percent of that particular material. If check marks were placed on more than one soil type without giving the percentage, the data were not taken into consideration. Of the 31 respondents, 12 indicated that their berms were constructed of 100 percent sand. Figure 18 indicates that a variety of other materials in addition to clay and sand have been used. Impact berms at naval bases on islands such as NAVSTA Guam tend to be built out of coral, while a few indicated that (undefined) crushed rock was used for the core to provide support.

Question 11: Typical Berm Size

Berms come in many sizes with heights varying from as low as 5 feet to as high as 50 feet and with lengths varying from 15 feet to a mile long, such as at NAVSTA Panama Canal. While some impact berms are built out of dirt from near the range, several respondents indicated that their impact berms were actually the side of a hill, such as at NAVSTA Panama Canal. Based on the responses, there was some confusion over the definition of the width and length of the berm. When the width was longer than the length, we took the liberty to switch the measurements around. Figures 19, 20, and 21 summarize the responses for the height, width, and length of the berms. The mean height, width, and length of a berm are 18, 42, and 340 feet, respectively. These averages include two very long berms. The two clusters of data on the length of the berm confirm field observations of two different sizes of small arms ranges. One class of a small arms range has a berm with an average length of 130 feet. The other class consists larger ranges with berm lengths in excess of 500 feet. Two of these long berms reported in the survey, NAVSTA Panama Canal with a berm length of 5,280 feet and MCRD Parris Island with a berm length of 1,500 feet, were not included in Figure 21.

In terms of the shape of the berm cross section, most berms are trapezoidal rather than rectangular. To quantify the total volume of soil in a berm, the width of the crown (i.e., top) of the berm would be required along with the slopes of the impact side and back side of the berm. We have made some approximations to facilitate this calculation.

The slopes of the front (impact side) and back of the berm vary from 1.0 to 2.0 (based on several engineering drawings on impact berms provided by Marine Corps Base Camp Pendleton, California). To compute the volume of soil, we have assumed a slope of 1.5. If the width of the berm was less than twice the height of the berm divided by the slope, we assumed that the berm was rectangular in shape. If not, the berm was assumed to be trapezoidal. The total volume of the berms from the various responses was plotted with group intervals in increments of 1,000 cubic yards (Figure 22). The mean volume of a berm is 3,100 cubic yards per site excluding the two outliers.

As shown by the Karr, et al. (1990) study, soils are not contaminated uniformly. The area directly behind a target (bullet pockets) is obviously the most contaminated. Contamination decreases as one moves away from the bullet pockets and also as one moves deeper into the berm. Some of the soil may not be contaminated enough to fail a TCLP test, therefore, not all soil on the berm needs to be regarded as hazardous. The contaminated soil that is hazardous is certainly only a fraction of the total volume of the berm. To compute this fraction, we assumed that the full length of the impact side of the berm is contaminated to a depth of 3 feet, which probably is a conservative assumption because bullets are unlikely to penetrate that far into the ground. This calculation yields a mean contaminated soil volume of 820 cubic yards per site (excluding the two outliers). Figure 23 illustrates the distribution of contaminated soils based on the above criteria.

The fraction of lead by volume in the contaminated soil was estimated to be about 1.3 percent based on a specific gravity of 11.4 for lead, an annual accumulation of 3,190 kg of lead over a 30-year period in a volume of 820 cubic yards. Localized pockets can contain up to 30 percent lead by volume or more, as reported by Karr, et al. (1990).

The safety and protective sides of the berms were not included in the volume calculations because many respondents did not provide these data. Note, however, that soil from the side berms may also be contaminated because of possible dispersion of fragmented and stray bullets and aerial dispersion from airborne lead particles.

Question 12: Disposal of Soil

For question 12 (see Figure 24), a total of nine respondents indicated that the contaminated soils are mined when a ricochet problem occurs, while four indicated that the soil was removed and disposed of as hazardous waste. Five respondents indicated that the soil was removed and used on-site as fill. Fourteen indicated that other actions were taken. Of these 14 respondents, three indicated that more soil was added to the berm, one indicated that the soil will be analyzed and disposed of accordingly, while the rest indicated that they do not have a ricochet problem. Four did not respond to this question.

As a followup to this question, we attempted to contact the nine respondents that indicated their soils were mined. We were able to contact four of the nine. At MCRD Parris Island, South Carolina, the berm was mined once about 8 months ago. Officials tentatively plan to mine the berm every 12 to 18 months. Manual labor was used and dirt was screened through a 3- by 4-foot frame with a 1/8-inch mesh rabbit wire. Berms at NAS Kingsville, Texas, are mined yearly or more frequently, depending on the number of rounds expended. Again, the soil is sieved. The Officer in Charge did not know what size mesh is used.

At NAS Pensacola, Florida, the Officer in Charge reported that the berms are mined every month. Dirt is screened through a 1/4-inch mesh screen held by a 2- by 4-foot frame. Material remaining in the screen is placed in 55-gallon drums and sent to DRMO, while the soil is returned to the berm. Similar practices are carried out at SUBASE San Diego except that the berms are mined annually, and protective clothing (including masks) is used during shoveling and screening. All four respondents indicated that employing a subcontractor to mine the berm is expensive, and that they do not know to whom DRMO sells the recoverable metals.

The practice of using the soil from impact berms as fill without treatment could possibly result in the transfer of contamination from one site to another. Mining or recycling is clearly a preferred practice.

Questions 13 and 14: Distance to Nearest Surface Water and Depth of Groundwater

Figure 25 illustrates the responses for question 13. The responses show a great range in distances and depths, depending on the site. With regard to depth to groundwater (Figure 26), 11 responded that the depth was less than 10 feet, while 18 indicated that the depth was less than 20 feet. This was expected because most naval bases are close to the coast.

Question 15: Chemical Analysis of Surface Water and Groundwater

Survey responses for this question are shown in Figure 27. A total of seven responses indicated that surface water or groundwater wells were chemically analyzed. Most did not possess data on the concentration of lead and other metals. The respondents were as follows:

- NAS, Mayport, Florida
- MCLB, Albany, Georgia
- MCRD, Parris Island, South Carolina
- NAS, Patuxent River, Maryland
- NAB, Little Creek, Virginia
- MVSEC, Sabana Seca, Puerto Rico
- NAS, Alameda, California.

Table 10 lists the groundwater data for wells that were near the impact berms. The groundwater taken from Well M-3 at NAB Little Creek, about 100 feet from the impact berm (Figure 28), had a concentration of 83 µg/L of lead, which is higher than the drinking water standard for lead of 50 µg/L. This well is also close to an old disposal pit, which could also be the source of the elevated lead levels. More data need to be collected to resolve this issue.

Table 11 lists chemical analysis data that were provided on surface water and surface runoff. At NAS Mayport, surface runoff water collected close to the impact area after a storm indicated lead levels as high as 2.36 mg/L (or 2,360 µg/L). Water at the drainage ditch, however, showed much lower levels of lead. Also included in Table 11 are data on surface water from an environmental assessment study at Quantico, Virginia. These data revealed that lead levels in the stream more than 1,000 feet away from the berm were normal and were less than the drinking water standard.

Question 16: Analysis of Soil

Three respondents indicated that soil from their impact berms was chemically analyzed. In addition to the soil analysis from NAS Mayport, we have included in Table 12 soil analysis data from the case studies discussed earlier. These data positively show that the soils from impact berms are contaminated with lead, zinc, and copper and that the failure of the TCLP test for lead would classify certain soils as hazardous.

SIGNIFICANT FINDINGS AND CONCLUSIONS

Bullets are made of a lead alloy consisting of copper, tin, and antimony. Jacketed bullets have a coating material consisting of copper plate or a copper zinc mixture. Other metals are used as tracers and ignitors and may be a source of contamination.

Lead is ubiquitious in nature and is found at an average concentration of 16 ppm in the soil. It is not an essential element and can bioaccumulate in human, animal, and plant tissue and cause chronic health effects. It can cause severe central nervous system disorders in humans. Grazing cattle have been poisoned by lead.

Copper is ubiquitious in nature and is found in the soil at an average concentration of 30 ppm. It is an essential element at levels of 1 to 3 mg/day, but can be harmful in excess of 15 mg/kg. Chronic health effects are rare, but acute effects such as digestive problems are more common. Sheep are sensitive to copper and fish can tolerate concentrations only up to 12 µg/L.

Zinc is ubiquitious in nature and is found in the soil at an average concentration of 90 ppm. It is an essential element at 15 mg/day, but can cause food poisoning at over 1,000 ppm. Zinc is not very toxic to aquatic organisms, fish can tolerate up to 110 µg/L. Earthworms can bioaccumulate enough lead to supply a lethal concentration to birds and small animals.

There are no guidelines for elevated levels of lead, copper, and zinc in vegetation.

Elevated levels of lead, copper, and zinc in the soil and vegetation have been found in the berms at small arms ranges, in areas 250 feet behind the impact berms, and in the drainage from the berms. These levels of lead, copper, and zinc indicate that the berms represent a nonpoint source of pollution. Levels of lead exceeding the RCRA hazardous waste criteria have been found in the soil of the berms.

How small arms ranges are regulated under various Federal, State, and local laws is a nebulous subject. Generally, if it is intended to recover and recycle all of the bullets and fragments, the site is not regulated under RCRA. The site may be regulated under CERCLA if more than 1 pound of lead is transported in storm-water runoff from the site or the site is abandoned. The site may also be regulated under the Clean Water Act as a nonpoint source of pollution. A NPDES permit may be needed for collected storm-water runoff from the site or if the site has no impact berm and bullets are discharged directly into a surface water. It is highly recommended that environmental legal counsel be sought for determining how the regulations impact small arms ranges at specific facilities.

Results of limited groundwater sampling and geochemical modelling indicate that lead may cause groundwater pollution at sites with sandy soil, a soil pH less than 7, and shallow groundwater (less than about 10 feet). Groundwater modelling indicates that copper or zinc can cause groundwater pollution at sites where the soil pH is less than 6 and groundwater is shallow. Field sampling has not been performed to acquire data to support the modelling.

The Navy and Marine Corps have an estimated 89 bases with 245 active ranges. There are an estimated 56 abandoned ranges.

It is estimated that a total of 860 tons of lead and 95 tons of copper are discharged into the environment at all naval ranges.

Most of the 89 bases have one or two small arms ranges. The Marine Corps have several bases with over 20 small arms ranges each.

There are two size classes of small arms ranges. The most common class is a site with 15 targets and a berm 130 feet long. The other class contains much larger ranges with 50 or more targets and berm lengths of over 500 feet.

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Table 1. Chemical Composition of Bullet Cores
(from MIL-L-13283B (MR) 19 Aug 1970)
(Fedoroff & Sheffield, 1975)

Element	Grade 1	Grade 2	Grade 3
Lead and Antimony % minimum	99.2	90.0	90.0
Antimony	1.0-2.5	9.0-10.5	9.0-9.1
Copper % maximum	0.1	0.1	0.1

Table 2. Typical Chemical Composition of
Jacket Materials

Element	ASTM B 130-86 Brass[a]	"95/5 Brass" Gilding Metal[b]	"90/10 Brass" Gilding Metal[b]
Copper	89.0-91.0	94-95	89-91
Lead, max	0.05	0.03	0.03
Iron, max	0.05	0.05	0.05
Zinc	remainder	5-6	9-11

[a]ASTM Standard Specification for Commercial Bronze Strip for Bullet Jackets.
[b]Encyclopedia of Explosives and Related Items (Fedoroff & Sheffield, 1968).

Table 3. Typical Formulas for Igniter and Tracer Compositions (Kaye, 1978)

Compound	Delay Action Igniter I-136	Dim I-194	Daylight Bright) Igniter I-276	Red Tracer R-257	Fumer R-284
Strontium Peroxide	90	--	--	--	--
Magnesium	--	6	15	28	28
I-136 Igniter	--	94	--	--	--
Calcium Resinate	10	--	--	4	--
Barium Peroxide	--	--	83	--	--
Zinc Stearate	--	--	1	--	--
Toluidine Red (Identifier)	--	--	1	--	--
Strontium Nitrate	--	--	--	40	55
Strontium Oxalate	--	--	--	8	--
Potassium Perchlorate	--	--	--	20	--
Polyvinyl Chloride	--	--	--	--	17

Table 4. Military Primer Compositions (from Juhasz, 1977)

Ingredients	Composition (Percent by Weight) FA70	FA90	PA100	PA101	793	NOL60	NOL130
Lead Styphnate (Basic)	--	--	--	53	39	60	40
Lead Styphnate (Normal)	--	--	38	--	--	--	--
Barium Nitrate	--	--	39	22	44	25	20
Lead Azide	--	--	--	--	--	--	20
Tetracene	--	--	2	5	2	5	5
Lead Dioxide	--	--	5	--	--	--	--
Calcium Silicide	--	--	11	--	14	--	--
Aluminum Powder	--	--	--	10	--	--	--
Antinomy Sulfide	17	12	5	10	--	10	15
Lead Sulphocyanate	25	25	--	--	--	--	--
PETN	--	10	--	--	--	--	--
TNT	5	--	--	--	--	--	--
Potassium Chlorate	52	53	--	--	--	--	--

Table 5. Summary of Metals Background Data

Standard	Pb	Cu	Zn
Drinking Water Standards (μg/L)	50	1000	5000
Natural Occurrence:			
Groundwater (μg/L) -			
Range	1-10[a]	--	--
Freshwater (μg/L) -			
Mean	3	3	15
Range	0.06-140[a]	0.2-30	0.2-100
Seawater (μg/L) -			
Mean	0.3	0.25	4.9
Range	0.03-13	0.05-12	0.2-48
Soil (mg/kg) -			
Mean	16[b]	30	90
Range	10-37	2-250	1-900
Sediments (mg/kg dry wt)[c]:			
Median	16	4.0[d]	41
95 Percentile	199	32.0[d]	379
Toxicity Criteria in Aquatic Environment (μg/L):			
Freshwater (hardness = 100 mg/L) -			
Acute	82	18	120
Chronic	3.2	12	110
Seawater -			
Acute	140	2.9	95
Chronic	5.6	2.9	86

[a]Sittig (1980).
[b]Davies and Wixson (1986).
[c]Based on analyses of stream, river, lake, and reservior sediments.
[d]Wet weight basis.

Table 6. Total Metals Concentrations in Impact Berm Soil
NAB Little Creek, VA and MCCDC Quantico, VA

Soils	Little Creek			Quantico		
	Pb (ppm)	Cu (ppm)	Zn[a] (ppm)	Pb (ppm)	Cu (ppm)	Zn (ppm)
Natural Occurence, Soil[b]:						
<u>Mean</u>	16.0	30.0	90.0	16.0	30.0	90.0
<u>Minimum</u>	20.0	2.0	1.0	20.0	2.0	1.0
<u>Maximum</u>	37.0	250.0	900.0	37.0	250.0	900.0
Horizon A:						
<u>Mean</u>						
Samples	2954.3	137.0	22.0	4772.7	559.6	112.7
Control	8.6	3.8	13.8	26.0	6.9	19.2
<u>Minimum</u>						
Samples	15.1	1.9	1.3	161.0	61.7	53.6
Control	4.8	2.9	3.2	12.5	4.1	13.0
<u>Maximum</u>						
Samples	15100.0	957.0	173.0	23200.0	1619.0	294.0
Control	18.2	5.5	40.2	37.0	10.3	26.8
Horizon B:						
<u>Mean</u>						
Samples	1243.0	82.4	11.1	1222.9	397.3	130.2
Control	24.5	40.8	25.6	31.9	4.9	13.0
<u>Minimum</u>						
Samples	7.2	2.0	1.5	87.7	71.6	60.2
Control	5.0	2.2	1.7	11.5	2.7	10.7
<u>Maximum</u>						
Samples	8421.0	416.0	56.3	4221.0	1139.0	294.0
Control	61.2	121.0	91.0	103	6.6	19.2
Vegetation:						
<u>Mean</u>						
Samples	57.9	14.1	38.4	61.9	9.3	62.6
Control	1.2	13.2	151.7	1.1	4.7	41.6
<u>Minimum</u>						
Samples	25.0	6.7	21.2	20.1	6.5	45.2
Control	0.8	7.9	32.3	0.7	3.8	33.3
<u>Maximum</u>						
Samples	265.0	26.1	111.5	125.0	13.0	92.6
Control	2.0	13.2	151.7	1.5	5.4	68.6

[a]The control sample for zinc may have been contaminated from other sources.
[b]Values are from Table 5.

Table 7. Groundwater Compositions (mg/L) (Hem 1986)

Chemical Characteristics	Geological Terrain		
	Basalt	Sand/Gravel	Limestone
pH	7.8	7.0	7.6
Total Dissolved Solids	225.0	314.0	594.0
Conductivity	358.0	517.0	885.0
Potassium	5.2	2.8	2.1
Sodium	30.0	23.0	13.0
Calcium	32.0	58.0	126.0
Magnesium	12.0	13.0	43.0
Iron	0.01	0.04	2.3
Manganese	--	1.3	--
Aluminum	--	0.1	--
Bicarbonates	220.0	101.0	440.0
Sulfates	11.0	116.0	139.0
Chloride	7.9	39.0	100.0
Fluoride	0.2	0.0	0.7
Nitrates	2.9	0.6	0.2
Orthophosphates	--	0.1	--
Hardness as CO_3	129.0	198.0	490.0
Categories:			
Sulfate	low	moderate	moderate
Carbonate	moderate	moderate	high

Table 8. Solubility Product (Log K_{sp}) of Lead Compounds and Lead Minerals at 25°C (Nriagu, 1978)

Lead Compounds and Minerals	Solubility Product (log K_{sp})
PbO (red)	12.7
$PbCl_2$	-4.77
$PbSO_4$	-7.72
PbS	-28.1
$PbCO_3$	-12.8
$Pb_3(CO_3)_2(OH)_2$	-17.0
$Pb_3(PO_4)_2$	-44.3

Table 9. Approximate Weights for Different Ammunition

	Weight of Bullet	
Rounds	Grains	Grams
5.56 mm	56	3.6
7.62 mm	147	9.5
0.90 mm	115	7.5
0.45 caliber	234	15.2
0.38 caliber	130	8.4
12 GA 00 buckshot	120 (assumed)	7.8

Table 10. Summary of Groundwater Contamination

Site	Description	pH	Depth (ft)	Distance from Berm (ft)	Pb (mg/L)
MCLB Albany, GA	June 1989	5.77-10.69	50	--	0.001-0.019
NAB Little Creek, VA	February 1989	--	11	~100	0.083

Table 11. Summary of Surface Runoff/Surface Waters

Site	Description	pH	Distance from Berm (ft)	Pb (mg/L)
MCCDC Quantico	Sample from creek	7.0	>1000	0.0063
NS Mayport	Samples from impact berm	--	5-10	2.36
NS Mayport	Samples from drainage ditch	--	300	<0.005

Table 12. Summary of Lead Analysis at Small Arms Ranges

Site	Description	pH	Depth (ft)	Total Lead (mg/L)	Soluble Lead (mg/L)
NS Mayport	Impact berm	--	0-6	--	0.66-661.0
MCCDC Quantico	Impact berm Base of berm 0-200 ft behind berm Drainage swale next to berm				
NAB Little Creek	Impact berm				

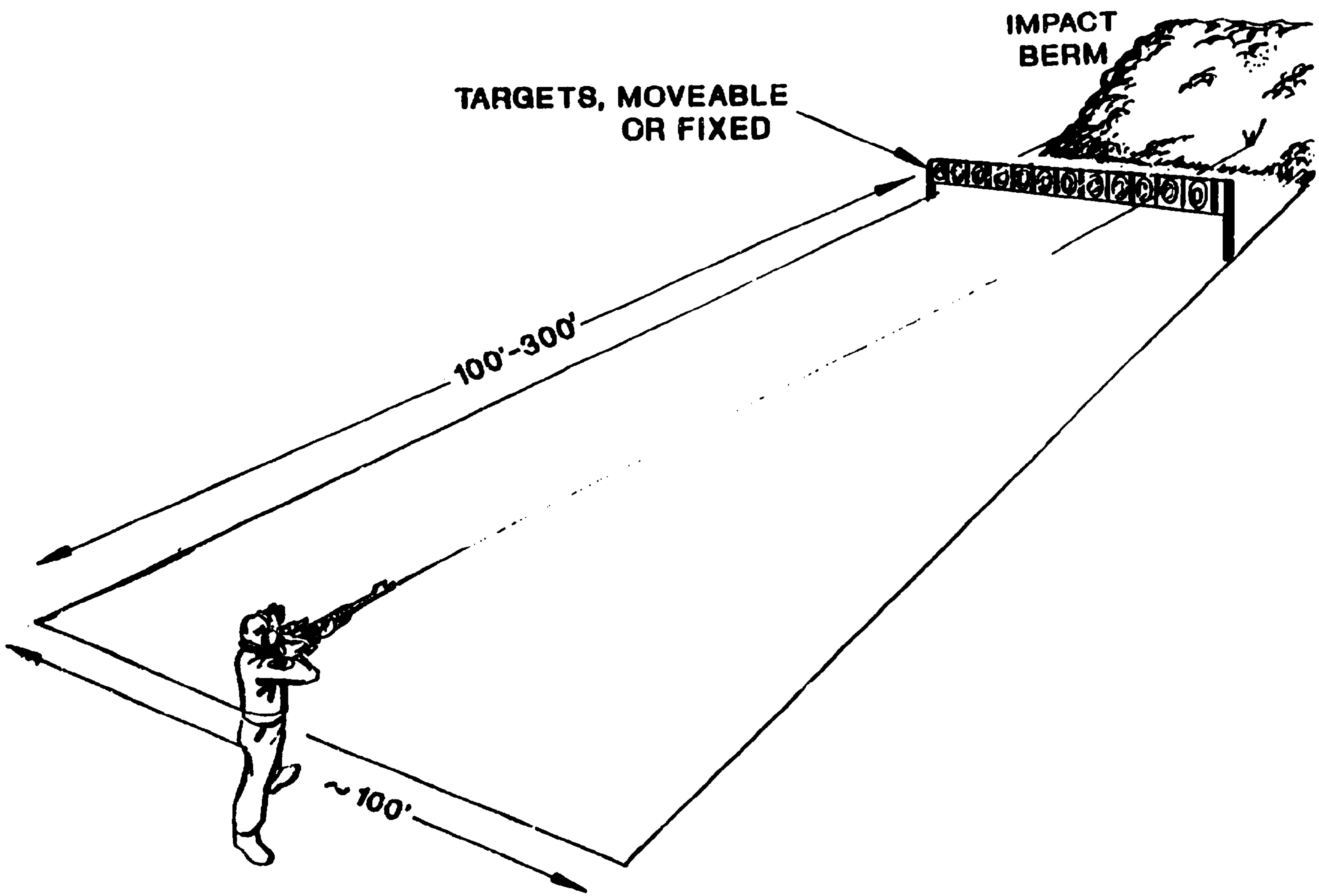


Figure 1. Typical pistol range.

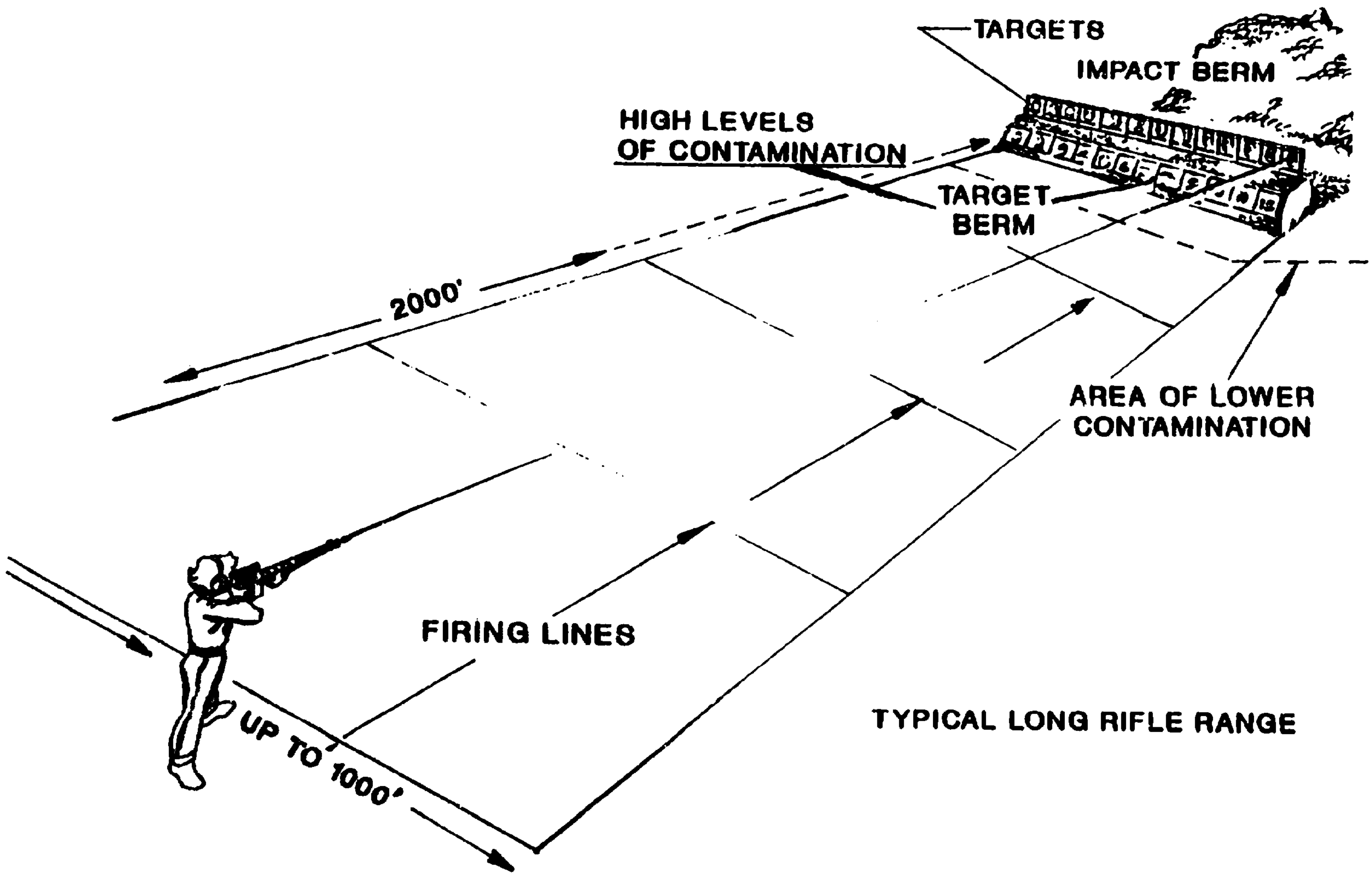


Figure 2. Typical long rifle range.

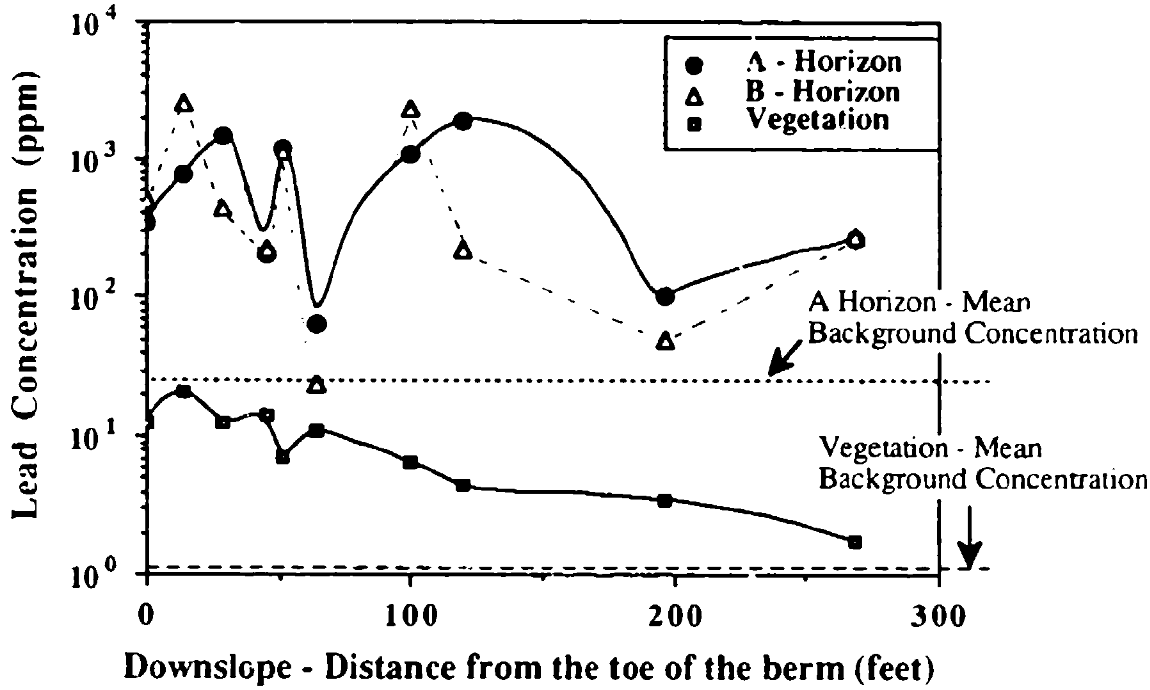


Figure 3. Lead concentration in the downslope transect of an impact berm.

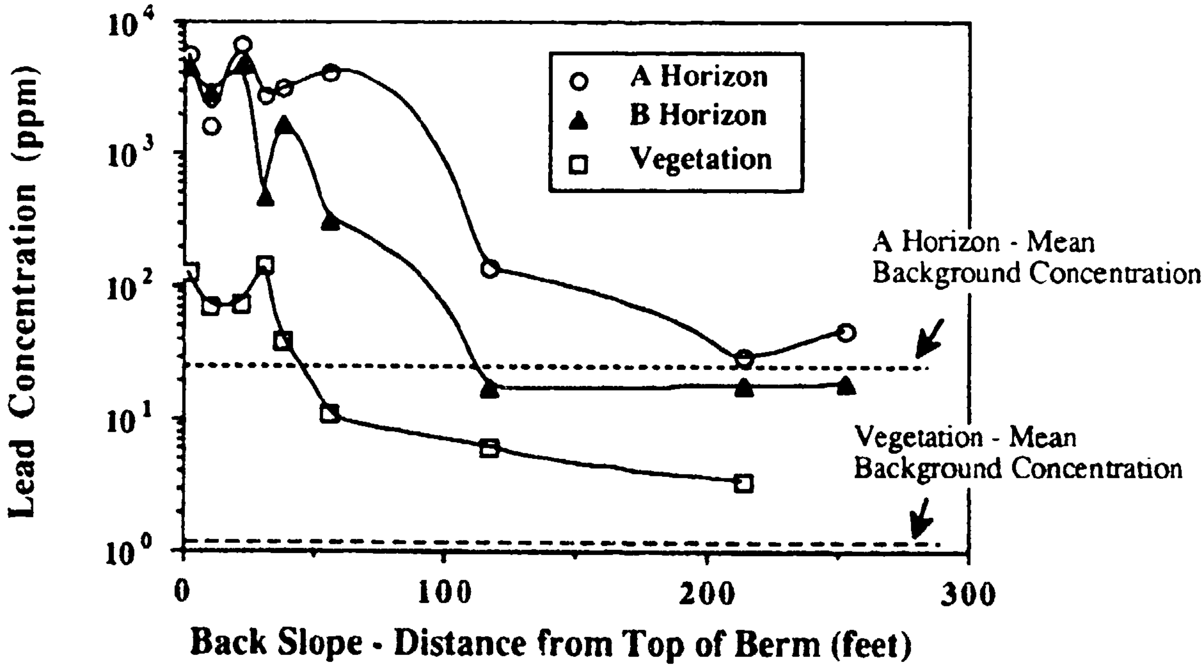
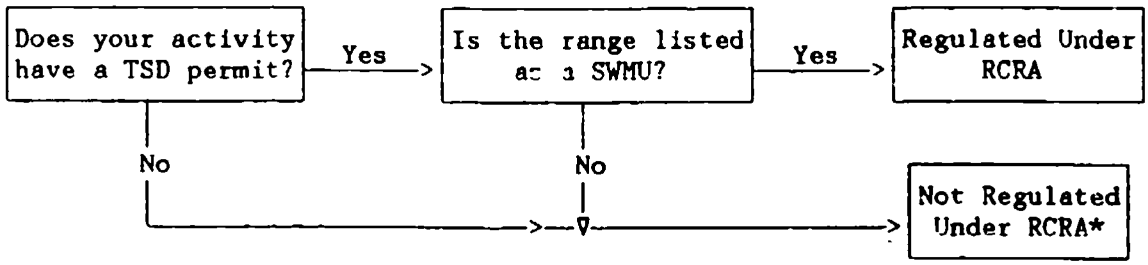


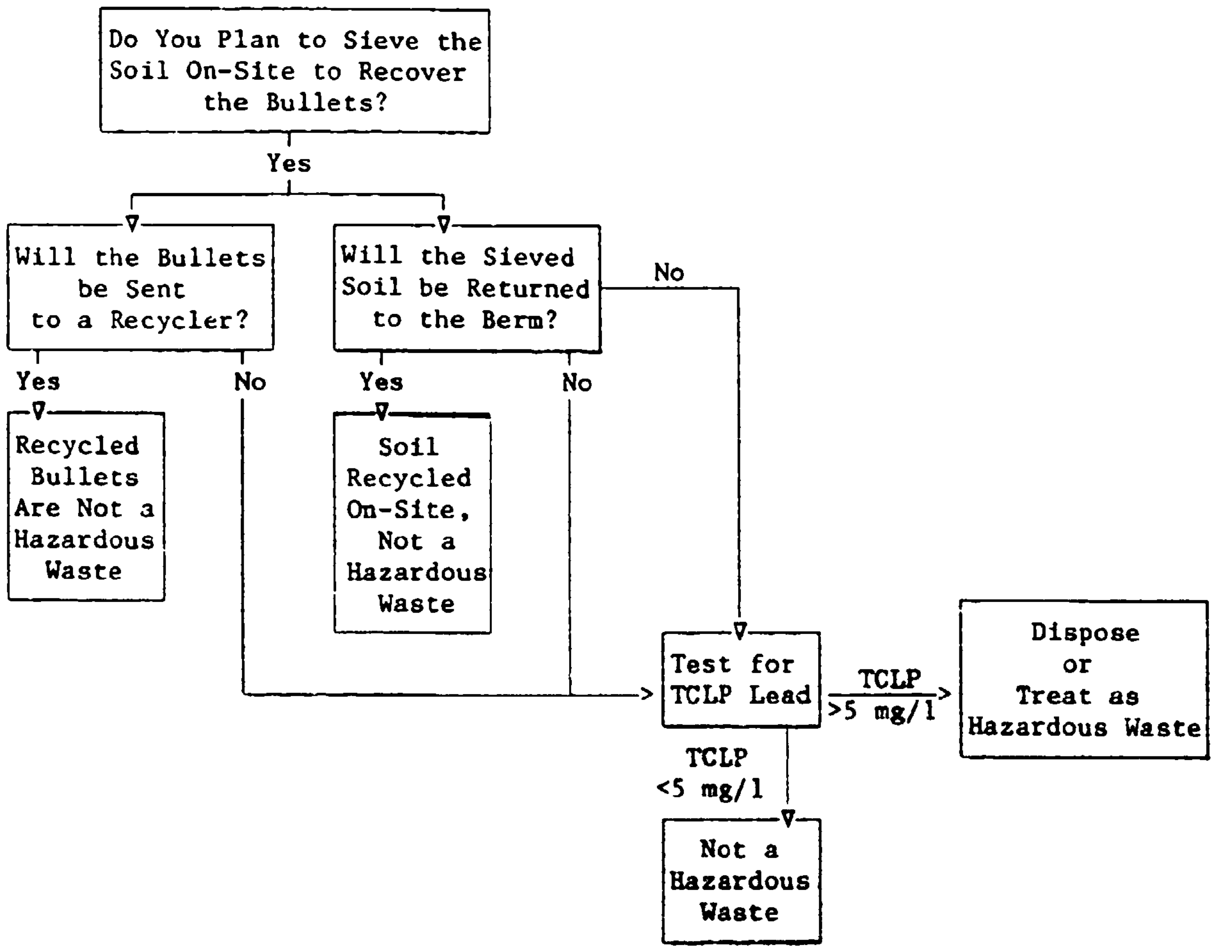
Figure 4. Lead concentration in the backslope transect of an impact berm.

1. Is my currently operating small arms range considered a hazardous or solid waste treatment storage, or disposal (TSD) site?



*This is based on the contention that you eventually plan to recover or recycle the lead from the bullets.

2. I have a ricochet problem with the impact berm at my small arms range. The range is not listed as a SWMU on my activity's RCRA TSD permit. What are the consequences of my actions to reduce the ricochet problem?



If the range is listed as a SWMU, contact regulatory agency and legal council for consequences of actions.

Figure 5. Small arms ranges RCRA minimum criteria.

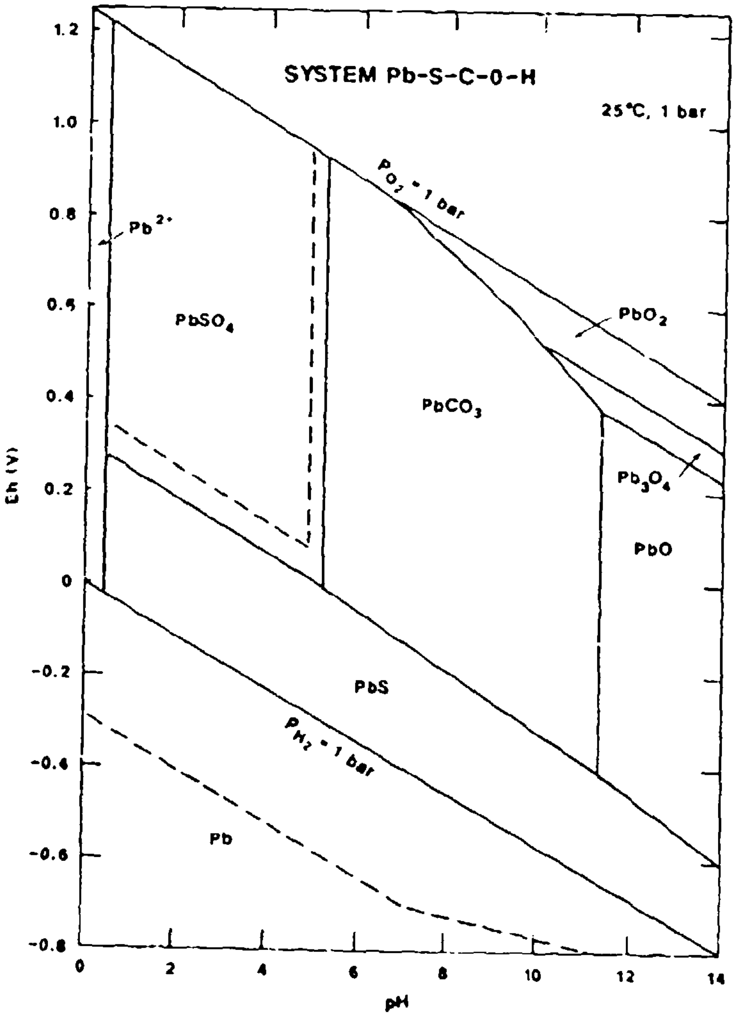


Figure 6. Eh-pH diagram for system Pb-S-C-OH (Pb = 10^{-6}, S = 10^{-3}, C = 10^{-3} M) (from Brookins, 1988).

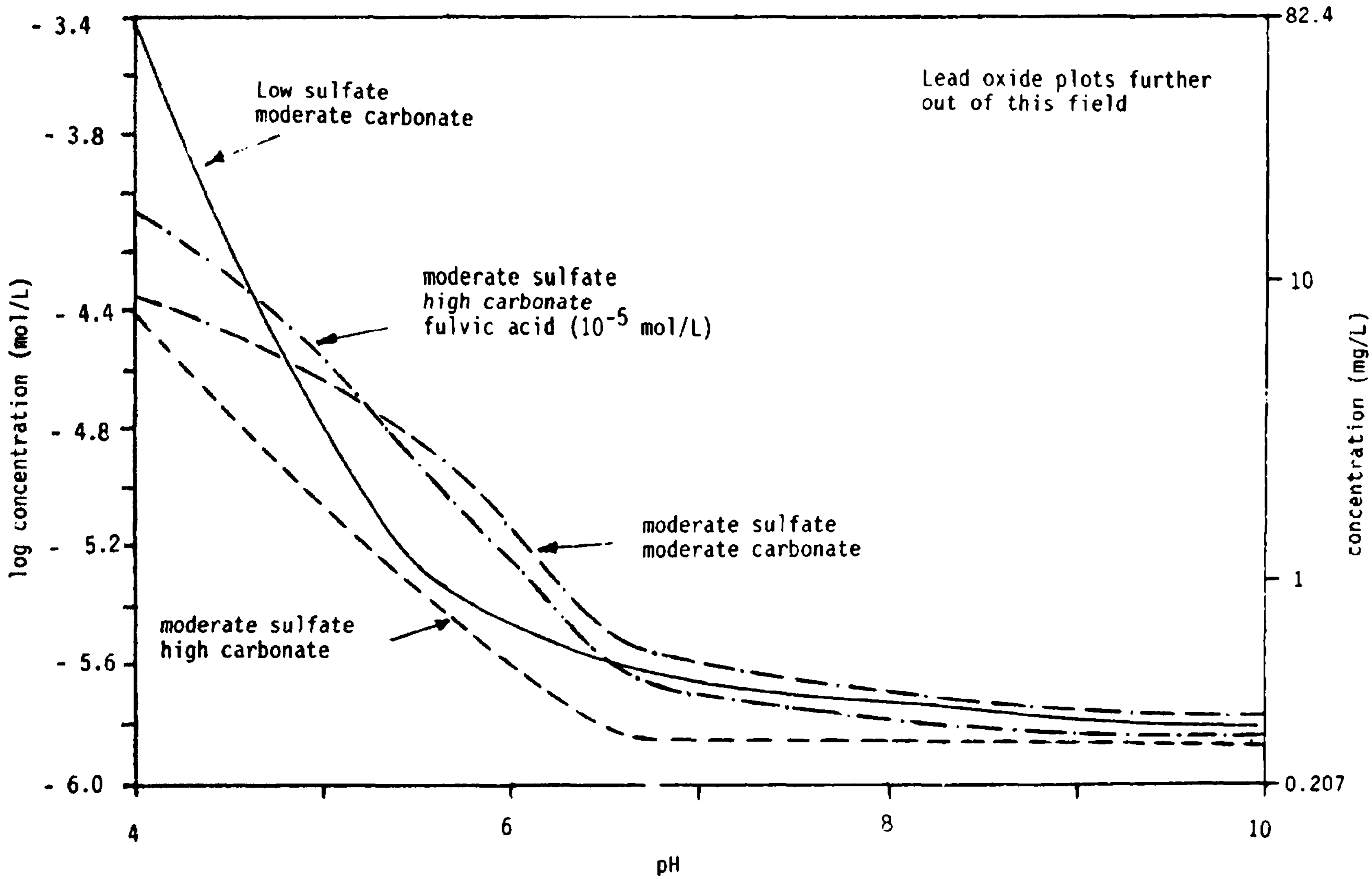


Figure 7. Solubility of lead in three different groundwaters.

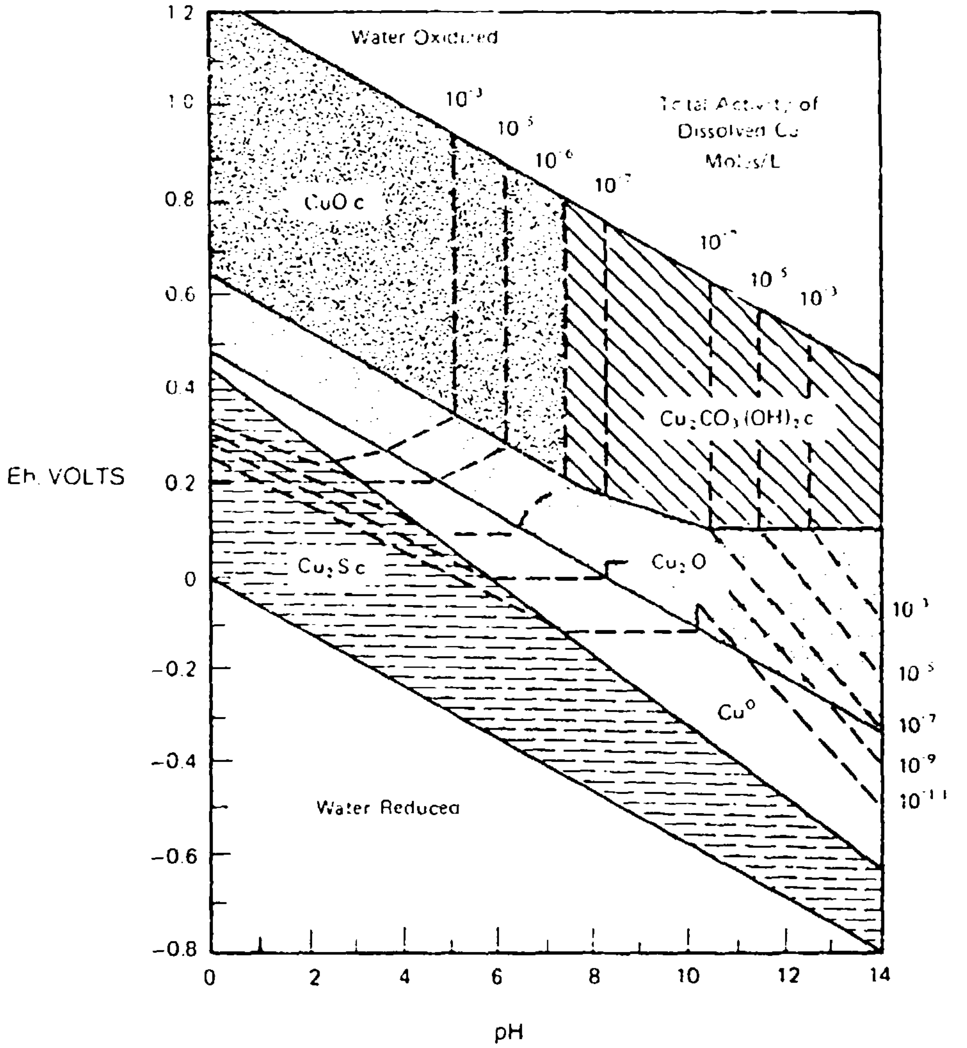


Figure 8. Eh-pH diagram for system $Cu\text{-}H_2O\text{-}C\text{-}S$ ($Cu = 10^{-3}$ M, $S = 10^{-4}$ M) (courtesy J. Anderson).

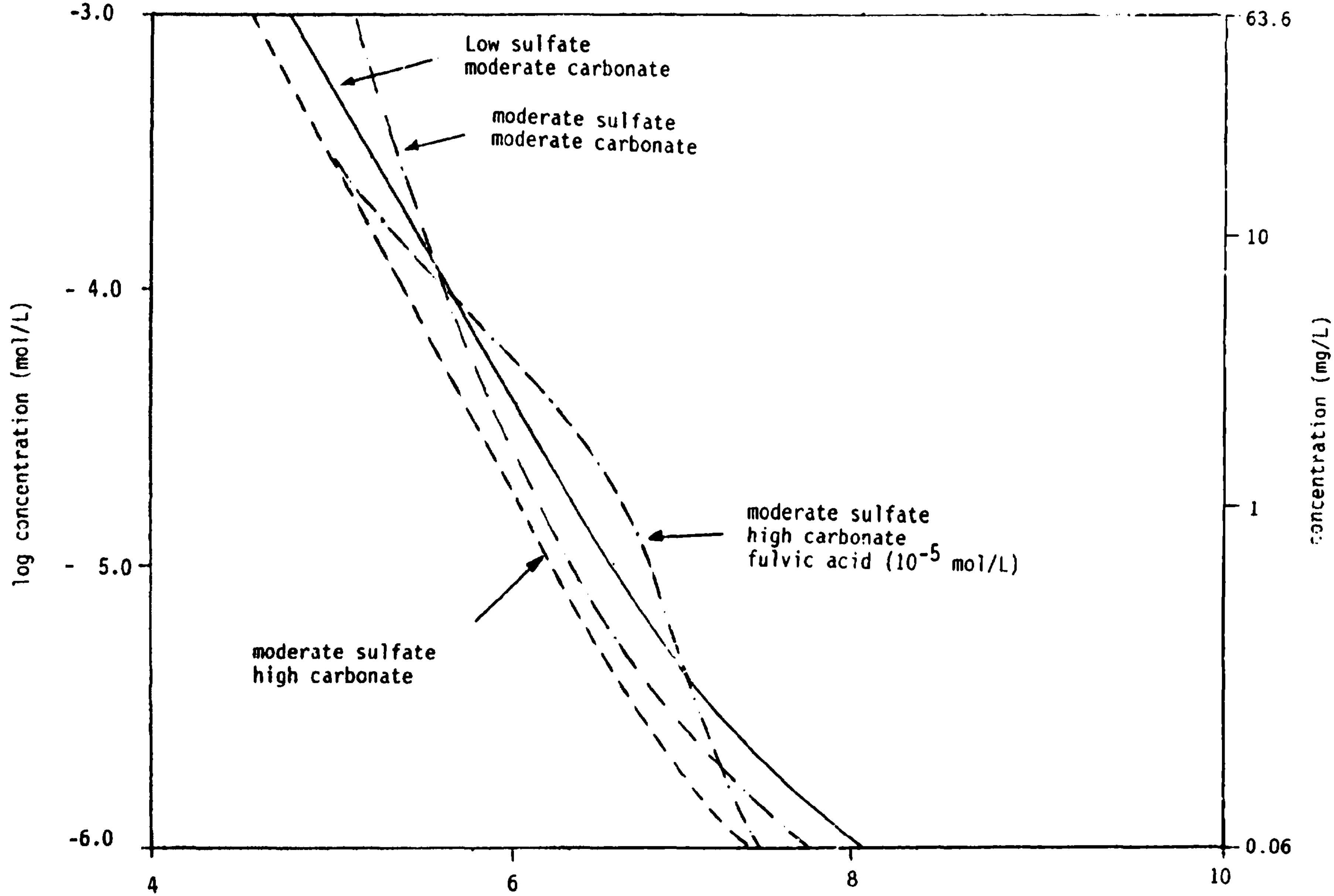


Figure 9. Solubility of copper in three different groundwaters.

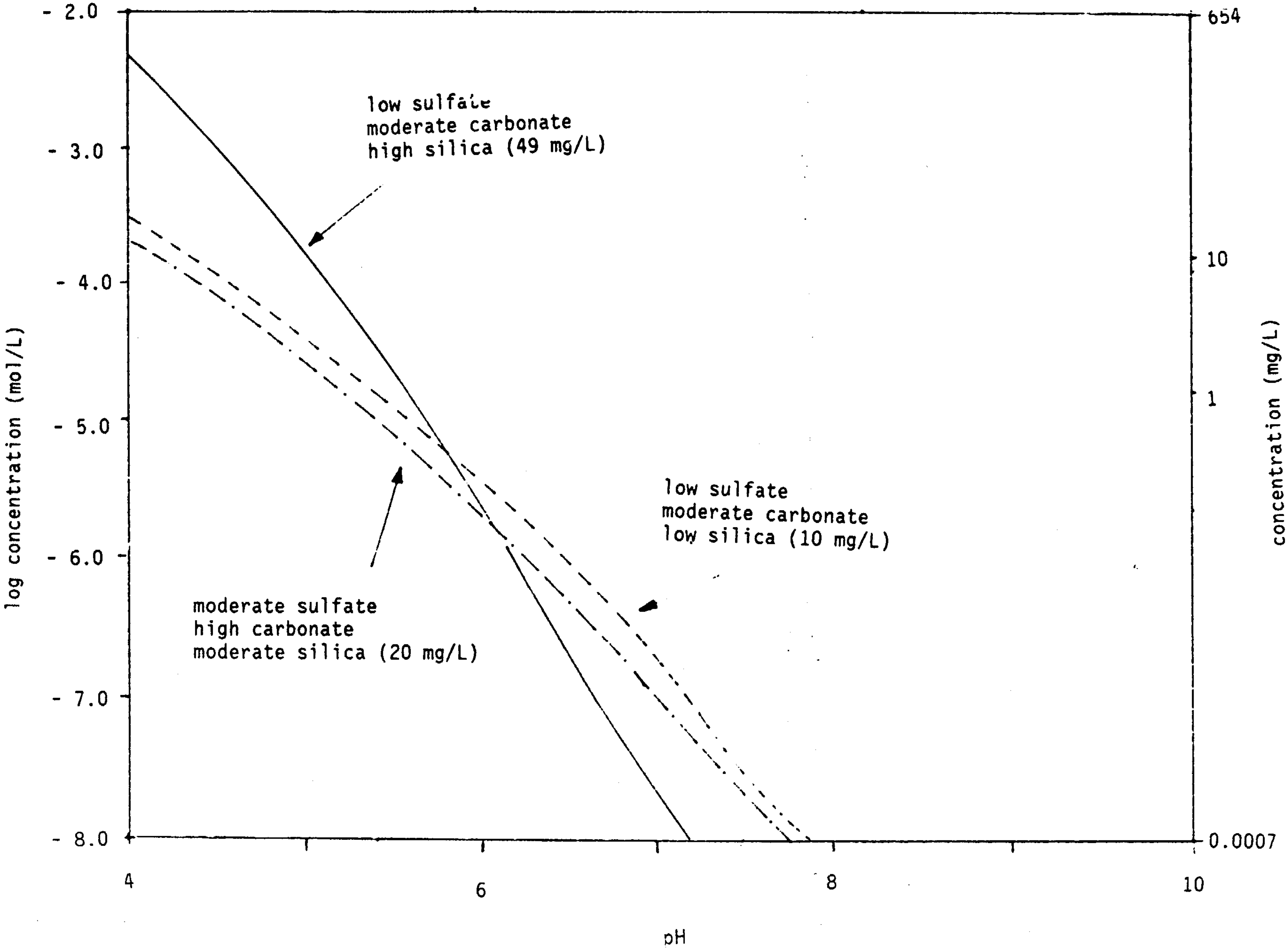


Figure 10. Solubility of zinc in three different groundwaters.

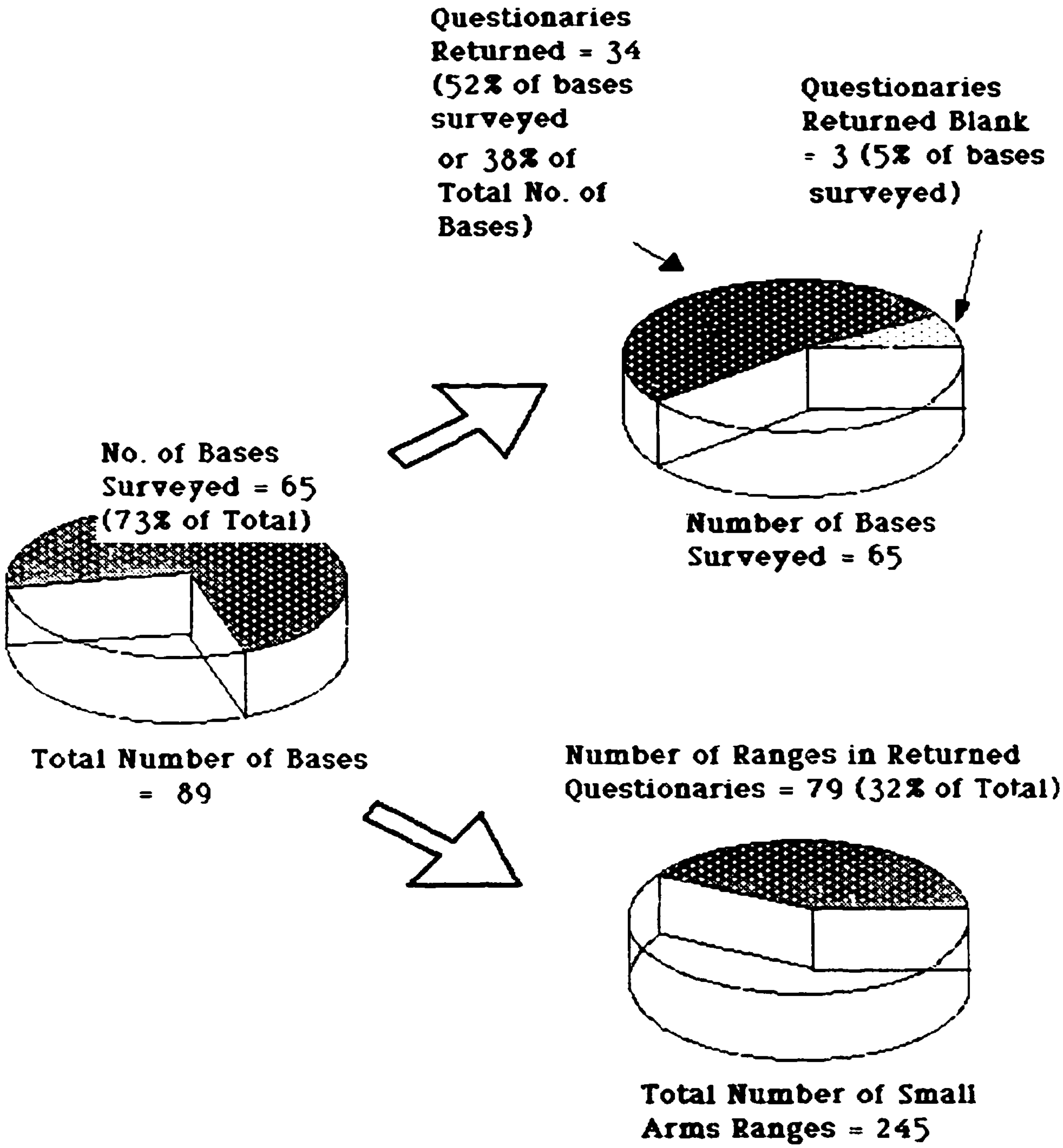


Figure 11. Response from the small arms range survey.

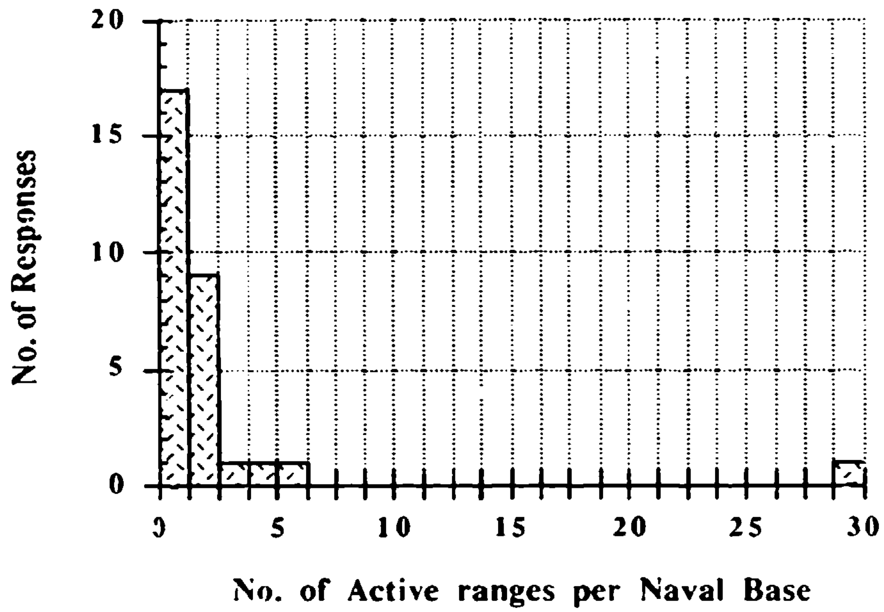


Figure 12. Survey responses to Question 2: Active ranges

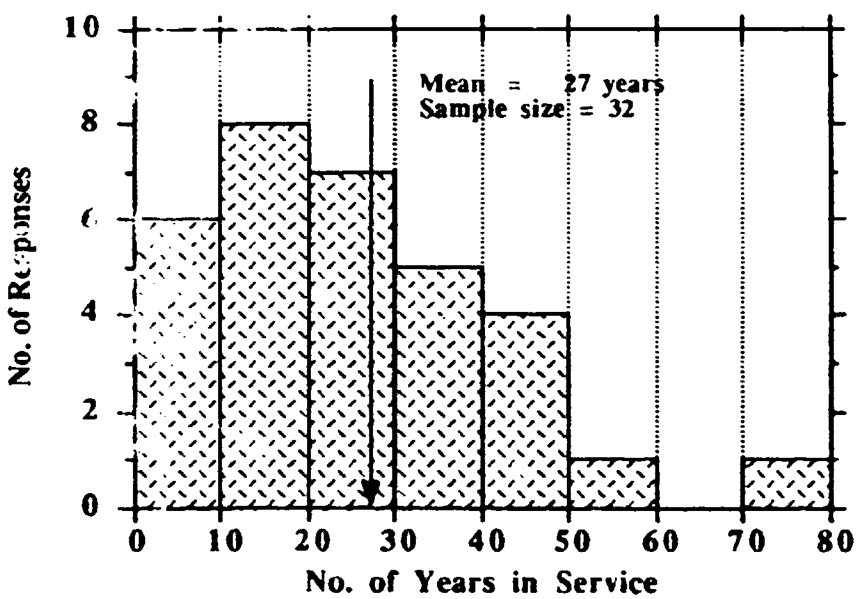


Figure 13. Survey responses to Question 3: Number of years in service for small arms ranges.

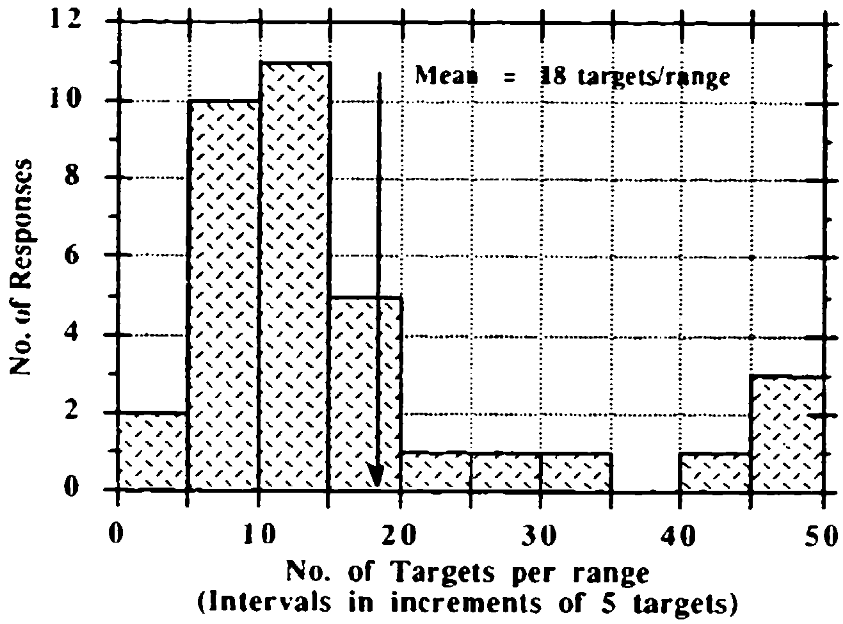
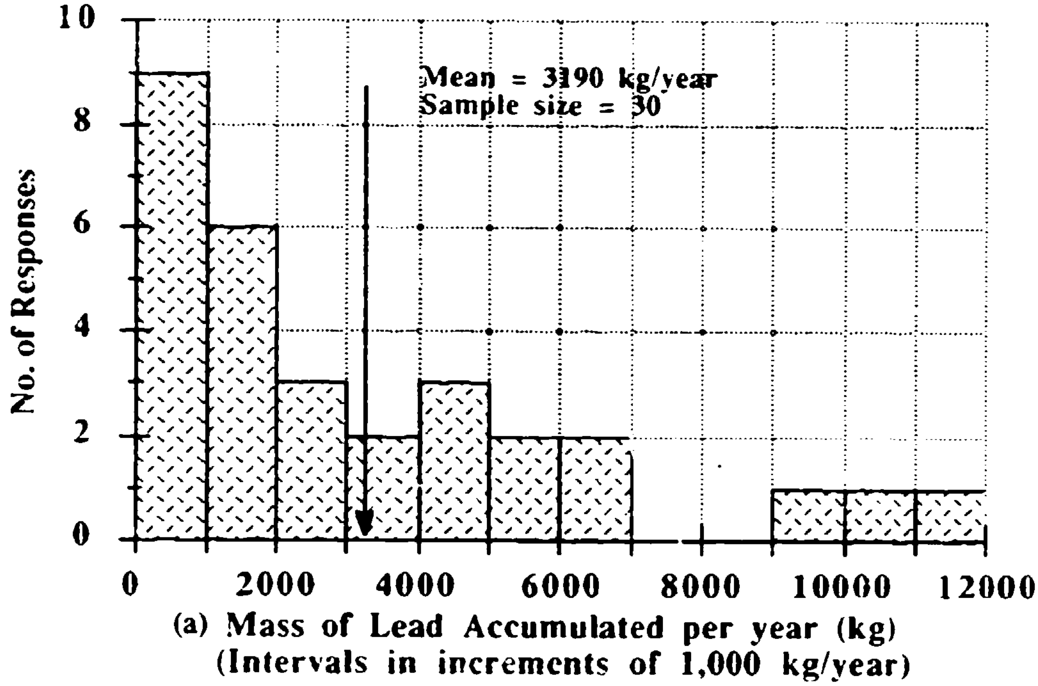


Figure 14. Survey responses to Question 6: Number of targets per site.



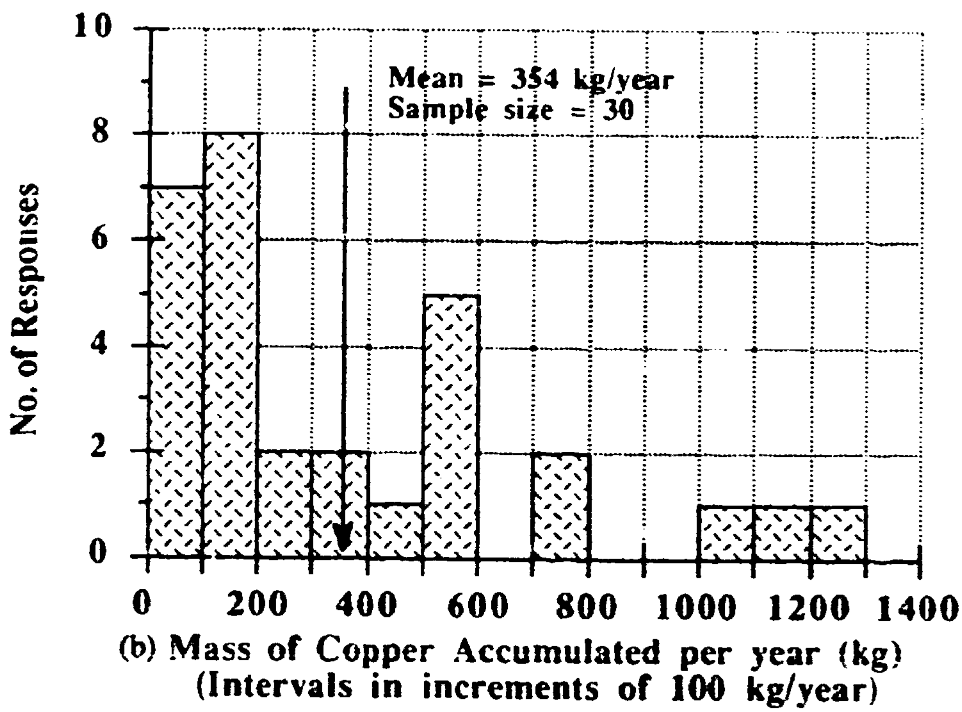


Figure 15. Survey responses to Question 7.

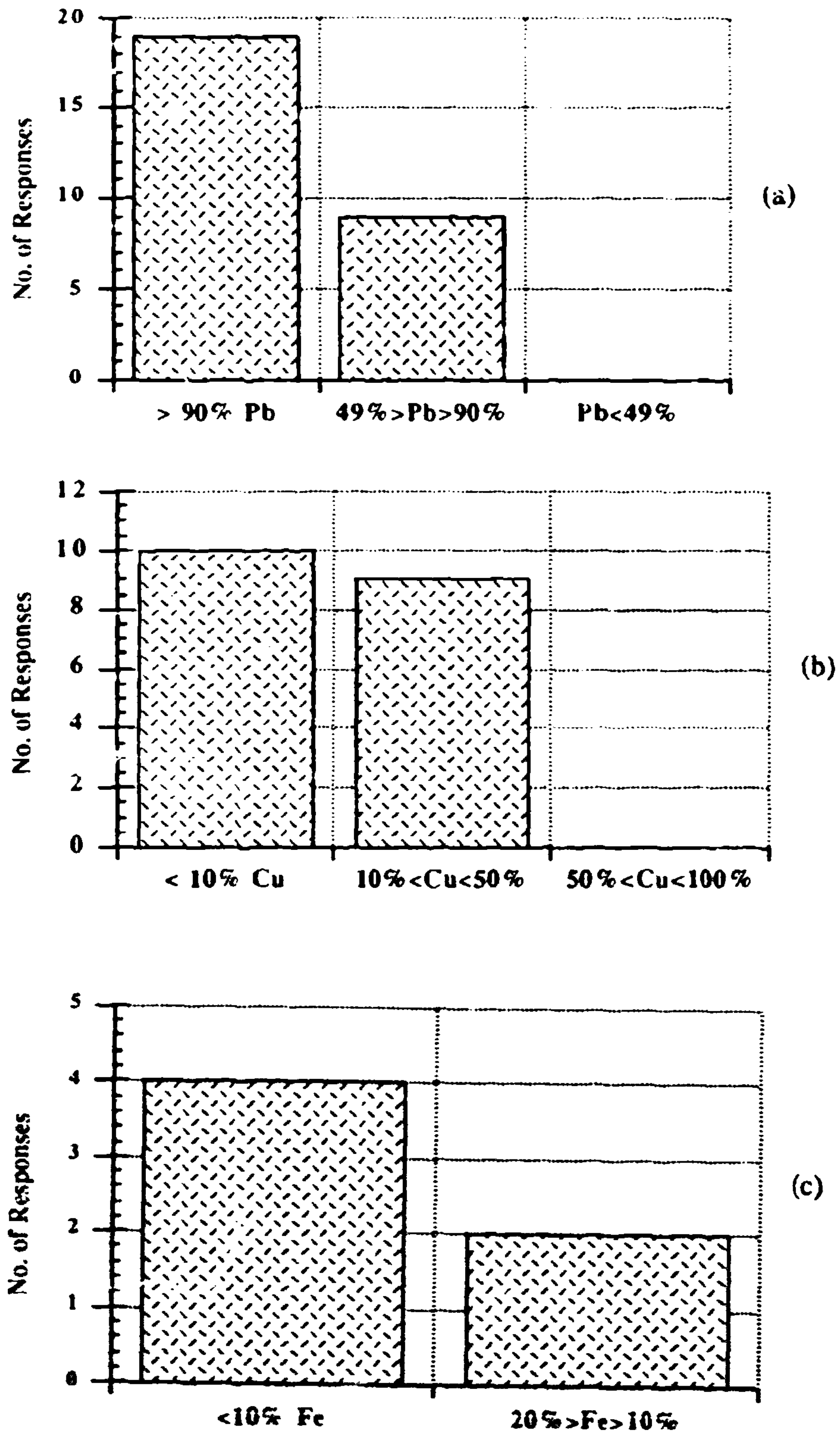


Figure 16. Survey responses to Question 8: Chemical composition of ammunition used.

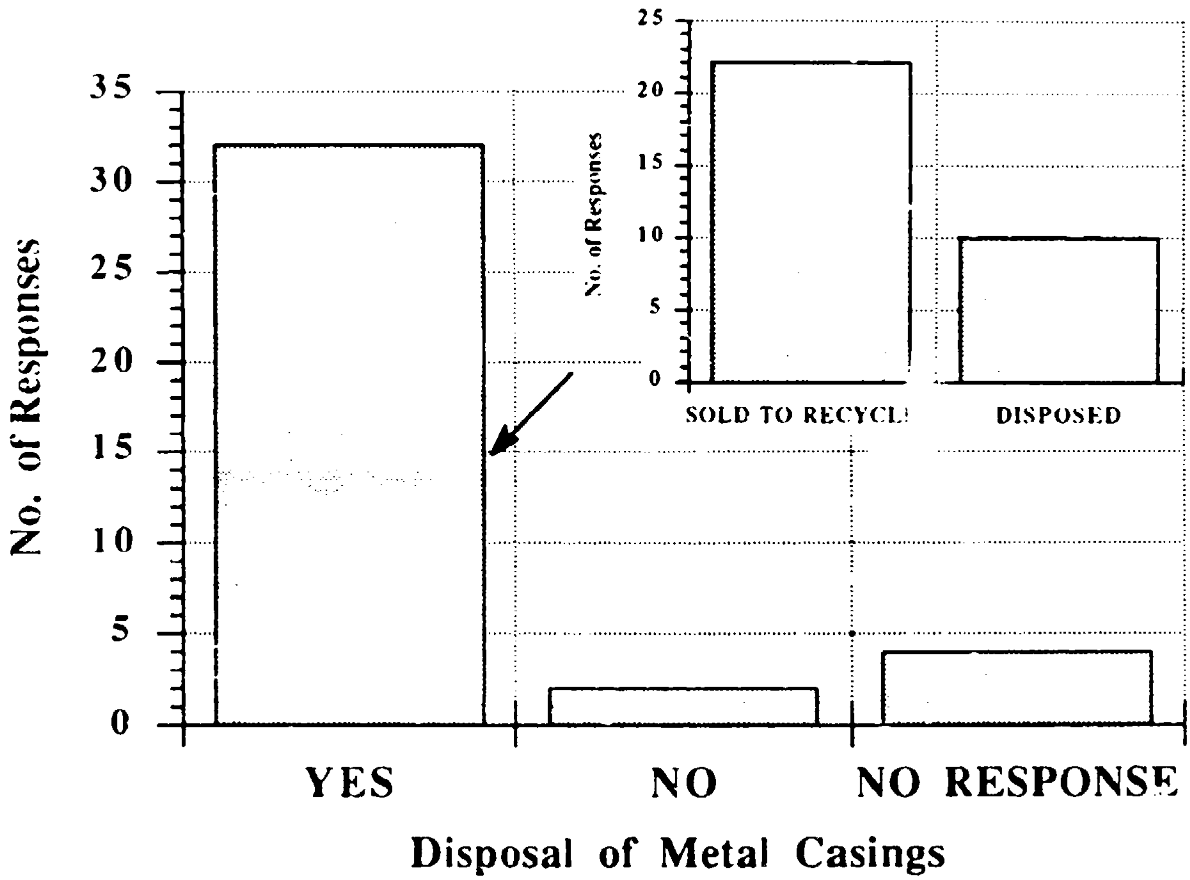


Figure 17. Survey responses to Questions 9 and 10: Disposal of metal casings.

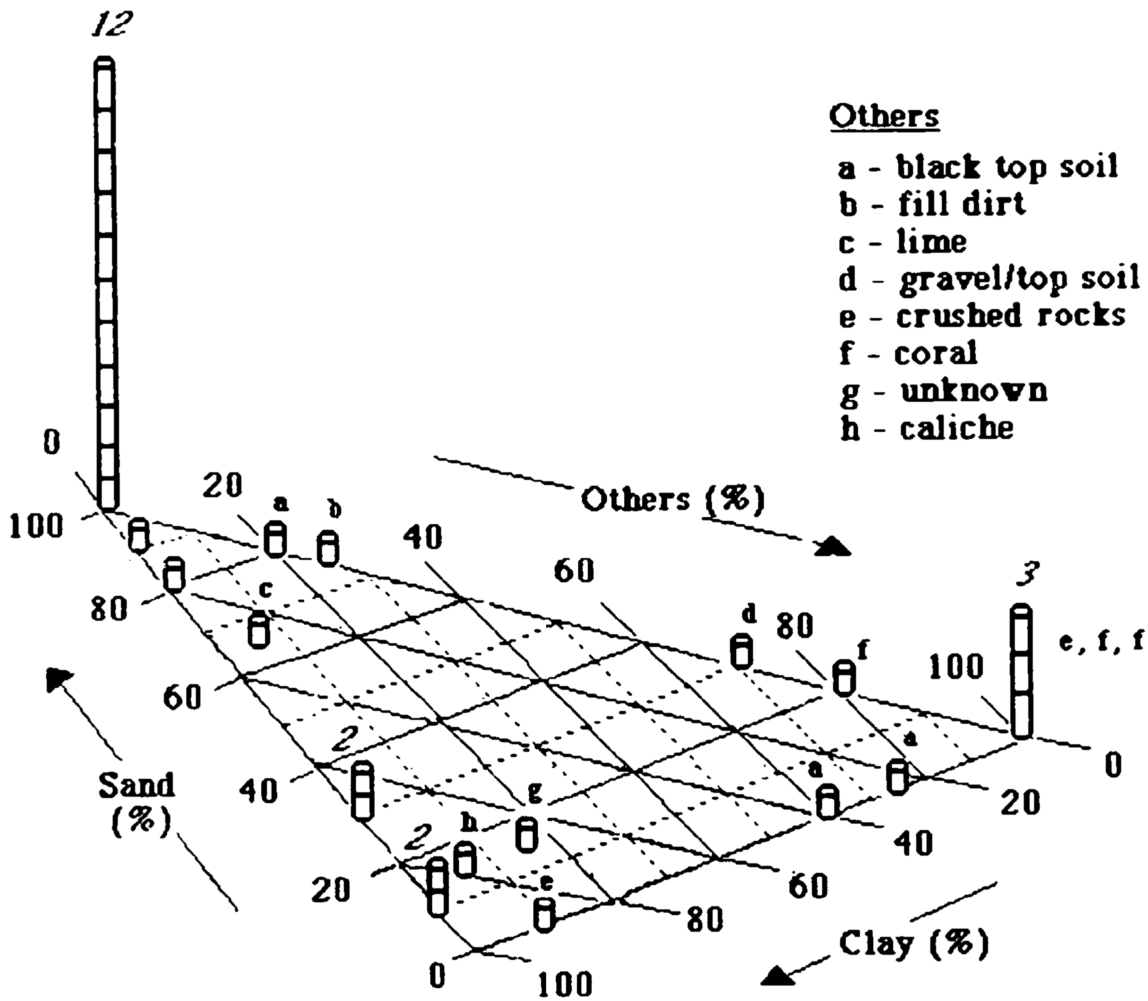


Figure 18. Survey responses to Question 11: Type of material used for impact berms.

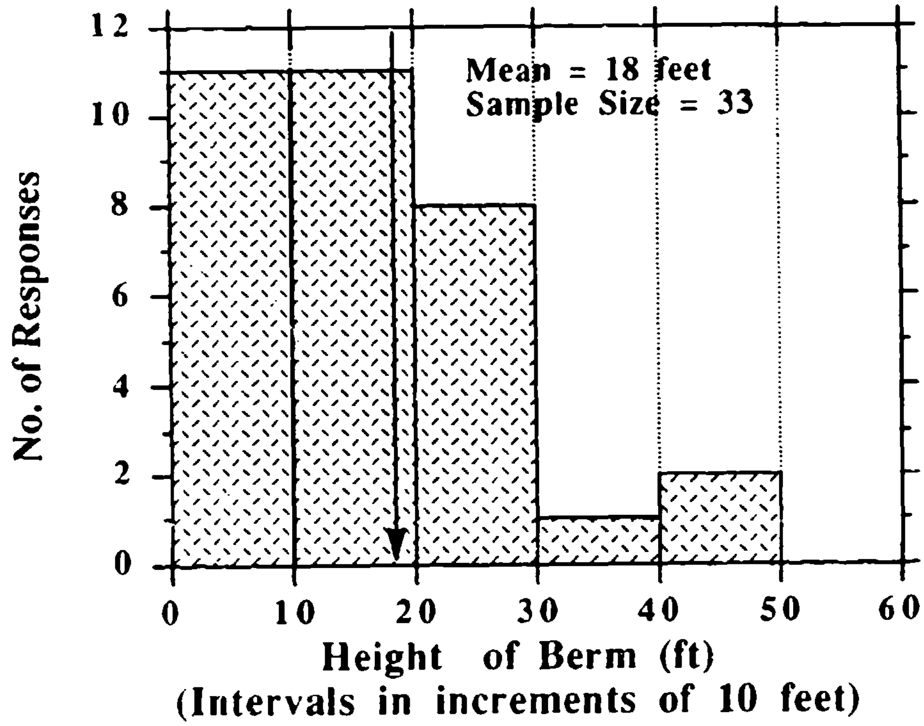


Figure 19. Survey responses to Question 12: Typical berm size - height.

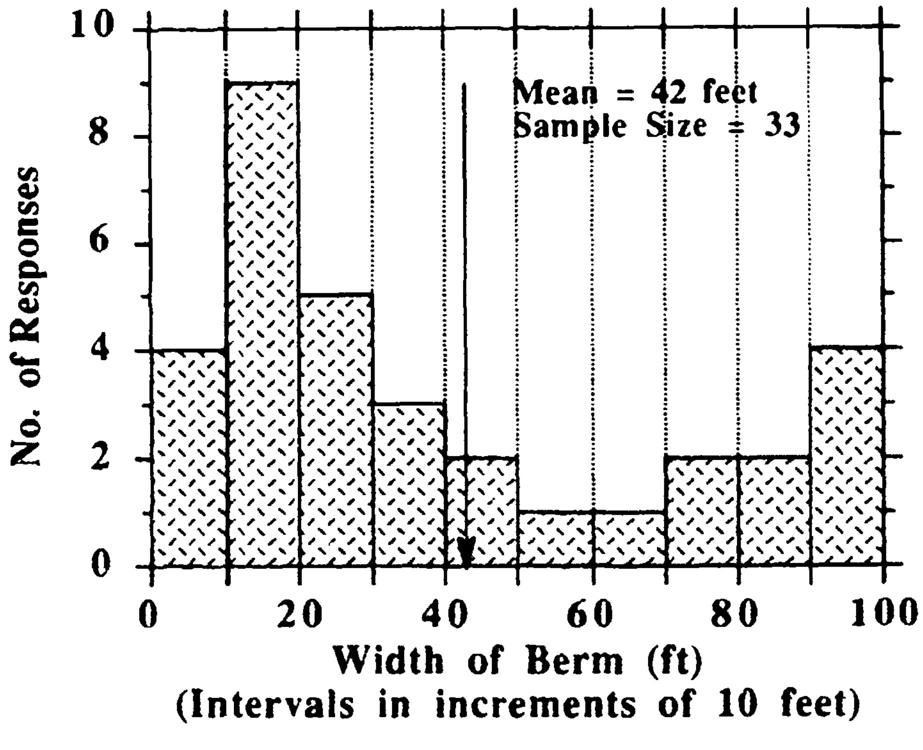


Figure 20. Survey responses to Question 12: Typical berm size - width.

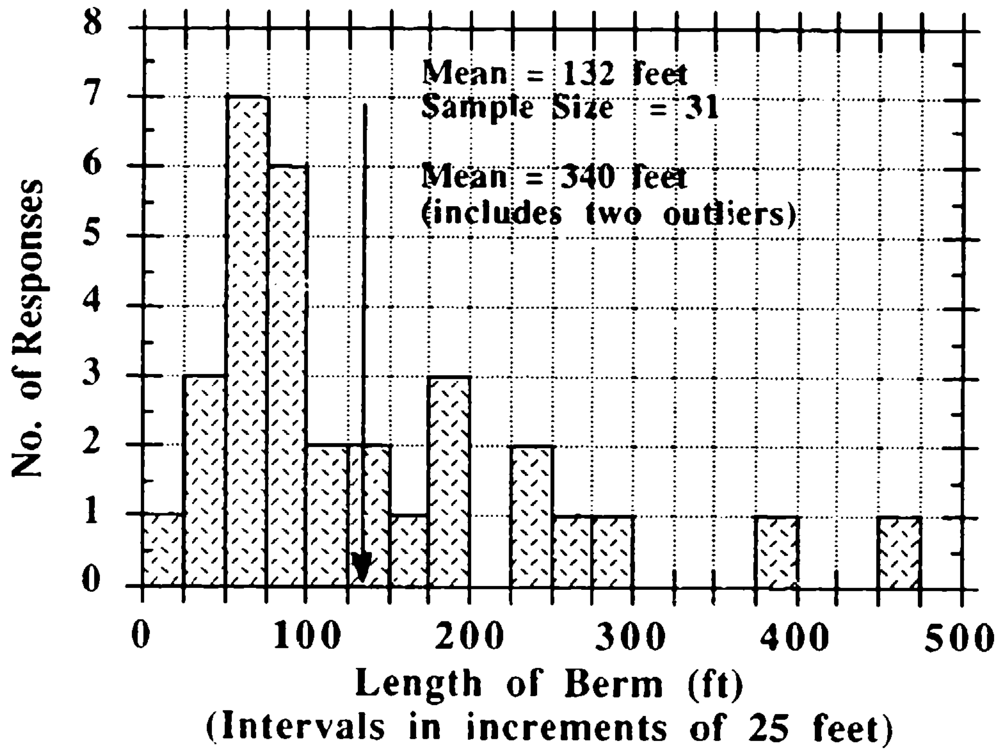


Figure 21. Survey responses to Question 12: Typical berm size - length. (Outliers are for NAVSTA Panama Canal and MCRD Parris Island)

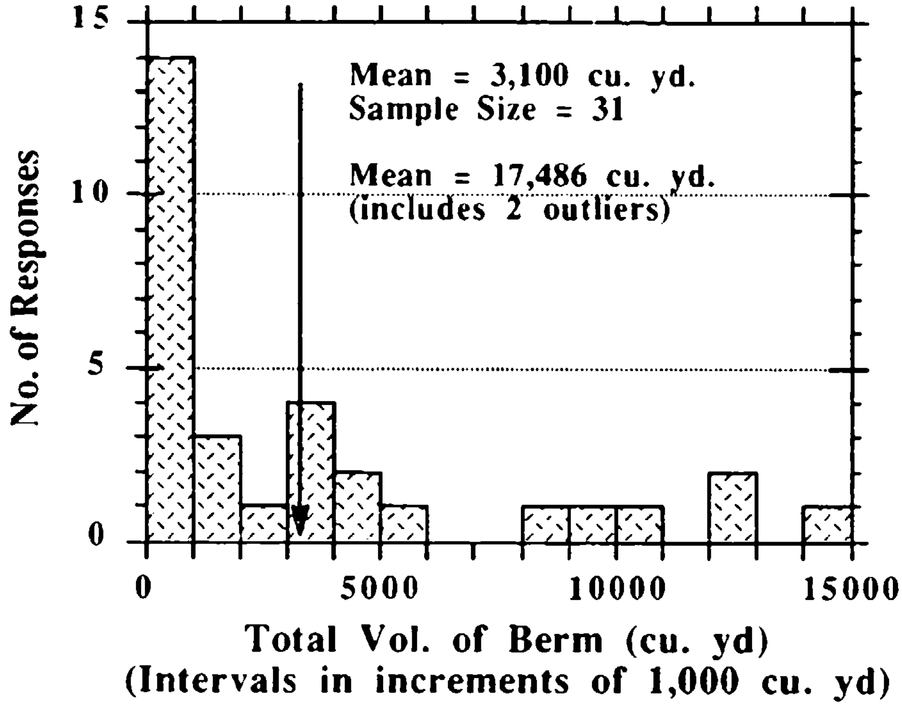


Figure 22. Survey responses to Question 12: Volume of impact berms.

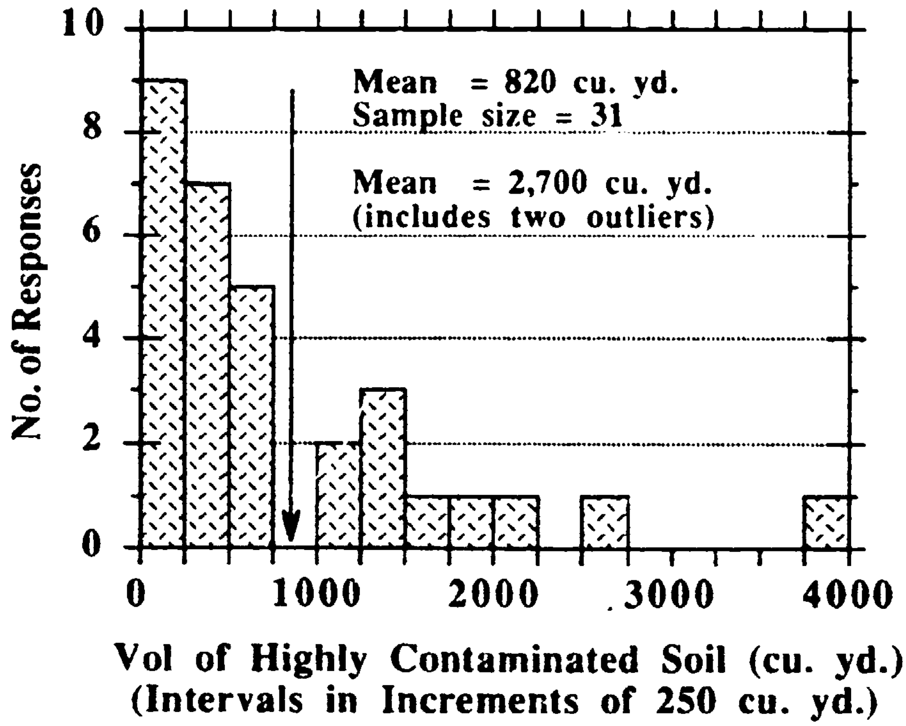


Figure 23. Survey responses to Question 12: Estimated average volume of contaminated soils of impact berms.

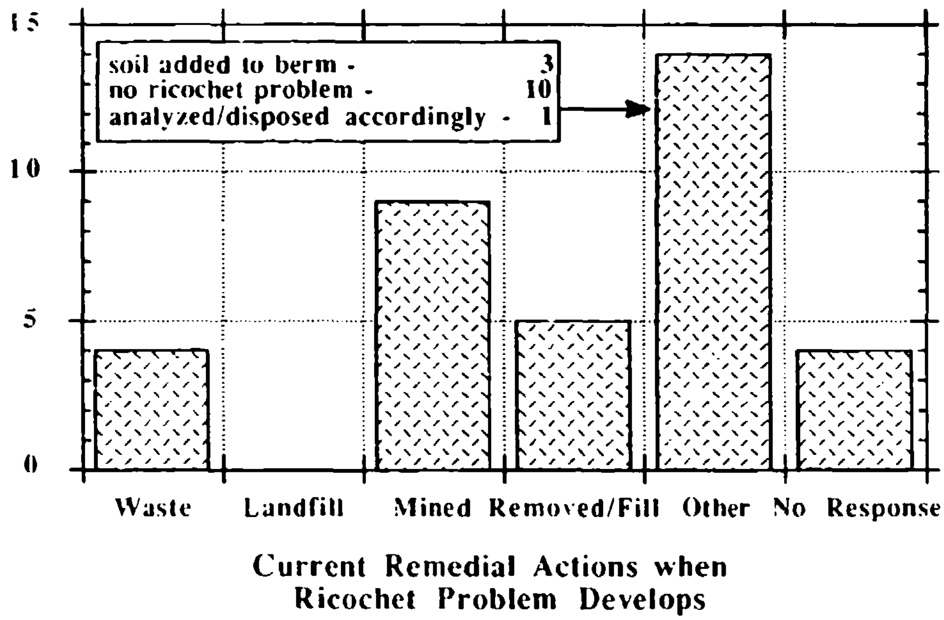


Figure 24. Survey responses to Question 12: Disposal of berm soil.

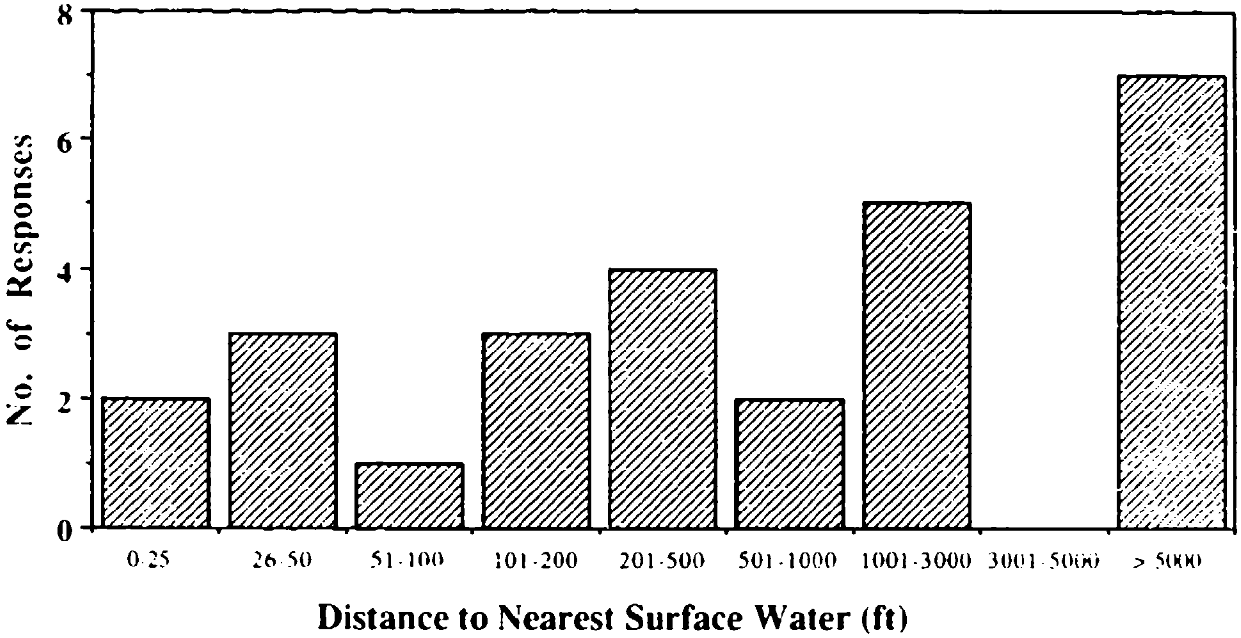


Figure 25. Survey responses to Question 13: Distance to nearest surface water.

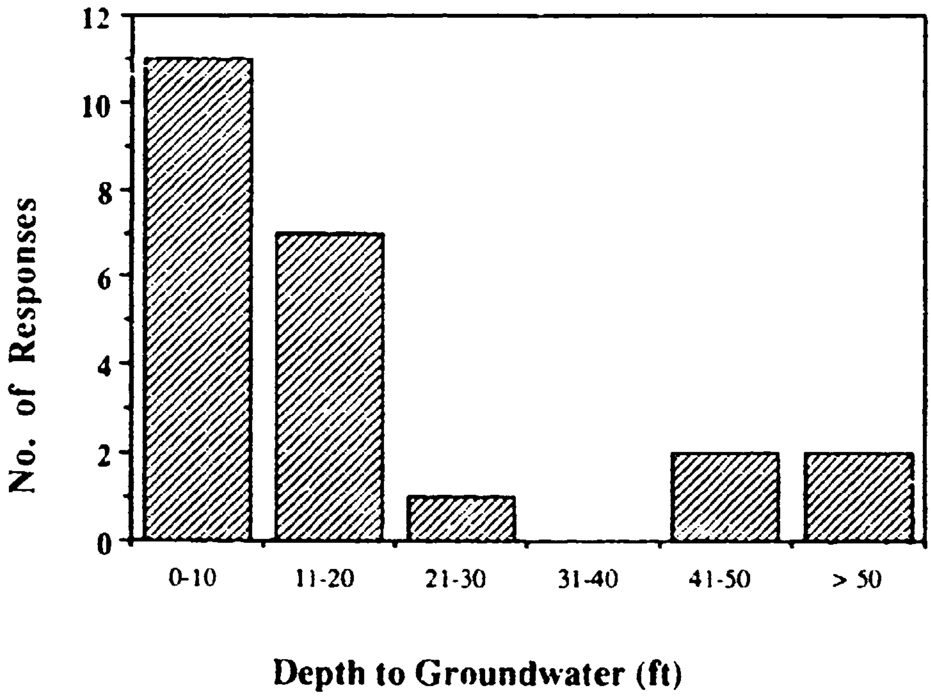


Figure 26. Survey responses to Question 14: Depth to groundwater.

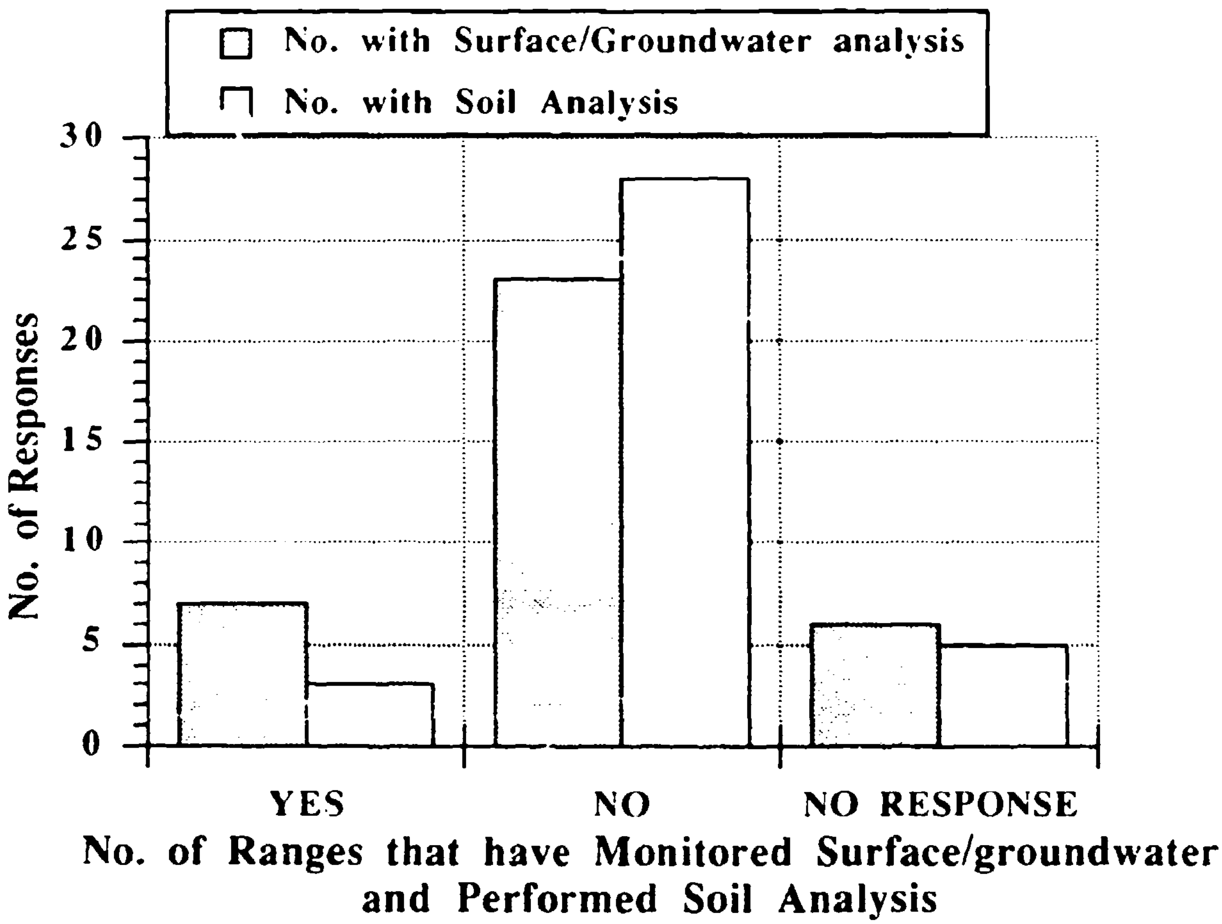


Figure 27. Survey responses to Question 15: Chemical analysis of surface water and groundwater.

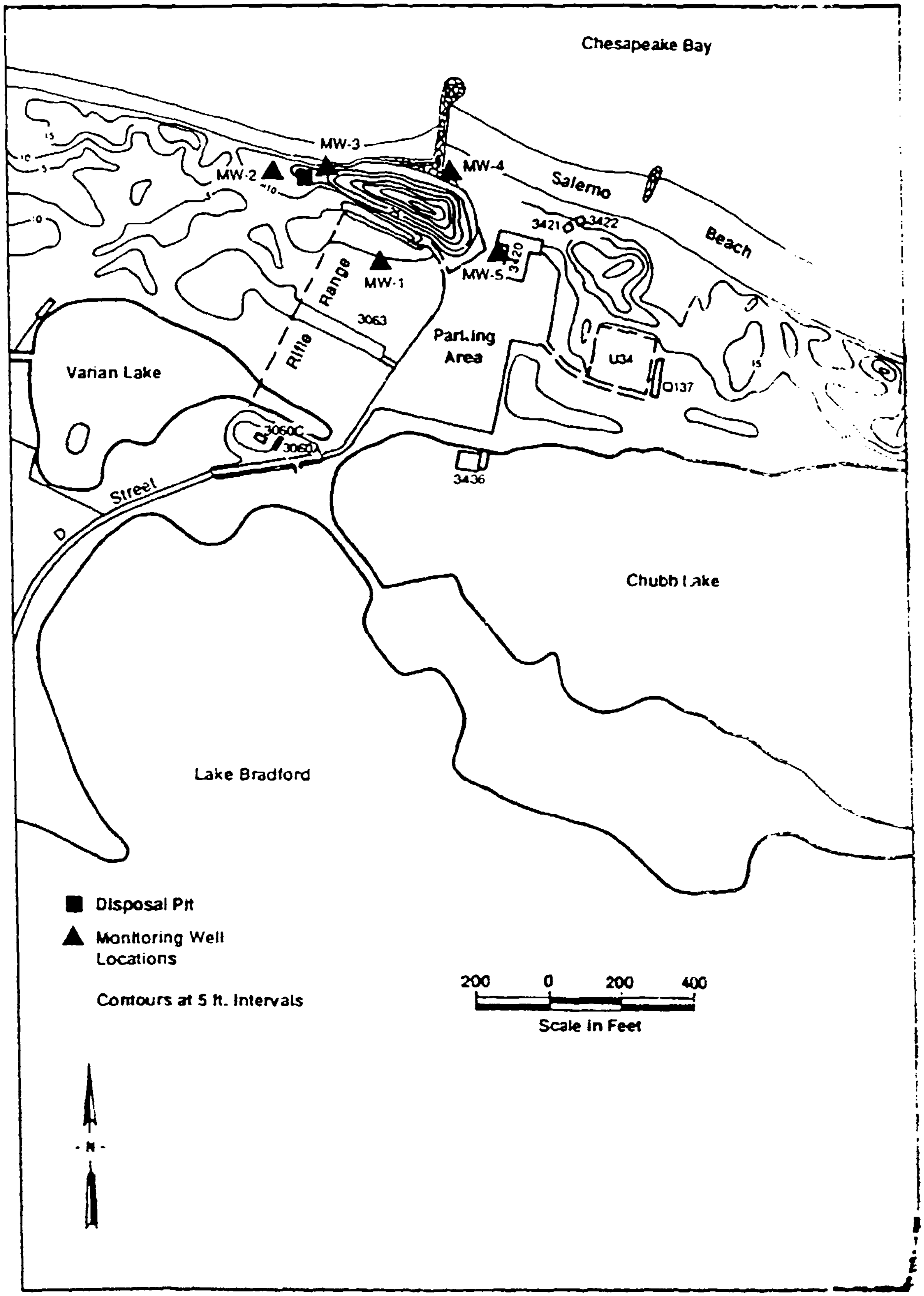


Figure 28. Approximate locations of monitoring wells at the small arms range, NAB, Little Creek, Virginia.

APPENDIX A

SURVEY QUESTIONNAIRE

Please complete and return this survey to:

Jeffrey L. Means, Ph.D.
Battelle
505 King Avenue
Columbus, Ohio 43201-2693

SMALL ARMS PRACTICE RANGE SURVEY

(1) Name, position, and address of person responding to survey:

Name: ______________________________

Position: ______________________________

Telephone Number: ______________________________

Address: ______________________________

____

____

(2) Number of active ranges: ____________

(3) Number of years that ranges have been used: ____________

(4) Number of abandoned ranges: ____________

(5) Approximate average lifetime of a range: ____________

(6) Approximate number of targets per active range: ____________

(7) Approximate average number of rounds shot per year over the last five years. Please indicate by type of ammunition (caliber or other description), if known:

Type of Ammunition	Rounds per Unit Time (____ per ____)
____________	______ / ____________
____________	______ / ____________
____________	______ / ____________
____________	______ / ____________

(8) Is most of the shot lead, or are other types also used? __________
Please indicate the relative proportions, if known:

_____________ % Lead

_____________ % Copper

_____________ % Steel

__ _________ % Other, please specify: ______________________

(9) Are the spent casings periodically collected and removed from the practice range?

__________ Yes

__________ No

If yes, what is done with the spent casings?

__________ Sold to a metal recycler

__________ Disposed

__________ Other, please specify: _________________________

(10) What type of soil was used in the construction of the berm? (Approximate proportions in percent, if known):

__________ % Clay

__________ % Sandy

__________ % Lime

__________ % Other, please specify: ________________________

(11) Typical berm size and dimensions:

__________ Height

__________ Width

__________ Length

Please draw a sketch if your berms are not rectangular:

(12) What is done to the soil from the berm if a ricochet problem occurs?

_______ The soil is removed and disposed of as a hazardous waste.

_______ The soil is disposed in a landfill.

_______ The soil is mined for recoverable metals and returned to the berm.

_______ The soil is removed and used on-site as fill.

_______ Other, please describe below:

(13) At what distance is surface water located in relationship to the ranges? ___________

(14) What is the depth of the groundwater from the surface of the soil in the vicinity of the ranges? ___________

(15) Have nearby surface waters or groundwater wells ever been chemically analyzed for lead or other metals?

_______ Yes

_______ No

If yes, may we please obtain a copy of the analyses or report?

(16) Has soil from your berms ever been analyzed for lead or other metals?

_______ Yes

_______ No

If yes, may we please obtain a copy of the analyses or report?

(17) Would you be interested in allowing your berm soils to be sampled as part of a berm characterization study?

_______ Yes

_______ No

(18) Would you like to receive a copy of the results of this survey?

_______ Yes

_______ No.

THANK-YOU AGAIN FOR TAKING THE TIME TO FILL OUT AND RETURN THIS SURVEY! YOUR INPUT IS EXTREMELY VALUABLE.

APPENDIX B

MAILING LIST FOR WRITTEN SMALL ARMS PRACTICE RANGE SURVEY

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U.S. Naval Air Facility
Atsugi, Japan
C/O Commanding Officer
U.S. Naval Air Facility
FPO Seattle 98767-1200

Commanding Officer
Naval Air Facility
El Centro, CA 92243

Commanding Officer
U.S. Naval Air Station
Bermuda
C/O Commanding Officer
U.S. Naval Air Station
FPO New York 09560

Commanding Officer
Naval Air Station
Cecil Field, FL 32215-5000

Commanding Officer
U.S. Naval Air Station
Guantanamo Bay, Cuba
C/O Commanding Officer
U.S. Naval Air Station
FPO New York 09508-0006

Commanding Officer
Naval Air Station
Jacksonville, FL 32212-5000

Commanding Officer
Naval Air Station
Key West, FL 33040-5000

Commanding Officer
Naval Air Station
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FPO Seattle 98791-1200

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Naval Air Station
Alameda, CA 94501

Commanding Officer
Naval Air Station
Barbers Point, HI 96862

Commanding Officer
Naval Air Station
Fallon, NV 89406

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Naval Air Station, North Island
San Diego, CA 92135

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Naval Air Station
Kingsville, TX 78363-5000

Commanding Officer
Naval Air Station
Meridian, MS 39309-5000

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Naval Air Station, Whiting Field
Milton, FL 32570-5000

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Pensacola, FL 32508-5000

Commanding Officer
Naval Air Station
Dallas, TX 75211-9501

Commanding Officer
Naval Air Station
South Weymouth, MA 02190-5000

Commander
Naval Air Test Center
Patuxent River, MD 20670-5304

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Naval Amphibious Base,
Little Creek
Norfolk, VA 23521

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Fleet Activities
Yokosuko, Japan
C/O Commander
Fleet Activities
FPO Seattle 98762-1100

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Fleet Combat Training Center,
Atlantic
Dam Neck
Virginia Beach, VA 23461-5200

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Naval Security Group Northwest
Chesapeake, VA 23322-5000

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U.S. Naval Group Activity
Homestead, FL 33039-6428

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C/O Commanding Officer
U.S. Naval Security Group Activity
FPO Miami 34060-9998

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FPO Miami 34053-1000

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Sonoma, CA 95476-1010

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Groton, CT 06349-5000

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140 Sylvester Road
San Diego, CA 92106-3521

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Concord, CA 94520-5000

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Colts Neck, NJ 07722-5000

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Seal Beach, CA 90740-5000

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Yorktown, VA 23691-5000

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Quantico, VA 22134

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4400 Dauphine St.
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U.S. Marine Corps Air Station
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C/O Commanding Officer
U.S. Marine Corps Air Station
FPO Seattle 98764

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Santa Ana, CA 92709

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R. N. STORER, Ph.D, P.E.
Technical Director

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Please answer on your behalf only; not on your organization's. Please check (*use an X*) only the block that most closely describes your attitude or feeling toward that statement:

SA Strongly Agree A Agree O Neutral D Disagree SD Strongly Disagree

---

		SA	A	N	D	SD
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3.	The report acknowledges related work accomplished by others.	( )	( )	( )	( )	( )
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