REMEDIATION OF LEAD-CONTAMINATED FIRING RANGES: AN ECOLOGICAL APPROACH

by

MARCIE MONACO DIAZ

(Under the direction of Darrel Morrison)

ABSTRACT

The thesis is an exploration into the potential for applying ecological design principles to the remediation of a lead-contaminated outdoor firing range. Background research examines the fate of lead in firing ranges, its environmental effects and current options for remediation. The methods were analyzed using basic ecological design principles. The findings of the research were applied to the Dekalb Firing Range in Georgia. The results of soil, sediment and water samples that were collected and analyzed were used to determine the levels of contamination across the site. Based on the research and site analysis, it was concluded that remedial efforts to reduce the lead contamination need to be conducted in an environmentally sensitive manner. The conceptual plan designed for the site includes phytoremediation, stabilization and electrokinetics.

KEY WORDS: Lead, Remediation, Phytoremediation, Soil Contamination

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MARCIE MONACO DIAZ

Approved:

Major Professor: Darrel Morrison

Committee: Richard Westmacott
William Miller
Michael Ellis

Electronic Version Approved:

Gordhan L. Patel
Dean of the Graduate School
The University of Georgia
August 2002

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CHAPTER 1

INTRODUCTION

Purpose of Study

The purpose of this thesis is to explore the application of environmentally sensitive practices to the clean up of lead-contaminated sites as an exercise in the integration of sustainable practices with current remediation technologies from a landscape architectural perspective. Typically, engineers and scientists are called upon to develop remediation plans for the approximately 450,000 "brownfield" sites in the United States. If landscape architects are involved, they are often brought in at the end of the project to beautify the site for its new use. There is great potential for landscape architects to play a larger role at the beginning of the process, especially if the site is to be used as a public landscape. Once they understand the basics of the remediation process they can provide an overall design for the process that incorporates the need for human health and safety, environmental sensitivity and community education. This concept is beginning to take root. Harvard's Graduate School of Design hosted a conference in 1998 that introduced landscape architecture professionals to the issues of dealing with these sites. Michael Tymoff, in his MLA thesis at the University of Georgia in 2000, recognized that "by responding to the unique biophysical site conditions and integrating the formal implications of remediation technologies into the site design process, some landscape architects have seized the opportunity to engage in the systematic transformation of these spoiled sites..." in reference to such landscape architects as Julie Bargman, James Corner, Peter Latz and Niall Kirkwood. These innovative designers have taken the initiative to participate in the entire process of the cultural and ecological renewal of disturbed sites. They are defining a new course for the profession which brings the profession back to the original Olmstedian ideal that landscape architecture is a type of environmental engineering and the "nineteenth-century vision that the landscape is the body and the lungs of the city" (Thompson 1998).

Through the outcome of this thesis, I hope to provide a guide for landscape architects that will provide a cost effective and ecologically sensitive methodology, and which integrates remediation, environmental sensitivity and public education.

Background

Humans have used elemental lead for centuries. Its physical characteristics, such as malleability and stability, have lent it to a variety of uses. Unfortunately, some of these uses have been discovered to have biologically harmful consequences. Humans have been poisoned by lead in water pipes and flakes of lead-based paint. Lead has contributed to air pollution from leaded gasoline emissions. In most cases, once the dangers were identified, efforts have been made to reduce the risk of contamination. Within the last three decades, government agencies and the general public have become increasingly aware of the hazards of lead bullets on the environment. Studies have shown waterfowl and small mammals have been poisoned as a result of swallowing lead shot. These animals, in turn, are causing the deaths of predators, such as bald eagles, which ingest lead imbedded in the flesh of their prey. As a result of these findings, the U.S. Fish and Wildlife Service banned lead bullets for waterfowl hunting in 1991. Now the hazards of the accumulation of lead at outdoor firing ranges is being recognized. Not only is there the danger of children and wildlife eating small pieces of lead shot in the surface soil, but lead can also leach from bullets and shot that have accumulated in the impact berms and surrounding areas, then travel into nearby streams and groundwater. Landowners of current and defunct firing ranges have an ethical and sometimes legal responsibility to prevent further lead contamination from these sites. This thesis looks at the current choices of lead remediation techniques available for firing ranges, establishes a set of criteria for choosing techniques which will minimize further damage to the environment, and applies them to a remediation plan for a firing range in Dekalb County, Georgia.

The idea for this thesis evolved as I began to design a site masterplan for the non-profit organization, Atlanta Wild Animal Rescue Effort (AWARE) on public land in Dekalb County, Georgia. The organization's mission is stated as being "committed to the preservation and restoration of wildlife and its habitat".

AWARE is working in conjunction with Dekalb County government to open an environmental education and wildlife rehabilitation center. The current site being considered for the facility is located in the heart of Davidson Arabia Mountain Park, on a 63-acre tract owned by Dekalb County Parks and Recreation. The goals of the organization are to build a center that will provide the most advanced care and housing for wildlife rehabilitation in the area, and to allow for non-invasive public viewing of rehabilitation techniques. In addition, educational programs will be offered to schools, civic groups, and the general public on site, and through outreach classes. Education topics will include: environmental awareness, habitat conservation and preservation, natural history, peaceful coexistence with wildlife, and wildlife rehabilitation.

Currently, the site is being used as a public and police firing range. It has been in operation for over 30 years. There are seven impact berms on the site, and a former skeet shooting range. The firing range is scheduled to close within the next two years. The original masterplan concepts for the AWARE center worked around the site conditions. This included leaving the impact berms in place as barriers between animal housing facilities. As questions arose about effects of the high number of spent bullets scattered throughout the site on the temporarily captive wildlife, I began to look into possibility of lead contamination. From that initial research, I realized the potential for high lead levels in the soil and water on site as well as downstream and downwind from the firing range property. So the focus shifted to finding methods of lead contamination remediation that are compatible with the principles of AWARE and the future use of the site. Because this land is centered in a natural heritage area, the need for a high level of environmental sensitivity and consideration is essential.

Methods

The background research was conducted by reviewing recent literature on the movement of lead in soil and water, and the technologies available to remove the contamination. The site characteristics of the Dekalb Firing Range were inventoried and analyzed according to standard analysis procedures. To determine the approximate level of lead contamination, samples of soil, stream sediment and water were collected. The soil samples were collected along a series of transect lines at six of the seven impact berms. Stream sediment samples were taken from various points in the stream that crosses the property and the creek that the stream flows into. A total of thirty-two samples were collected. These samples were analyzed on a Perkin-Elmer 5000 Atomic Absorption Spectrometer. The water samples were collected at seven points within the property. Four of these were from the stream, one from Stephenson Creek upstream from where the stream flows into the creek and another in the creek downstream of where the two meet. Two samples were taken from standing water within one of the target areas. The samples were analyzed on an ICP Spectrometer. Based on all the data acquired, goals for the remediation were defined and a conceptual plan for the removal of the lead on the property was designed.

Chapter Outline

The intention of this thesis is to provide a greater understanding of how lead contaminated sites can be remediated with concern for human and environmental health. This understanding will be gained from a synthesis of background research on the characteristics of lead in the environment, various remediation methods, and a site-specific study in which these findings are explored through the design process.

Chapter Two is a literature review of the current knowledge available concerning lead and its removal. There is an explanation of the movements and hazards of lead concentrations in firing ranges and some of the basic guidelines for its removal. Remediation technologies can remove lead from the environment both *in-situ* and *ex-situ*. The technologies include: landfilling, solidification/stabilization, soil washing, electrokinetics, soil flushing, and phytoremediation. The advantages and disadvantages of each method are discussed.

In Chapter Three, the results of a site inventory and analysis of the Dekalb Firing Range are presented. Understanding the unique characteristics of the contaminated site is essential to developing a successful remediation plan. An analysis can reveal obstacles that may prevent some remediation methods from being feasible. This chapter examines the current uses, topography, slopes, soils, hydrology, and vegetation on the site. Soil, sediment and water were collected from the site and analyzed to determine the amount of lead contamination on the property. The methods used to collect and analyze the samples are explained as well as the results.

Chapter Four uses all the information assembled to suggest the future use of the site. A set of goals is established and a conceptual design for the remediation of the site is presented and explained.

Chapter Five provides a summary of conclusions and suggestions for further study. The conclusions are based on the research and design process incorporated in the previous chapters.

CHAPTER 2

LEAD CONTAMINATION AND REMOVAL AT FIRING RANGES

The Potential for the Migration of Lead at Firing Ranges

The toxic effects of lead have been known for many years. Only recently has the level of lead contamination from firing ranges been discovered. There are several paths for lead to enter the environment from the ammunition expended at these ranges. Lead can oxidize when exposed to air and dissolve in acidic soil or water. Dissolved lead can migrate through the soil or become absorbed by plants. Lead bullets, fragments or dissolved lead can be moved by stormwater run-off. Each of these pathways is site-specific and may or may not occur at each individual range. The following paragraphs explain the potential fate of lead in soils and water at firing ranges.

Soils

Lead naturally occurs in soils, but in relatively low concentrations of 1 to 300 parts per million (ppm) in soil (Kabita-Pendise 1992). The mean value in soils in the United States is 20 ppm lead (Nriagu 1978). The classification of lead/soil levels in Table 2.1 was published in the pamphlet, *Lead in the Soil: What You Can Do* (1985) by the Suffolk County Cooperative Extension Service at the University of Massachusetts.

Table 2.1 Levels of Lead in Soils

Level of Lead in Soil (ppm)	
LOW	Less than 500
MEDIUM	500 to 999
HIGH	1000 to 3000
VERY HIGH	Greater than 3000

At firing ranges, guns are fired at targets which have large piles of dirt, referred to as impact berms, behind them to collect the bullets. Through weathering over time, the lead may break down into lead oxides, carbonates, and other soluble compounds as it is exposed to acidic water and/or soil. Analyses of spent shot collected from shooting ranges in Denmark have shown pellets to be visibly corroded and covered with a crust of white, gray, or brown material (Jorgensen 1987). These compounds may be dissolved and the lead can then move in solution. The amount of soluble lead in soil is affected by several factors summarized in Table 2.2. Organic material, such as leaf litter, and soils with a high pH will absorb lead, rendering it insoluble and keeping it within the upper soil layers (Jorgensen 1987). If soils contain large amounts of calcium or magnesium, lead will be precipitated from the groundwater, limiting its movement. Clays have a high ionic lead bonding capacity due to the larger surface area to which the lead can bond. Clays also slow groundwater movement providing more contact time for lead to bond. In clean silica or gravel soils, most of the basic minerals have been removed so the lead in solution can move long distances through the ground relatively uninhibited (USEPA 2001).

Table 2.2 Factors Affecting the Transport of Lead in Soil, Surface Runoff and Groundwater

Risk factor	Safe	Moderate risk	High risk
Annual precipitation (cm)	< 51	80–115	150+
Topographic slope (m/100 m)	Flat	10	20
Soil type	Coarse sand or gravel for particulate lead in suspension Clay for dissolved lead in groundwater or surface runoff	Fractured rock and fine sand, silt	Clay and silt for particulate lead in suspension Coarse sand and gravel for dissolved lead in groundwater or surface runoff
Soil chemistry	Basic rock (dolomite)	Neutral soil, calcareous sand	Acidic soil and rock (granite)
Acidity of surface water or groundwater (pH)	> or = 8.0	6.5–7.5	< 6.0
Lead pellet contact time with water	No contact	Short duration of contact	Continuous contact (shot deposited directly into water)
Soil cover	Organic peat	Grass	No soil cover
Vegetative cover/barriers	Dams or dikes that stop water flow	Grass or forested area	No vegetative cover
Depth to groundwater (m)	61+	9–15+	< 3
Distance to surface stream (km)	1.5+	0.4–0.8	Shot deposited directly into water

Source: Scheuhammer 1995.

Water

The natural concentrations of lead in river waters range from 0.6 parts per billion (ppb) to 120 ppb (Craig et al. 1999). The Environmental Protection Agency (EPA) has set the drinking water limit of lead at 15 ppb. Once lead is soluble in soil, it moves toward streams and other water bodies by surface water runoff and groundwater flow. Table 2.2 summarizes the factors affecting the mobility of lead in surface runoff and groundwater. The contact time of lead with acidic water increases the amount of lead dissolved. With higher rainfall rates, the lead will weather faster and have more contact time with the acidic water, increasing the chance lead can move off site. The intensity of the rainfall affects the velocity of runoff, allowing larger particles of lead to be carried downslope. Groundwater can also carry lead underground from higher areas to be released into surface water flow. Shallow groundwater levels increase the risk of lead reaching water. The amount of soluble lead will be decreased if the subsurface soil layers contain minerals that raise the pH, such as calcium, magnesium or iron.

As water becomes more neutral, the dissolved lead will precipitate out of solution. In a study of surface water contamination at a firing range conducted by Craig *et al*. (1999) in Virginia, it was found that the highest levels of contamination in the stream were located immediately downslope of the target areas, with a rapid decline in lead levels downstream. They attributed high contamination results to the "constant presence of rapidly corroding fresh lead surfaces which are caused by the impact of bullets into the soils." They surmised that the rapid decline of lead they found beyond the target areas is due to the removal of lead out of the water, though they were not sure where lead in solution went.

Health Effects

Lead poisoning occurs as a result of the accumulation of hazardous levels of lead in body tissues and is a serious health risk for humans and wildlife (Friend 1999). Humans can be exposed to lead by consuming lead particles on their hands or inhalation of lead dust. Acute poisoning of humans at any age can cause convulsions, coma and even death. Infants and young children exposed to low concentrations can experience brain damage and learning and behavioral problems. Adults can suffer from high blood pressure, digestive problems, neurological disorders and kidney dysfunction at prolonged low concentrations (USEPA 2001).

Wildlife can be poisoned from directly ingesting bullets or lead fragments, or from consuming other organisms that have accumulated lead. Waterfowl can ingest whole bullets or fragments mistaking them for food or grit. Studies found earthworms living in contaminated soil can have lead levels 1.2 times more than normal in their tissues (Newman 1991). Another study found the lead concentration in earthworm and beetle-eating shrews collected on a shooting range in the Netherlands to be 10 µg/g, exceeding the level considered to constitute lead poisoning (Odum 2000).

Plants

Though lead is not essential for plants (Reeves 2000), low amounts of lead stimulate plant growth. Some plants accumulate lead in their tissues. The lead can become bound at the root surfaces and cell walls. Seed germination is not affected by lead quantity, but a lead toxicity can occur in some plant species at levels of 19 to 35 µg/g plant (Odum 2000).

Remediation Techniques of Lead Contaminated Sites

There are two overarching responses to the removal of lead accumulation on a site. The contaminated soil can be collected and treated or transported off site for remediation (*ex-situ*), or it can be remediated in place (*in-situ*). The traditional e*x situ* methods include solidification/stabilization and soil washing. *In situ* technologies have been developed as adaptations of traditional methods and include electrokinetics and soil flushing, or consist of innovative bioremediation techniques, such as phytoremediation.

Regardless of the method chosen, there are standards set by the government that must be followed during the remediation effort. Section121 of the Comprehensive Environmental Response, Compensation, and Liability act (CERCLA) states that remedial actions must be undertaken in compliance with Applicable or Relevant and Appropriate Requirements (ARAR), federal and state laws to protect human health and the environment (Lowe 2000). The ARAR includes: The Resource Conservation and Recovery Act (RCRA), The Clean Air Act (CAA), the Safe Drinking Water Act (SDWA), the Toxic Substance Control Act (TSCA) and the Occupational Safety and Health Administration (OSHA).

Landfilling

Once the soil is collected and large particles of lead have been sifted for recycling, the contaminated soil is hauled off to a landfill. The soil will require testing to determine if the leachable lead level is at or above 5 ppm. If this is the case, it is a RCRA hazardous waste, and must be placed in a hazardous waste landfill (USEPA).

Solidification/ Stabilization

The goal of solidification treatment is to change the physical characteristics of the contaminants to ease removal or reduce the mobility by creating a physical barrier to leaching. Stabilization treatments convert contaminants to less mobile forms through chemical or thermal interactions. The soil is mixed with a cement, then the inert mixture is deposited back on site or used for construction purposes elsewhere. Another type of solidification, vitrification, uses electrical power to heat and melt the lead soils. Once cooled, a hard, glassy material forms, which has low leaching ability.

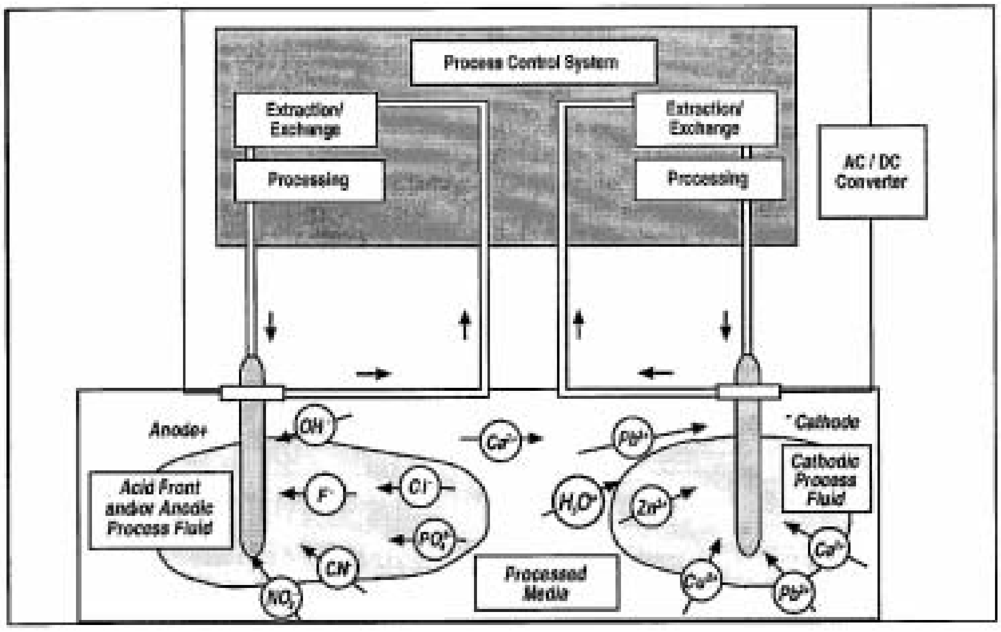
Soil Washing

This method involves the collection of contaminated soil, precipitation and removal of lead then the replacement or removal of the remaining soil. Donald F. Hlousek (2000) describes in great detail the process and costs of this method. The mobile units separate the large particles for recycling, then the soil is mixed with leaching agents such as hydrochloric acid. The leached soil can be mixed to result in 88% of the final product containing less than 500ppm lead. The remaining solution must be tested to determine if it meets the standards that apply to the discharge of wastewater. If it does, it can be released into sewage treatment plants or surface water bodies. If not, the water will need further treatment. Many site-specific parameters can affect the cost and applicability of soil washing technology, but generally, the technology applies to sites with low clay-content soils (less than 25 percent clay) and larger amounts of material requiring treatment (more than 2,600 tons). Before employing this technology, a bench scale treatability test should be performed for the site-specific soil and target metals to be removed and recycled. The data indicate that for a 10,000-ton site with soils of approximately 25 percent clay, the hydrochloric acid process will cost approximately $170 per ton.

Electrokinetics

Elecrokinetic remediation, also called electrokinetic soil processing, electromigration, electrochemical decontamination, or electroreclamation, has been used since the 1970's in mining operations. It is an *in situ* process of applying low-density, direct current between electrodes placed in the soil to mobilize contaminants in the form of charged species that migrate toward the electrodes (Figure 2.1). When the contaminants arrive at the electrodes they can be removed by electroplating at the electrode, precipitation or co-precipitation at the electrode, pumping of water near the electrode or complexing with ion exchange resins. This method works best in fine-grained, highly permeable soils that have high moisture content. Therefore, it may be applied to saturated and partially saturated soils (PRC 1997). There are a number of factors that can determine the direction and extent of the movement in the soil such as the type and concentration of the contaminant, the type and structure of the soil, and the interfacial chemistry of the system. Suitability is site-specific and heterogeneities or anomalies, such as rubble, large quantities of iron oxides or large rocks will reduce effectiveness.

The efficiency and cost-effectiveness of electrokinetics have not been evaluated at full scale in the U.S. Louisiana State University and Electrokinetics, Inc have completed pilot-scale studies of electrokinetic soil processing in the laboratory. Electrokinetics, Inc. is also carrying out a comprehensive demonstration study of lead extraction from a creek bed at a U.S. Army firing range in Louisiana. The study so far has shown the lead in soils on this site decreased from 4,500 ppm lead to less than 300 ppm lead after 30 weeks of processing. It has been estimated that the direct costs of this method could be in the range of $50/per cubic meter of treated soil (PRC 1997).



Source: USEPA 1997

Figure 2.1 Electrokinetic Processing

Soil Flushing

This is an *in-situ* method of treatment of heavy metals that involves the physical separation of the contaminant from the soil. Solutions are applied to the land, flushing the contaminants out and leaving the soil matrix intact. The fluid may be applied to the surface through flooding, sprinklers, leach fields or injection wells (Anderson 1993). Flushing solutions include hydrochloric acid (HCL), ethylenedinitrilo-tetraacetic acid (EDTA), and calcium chloride ($CaCl_2$). The solution percolates through the soil and the contaminated groundwater is recovered. Metal contaminated groundwater is typically collected by pumping the solution up to a treatment facility where the collected mixture is treated before the fluids are recycled or released into wastewater treatment sites or receiving streams. The choices of treatment systems for heavy metals include standard precipitation, electrochemical exchange, ion exchange, or ultra-filtration systems.

Soil flushing for lead has only been conducted on a limited basis. The effectiveness of this treatment is based on a sound understanding of soil chemistry, relative permeability, and hydrogeology. Because it increases the mobility of contaminants and the associated risk of contamination of the underlying aquifer with unrecovered flushing solution containing solubilized contaminants, a complete understanding of the hydrology of the site is essential (PRC 1997).

Phytoremediation

Phytoremediation is the use of living plants and their associated microorganisms to remove, contain, immobilize or convert environmental pollutants. This innovative technology has been proposed or applied to ecosystem restoration and soil, surface water, groundwater, and sediment remediation (NRMRL 2000). It already has widespread use treating stormwater and wastewater in constructed wetlands (Thompson 2000), though it is not often referred to as phytoremediation in these situations. The use of plants on lead-contaminated sites is still in the early stages of large-scale implementation. Plants are used to remove both organic and inorganic contaminants. The metals targeted for phytoremediation include lead, cadmium, chromium, arsenic and radionuclides. This method is cheaper to initiate and maintain than many traditional remediation methods. However, it requires longer treatment time than the other technologies. The advantages of this method are the low input costs, soil stabilization, aesthetic quality, reduced leaching of water and transport of inorganic contaminants in the soil. The main costs are for planting, maintaining plant growth, harvesting, disposal of contaminated biomass and repeating the plant-growth cycle. Cornich *et al*. (1995) give an example where phytoremediation may have a three-fold lower costs than soil washing for removing inorganic contaminants from a 0.5ha waste site. The time frame is much longer than soil washing and may take up to 20 years. It is most effective on sites where soil and groundwater contaminants are within the top few feet of soil, and the level of contamination is low enough to allow plants to survive.

There are three types of phytoremediation: phytoextraction, phytostabilization and rhizofiltration. Each of these is limited by the area of root contact with the lead contaminants. Therefore, the depth and spread of the chosen plant species' roots must reach the depth of contamination, or the contaminated media must be moved to within the reach of the plant. This movement can be accomplished by deep plowing the soil up from two to three feet below to within eight to ten inches of the surface for contact with shallow rooted crops. Contaminated groundwater can be used for irrigation of phytoremediating plants. Once the lead comes in contact with the plants, the mechanisms of phytoremediation which have been tested on lead are: the extraction of lead contaminants from the soil, the concentration of the contaminants in plant tissue, the immobilization of the contaminants in the root zone, and the control of runoff and erosion by vegetative cover (NRMRL 2000).

Phytoextraction involves the uptake of contaminants from the soil by plant roots, into the plant tissue. The hyper-accumulating plant species (a plant containing more than 0.1% lead) concentrate the metals in roots and aboveground shoots. The aboveground biomass can be periodically harvested and treated. The advantage of this method is that the mass of plant and contaminant that must be transported and disposed of is much smaller than soil excavation and landfilling. The estimated 30-year costs (in 1998 dollars) for remediating a 12-acre lead contaminated site are $12,000,000 for excavation and disposal, $6,300,000 for soil washing, $600,000 for soil cap, and $200,000 for phytoextraction (NRMRL 2000). Indian mustard (*Brassica juncea*) has proven to be one of the most successful accumulators of lead. In field scale experiments, it was able to accumulate more than 1.8% lead in the shoots (dry weight) and 10.9% lead in the roots. Other plants that are lead hyper-accumulators include sunflower (*Helianthus annuus*) and tobacco (*Nicotiana tabacum).* Applying chelates to the soil to increase lead solubility has been shown to increase plant uptake (Blaylock 2000). Table 2.3 lists plant species that have been tested in phytoremediation studies.

There are some problems associated with this method of lead removal. Testing has found that the phytoextraction coefficient (ratio of g metal/g dry weight of shoot to g metal/g dry weight of soil) of lead is not as high as other metals (Nanda Kumar *et al* 1995). Many of the results gathered to date are from using hydroponically grown plants, with the contaminant added to a solution. The actual amount of metal absorption in soil may be less than what was found in these laboratory studies. Field studies are turning up other problems. The hyperaccumulator Indian mustard typically has a root zone of only one foot deep. While the pennycress has shown exceptional accumulating abilities in the laboratory, its small size and slow growth rate are prohibitive. There is also a concern that the accumulation of lead in leaves and flowers will increase the bioavailability of the contaminant. Researchers have just begun to investigate this potential problem. If harmful bioconcentrations up the food chain is a concern during the life of the remediation effort, appropriate exposure control measures should be implemented including perimeter fencing, overhead netting, and pre-flowering harvesting. It is not known if plants are capable of releasing the lead into the air through evapotranspiration.

Phytoextraction is a slow process, so it is not appropriate for sites that pose acute risks for humans and other ecological receptors.

Phytostabilization uses plants for the production of chemical compounds to immobilize the contaminants at the interface of roots and soil. This limits the mobility and bioavailability of the metals in the soil. The plants chosen should be able to tolerate high levels of metals and to immobilize them in the soil by sorption, precipitation, complexation (formation of stable chelate rings), or the reduction of metal valences. The plants chosen also should exhibit low levels of accumulation of metals in shoots to eliminate the possibility that residues in harvested shoots might become hazardous wastes. Stabilization can be done in conjunction with raising the pH of the soil. This method has been shown to be more effective for lead, but there is long-term maintenance involved. It has the added benefit of minimizing erosion and migration of sediment. Some consider phytostabilization an interim measure and not actually remediation because it does not remove the contamination from the site. However, in situations where there are limited funds for clean-up, this may be the best option. Scott Cunningham, in the paper "Remediation of Contaminated Soils and Sludges by Green Plants", included in the book, *Boiremediation of Inorganics* edited by Robert E. Hinchee et al. (1995), lists the following processes involved in phytostablization:

Plant processes that aid in stabilization:

1. Transport of ions across root-cell membranes
2. Water flux to the plant driven by plant transpiration
3. Absorption of organic matter into the roots
4. Entrapment of organic in the lignin fraction of plants (lignification).

Soil processes that aid in stabilization:

1. Biochemical fixation (humification) -enzymatic incorporation into humus
2. Chemical fixation: precipitation
3. Physical fixation: solid-state diffusion into soil structures (clays, organic matter, etc.), formation of oxide coatings.

Decontamination (pollutant destruction and/or extraction):

1. Bioactive microbial biofilm around plant roots (rhizosphere)
2. Plant and microbial-produced surface-active agents and chelates
3. Fungal symbionts on roots that extend out into the soil and increase soil-to-surface area ratios and provide additional enzymatic capacity
4. Root, stem, and leaf enzymatic metabolic activities for detoxification
5. Uptake of cations and some anions into the root
6. Translocation of absorbed ion from roots to shoots
7. Solar-driven solution flux from soil, through roots into plant shoots
8. Partitioning of lipophilic organic molecules into roots.

Soil processes that aid in pollutant destruction and/or extraction:

1. Agronomic practices that provide air, nutrients, surface area disruptions, crop residue cycling, chemical fluxes, and microbial stimulation
2. Bulk soil microbial degradation
3. Bulk soil chemical degradation (on catalytically active clay surfaces)
4. Wetting and drying cycles (reduction and oxidation)
5. Chemical/biochemical-general hydrolytic, substitution, and elimination reactions.

There are two types of rhizofiltration. Terrestrial plants are used to absorb, concentrate, and precipitate metals from wastewater, which includes leachate from soil. The plants are set up in a hydroponics situation. Terrestrial plants are used instead of aquatic plants because they tend to develop much longer, fiberous root systems covered with root hairs that have extremely large surface areas. This is a slower process than phytoextraction, and is best for the treatment of low concentrations of contaminant or large volumes of wastewater.

Table 2.3 Plants That Have Been Tested for Accumulation of Heavy Metals

Plant Common Name	Plant Latin Name	Lead Uptake[4] in mg/kg	
		Roots	Shoots
Alder[2]	*Alnus spp.*		
Alyssum[2]	*Alyssum wulfenianum*		
Bermuda grass[1]	*Cynodon dactylon*	9,340	420
Bladder campion[2]	*Silene vulgaris*		
Crabgrass[2]	*Digitaria sanguinalis*		
Corn[1]	*Zea mays*	2,110	490
Cottonwood[2]	*Populus deltoides*		
Dogbane[1]	*Apocynum androsaemifolium*	1,000	
Elderberry[2]	*Sambucus canadensis*		
Eucalyptus[2]	*Eucalyptus globulus*		
Fescue[2]	*Festuca spp.*		
Goldenrod[1]	*Solidago spp.*	8,130	96
Grama grass, Blue[2]	*Bouteloua gracilis*		
Grama grass, Side-oats[2]	*Bouteloua curtipendula*		
Hemp[2]	*Cannabis sativa*		
Knotgrass[2]	*Paspalum distichum*		
Lupin[1]	*Lupinus spp.*	7,830	189
Mustard, Indian[2,3]	*Brassica juncea*	2,000	2080
Mustard, White[2]	*Brassica alba*		
Pennycress[1]	*Thlaspi rotundifolium*		8,200
Poplars, hybrid[2]	*Populus charkowiieensis x*		
Ragweed[1]	*Ambrosia artemesiifolia*	5,073	110
Sorghum[1]	*Sorghum spp.*	3,730	150
Sunflowers[1]	*Helianthus annuus.*	19,900	85
Tamarisk[2]	*Tamarix ramosissima*		
Thistle, Canada[2]	*Cirsium arvense*		
Tobacco[2]	*Nicotiana tabacum*		
Water milfoil[2]	*Myriophyllum spicatum*		
Willow[2]	*Salix nigra*		

[1] Source: Cunningham 1995
[2] Source: NRMRL 2000.
[3] Source: Blaylock 2000.
[4] Blank space indicates information on uptake levels is not available.

Ecological Design Considerations

The removal of lead from firing ranges is a complicated issue that requires an immense amount of logistical planning. Economics, costs, safety, and laws and regulations are some of the deciding factors taken into consideration when determining which type/s of remediation will be appropriate for the site. In addition, preservation or restoration of the ecological health of the land on which the remediation is conducted of course also plays a part. Using ecological design principles as an overlay to defining remediation goals will maximize the benefits to the environment that has already been abused and the community around it. Design considerations include: preventing further contamination on and off the site, reducing adverse impacts on the current ecological functions, maintaining a sense of history and providing education and involvement of the community. As with any of the factors considered, the determination of ecologically oriented goals will need to be applied on a site-specific basis.

The site managers should acknowledge their responsibility for the clean-up of the contamination and all impacts resulting from attempts to remedy the problem should remain on site. Contaminated soil should not be permitted to pollute another landscape. If the contaminants cannot be contained or broken down on site, than it is best to find a facility that will recycle the materials. Recycling may even provide an opportunity to offset some of the costs of the remediation process.

Decisions about the timeframe of the process should be based on the severity of the pollution. It should be determined if it is better to implement less invasive remediation that will reduce the contamination on site over longer periods of time, or utilize more intense and land-altering techniques that will quickly remove the contaminants. In some situations, the land may be so drastically altered that it will require major usage of outside materials to restore and the costs will be prohibitively high. In this case, it may be best to use the remediation method of solidification/stabilization. While the treated site itself will not have a chance to recover, further risk of contamination off the site will be quickly minimized and the use of resources will be minimized. Intensive treatments may also be necessary if there is a very high level of contamination, or the risk of migration off site is high. The soil washing procedure can take as little as five days once the equipment is in place. This technique alters the soil structure, but it also can reduce amount of lead to low levels in a short period of time. It is the preferable method over soil flushing which leaves the soil structure in place, but introduces harsh chemicals directly into the environment.

If contamination levels are low, or there is a way to limit the risk of exposure, less invasive measures of remediation can be used. If measures are taken to limit unintended bioavailability and time is not a factor, phytoremediation is a viable solution for this type of situation. It is aesthetically pleasing, less energy intensive than mechanical methods and cheaper to install and maintain (Thompson 2000). There is still much to be learned in this new field, so using this method could provide research opportunities for local universities.

Understanding the history of the site can provide clues for the best types of remediation. It is not necessary to return the site to a specific time period. In fact, leaving remnants of the past human use can provide a greater understanding of the efforts needed to remedy our mistakes. However, natural processes should be restored to improve the ecological integrity of the site.

The community needs to be involved in the remediation process from its inception. Open communication will foster a better acceptance of the situation and the decisions that are made. The process should be open for viewing and if safety considerations permit, the public should be invited to help monitor the progress.

CHAPTER 3

SITE ANALYSIS OF DEKALB COUNTY FIRING RANGE

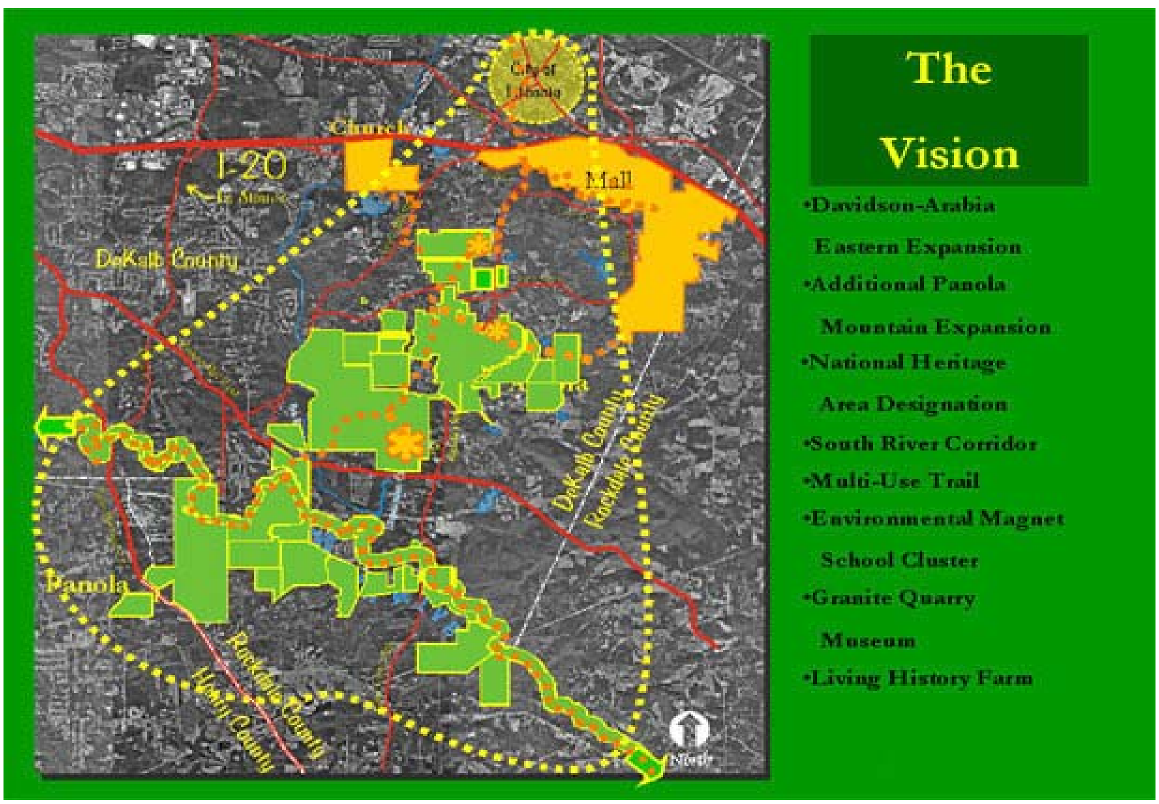
Site Inventory and Analysis

Location

Dekalb County Firing Range is located on North Goddard Road, approximately four miles southwest of the city of Lithonia, Georgia. The 60-acre property is owned by Dekalb County, and sits on the border of Davidson-Arabia Mountain Park. Dekalb County intends to incorporate the property into the expansion of Arabia-Davidson Park, and include it in the National Heritage Area Designation (Figure 3.1). The PATH foundation has plans to create a bike path along North Goddard Road, and the South River Corridor will follow Stephenson Creek through the site. There are also future plans to open an Environmental Magnet School Cluster in the vicinity.

Current Use

The site is currently being used as a firing range for metro Atlanta police departments and the public. Figure 3.5 shows the seven target areas that are in use at this time. Target Area A has a 25-meter shooting range. A layer of crushed gravel has been placed on the surface from the impact berm to the shooting pavilion. This was installed within the past two years. Target area B is also a 25-meter range. It is paved with concrete from the front of the berm to the shooting pavilion. Figure 3.2 shows Target Area C. This is a 25-meter range with bare earth and some turf. Target Area D is a 50-meter range. The targets of the 100-meter Target Area E are on top of a berm, with no backstop behind them to collect the bullets. Instead, the ammunition goes towards the stream, hits the tops of the trees growing in the floodplain, or impacts the bank on the opposite side of the stream near Target Area F. Figure 3.3 shows Target Area E with Target Area F behind it. The backstop for Target Area F has been cut out of the side of the forested ridge. The exposed earth of the excavated area is highly eroded. Figure 3.11 shows the target area with the exposed ridge and Figure 3.4 illustrates the topping of the floodplain trees in the line of fire between E and F and the erosion that is occurring on the slope. Both of these target areas are at high risk of lead mobility. The berm for Target Area G has only been in place for the last three years. It sits on a very thin layer of soil with partially exposed bedrock.



Source: Icon Architecture, Inc. 2001

Figure 3.1 Future Vision for the Expansion of Davidson-Arabia Mountain Park and the Proposed National Heritage Area

Figure 3.2 Target Area C

Figure 3.3 Target Areas E and F

Figure 3.4 Erosion and Topped Trees at Target Area F

Slope and Elevation

The site elevation changes from 730' to 910' with the lowest areas in the floodplain of the tributary stream and Stephenson Creek (Figure 3.6). In Figure 3.7, it can be seen that the majority of the site has a slope gradient of greater than 10%. This indicates that there is a moderate to high risk of lead mobility on site and potential problems with erosion during remediation, as most of the site is sloping towards the stream. The most suitable areas for construction are in the 0 to 5% slope range where the majority of target areas, office and pavilions already stand.

Geology and Soils

The site sits on underlying bedrock of Lithonia Gneiss. There are ten types of soils found on site, as shown in Figure 3.8. The majority of soils are in the Ashlar soil series. The series consists of: Ashlar sandy loam, very rocky, 6 to 15 percent slopes (AvD), Ashlar sandy loam, very rocky, 15 to 45 percent slopes (AvF), Ashlar-Wedowee complex, 2 to 10 percent slope (AwC), and Ashlar-Wedowee complex, 10 to 25 percent slope (AwE). These soils typically have a permeability of 2 to 6 inches per hour and a pH ranging from very strongly acidic to medium acidic (4.5 to 6.0). They are well drained to excessively drained soils formed from granite and gneiss. The Cartecay silt loam, frequently flooded (Ca) soil of the floodplain is somewhat poorly drained with a surface layer of silt loam. The soil is strongly acidic to slightly acidic (5.1 to 6.5 pH). Musella clay loams, MvD2 and MvE2, are well drained and shallow. They are naturally low in fertility and strongly acidic to medium acidic. MwF is a stony sandy clay loam with the same acidity as the previous two. The Pacolet sandy loam, 2 to 10 percent slopes (PfC) of the Pacolet series is a deep, well-drained soil. It is strongly acidic to very strongly acidic (pH of 5.5 to 4.5), and the root zone is deep and easily penetrated. The pH levels of all these soils promote the mobility of lead. Udorthents (Ub) on the east side of the road consists of areas that have been disturbed by human activity to expose the granite or gneiss (Thomas 1979).

Hydrologic Surface Flows

There are two streams on the property. North Goddard Road forms the ridgeline for the two streams on the property. The annual precipitation rate of Dekalb County is 122.4 cm (Thomas 1979). As shown in Figure 3.9, the majority of the runoff flows by sheet flow or swales towards the spring-fed perennial stream that traverses the property. The water in the stream flows southeast along the natural streambed through a culvert that takes it under the gravel road until it meets Stephenson Creek. The creek, in turn, is a tributary to the South River.

Vegetation

The majority of the site is a semi-mature stand of mixed hardwoods, predominated by white oaks, southern red oaks and red maples, as shown in Figure 3.10. Hardwoods of up two feet in diameter are growing on the backside of the impact berms for target areas C and D. The floodplain canopy consists of sweetgum, tulip poplars and red maples. The tops of these trees grow no taller than the bank of the slope in the area between Target Area E and F due to constant trimming by bullets (Figure 3.4). The land in front of the target areas is typically covered in turf, or in some areas is bare of vegetation. Short-leaf and loblolly pines predominate in areas of the property on the east side of the road.

Based on the risk factors identified in Table 2.2 and the physical characteristics found on site through the site analysis, the degree of risk for lead transport at the Dekalb County Firing Range is analyzed in Table 3.1 below.

Table 3.1 Degree of Risk for Lead Transport at the Dekalb County Firing Range

Risk Factor	**Site Condition**	**Degree of Risk**
Annual precipitation (cm)	122.4	Moderate risk
Topographic slope (m/100m)	10 or greater for the majority	Moderate risk
Soil chemistry	Acidic soil and rock	High risk
Acidity of surface water or groundwater (pH)	Unknown	Unknown
Lead pellet contact time with water	Continuous contact (shot deposited directly into water)	High risk
Soil cover	Grass	Moderate risk
Vegetative cover/barriers	Grass and forested area	Moderate risk
Depth to groundwater (m)	Unknown	Unknown
Distance to surface stream	Shot deposited directly into water	High risk

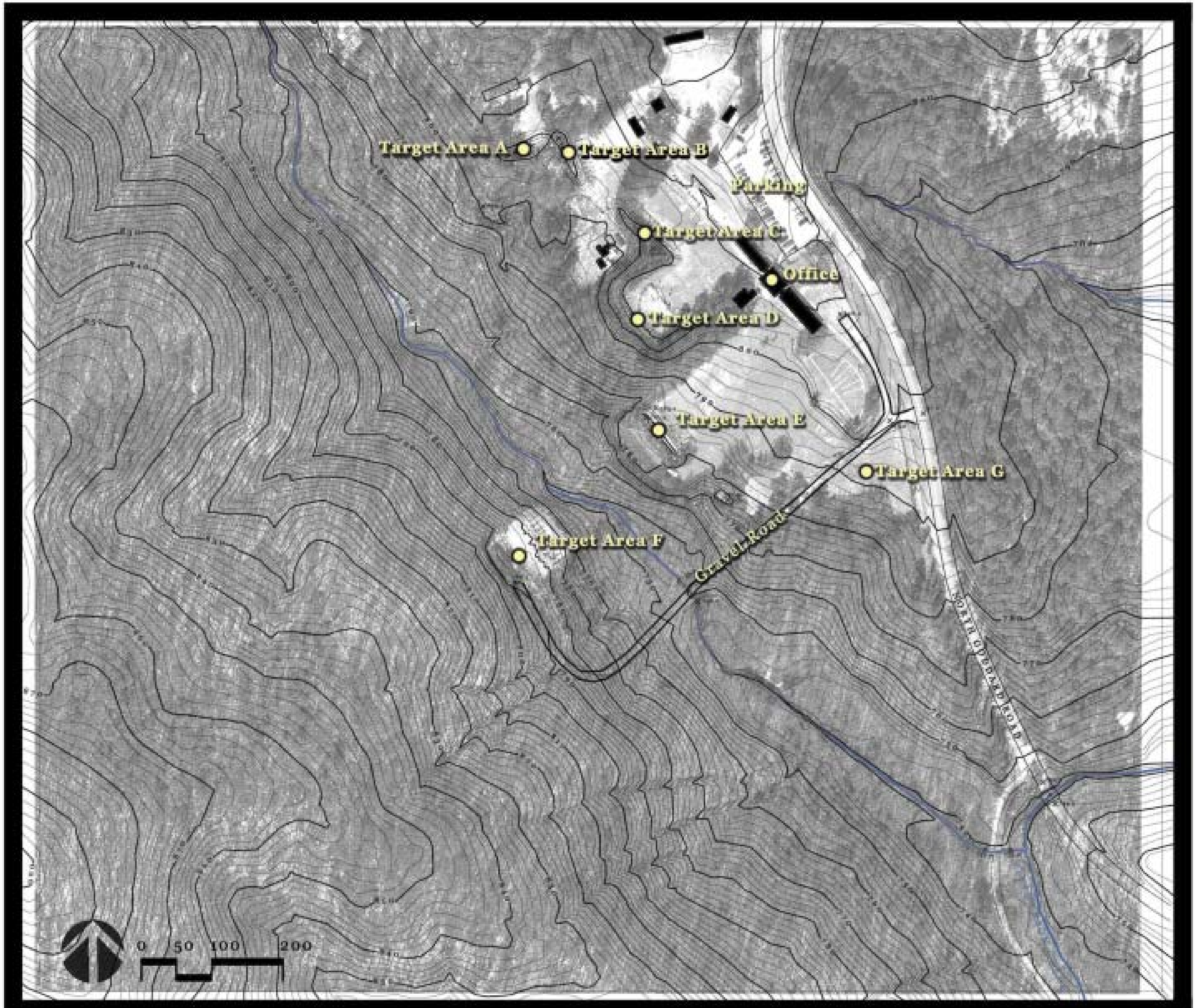


Figure 3.5 Current Use

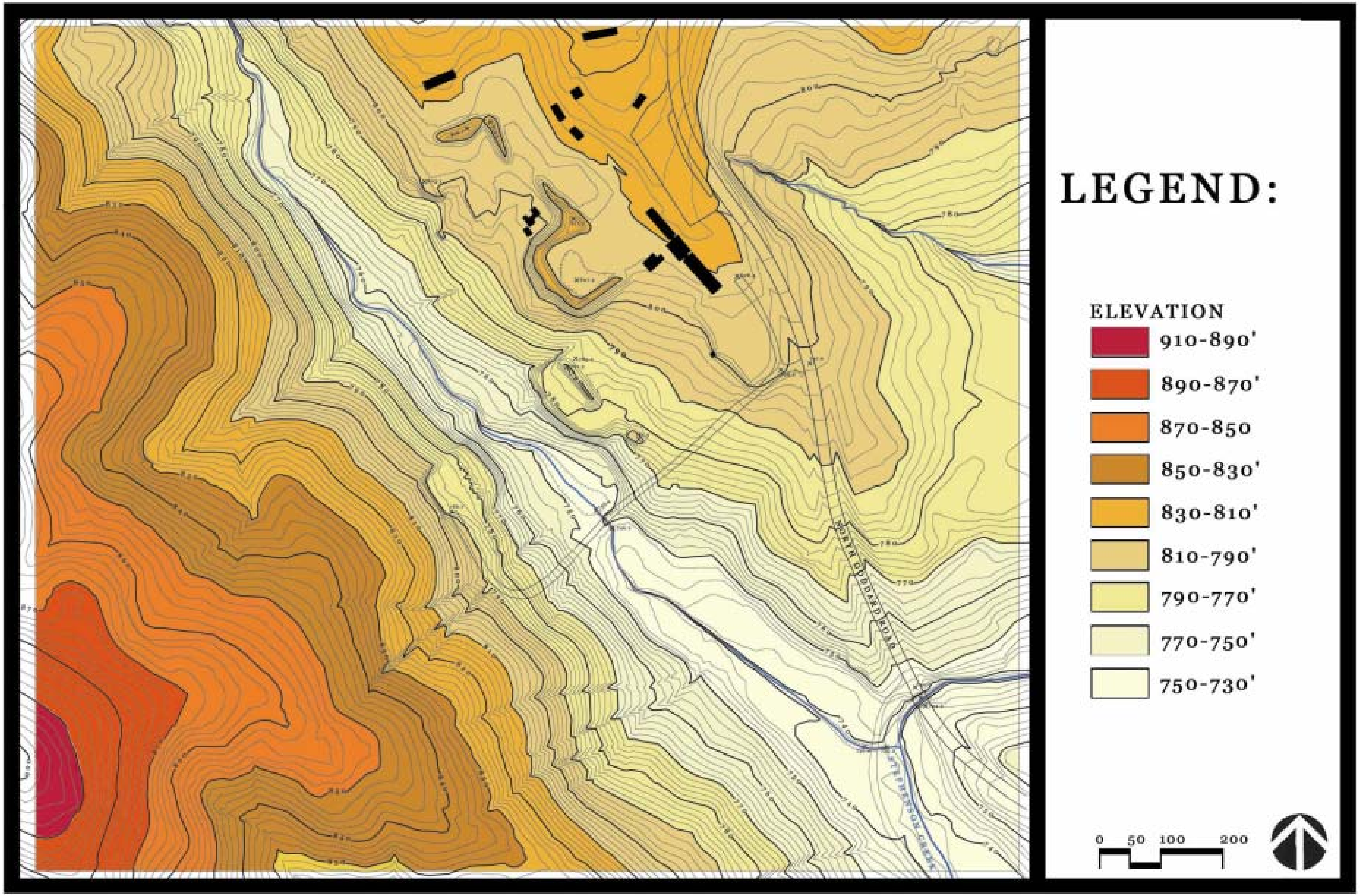


Figure 3.6 Topography

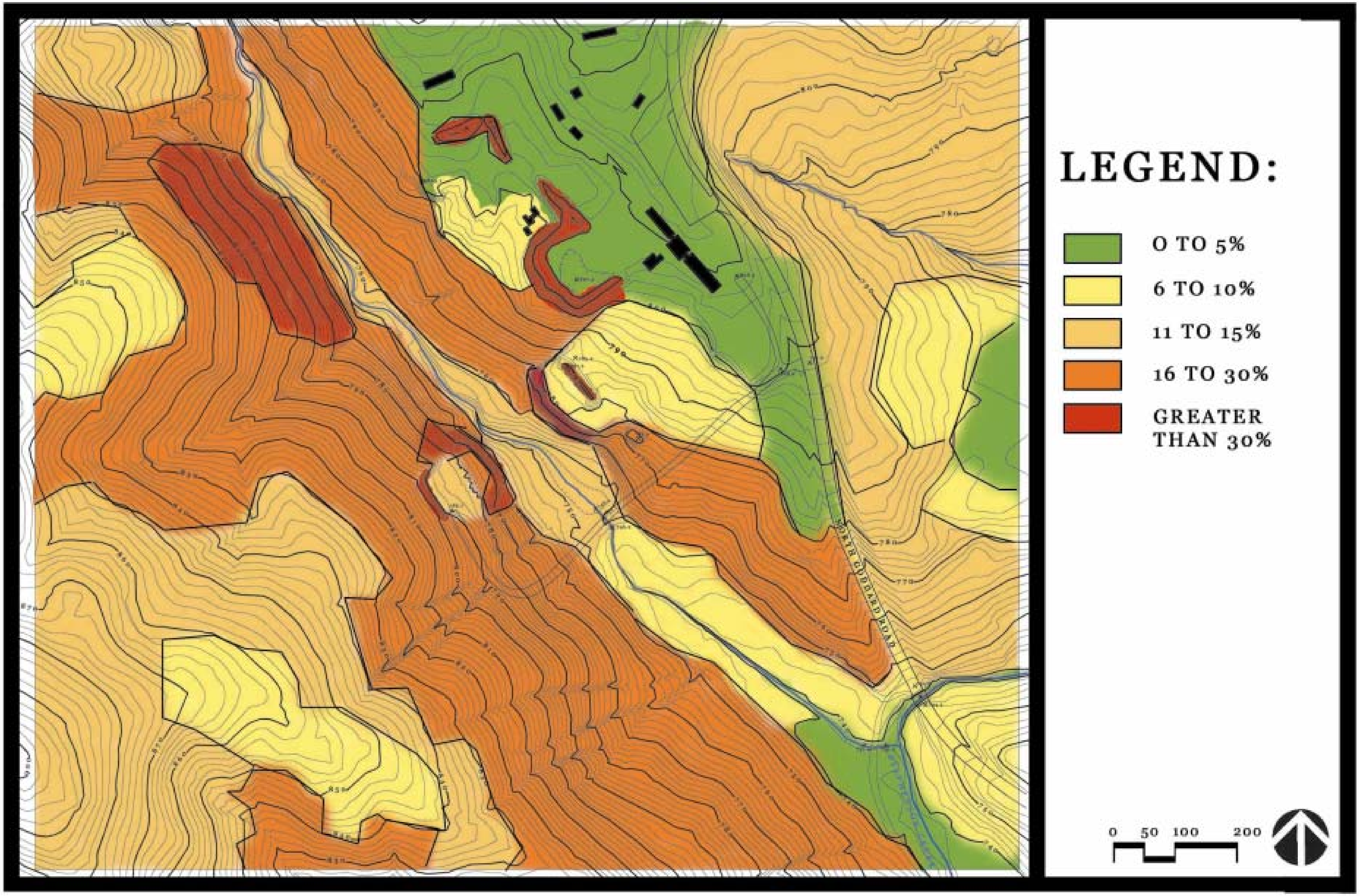


Figure 3.7 Slope Gradient

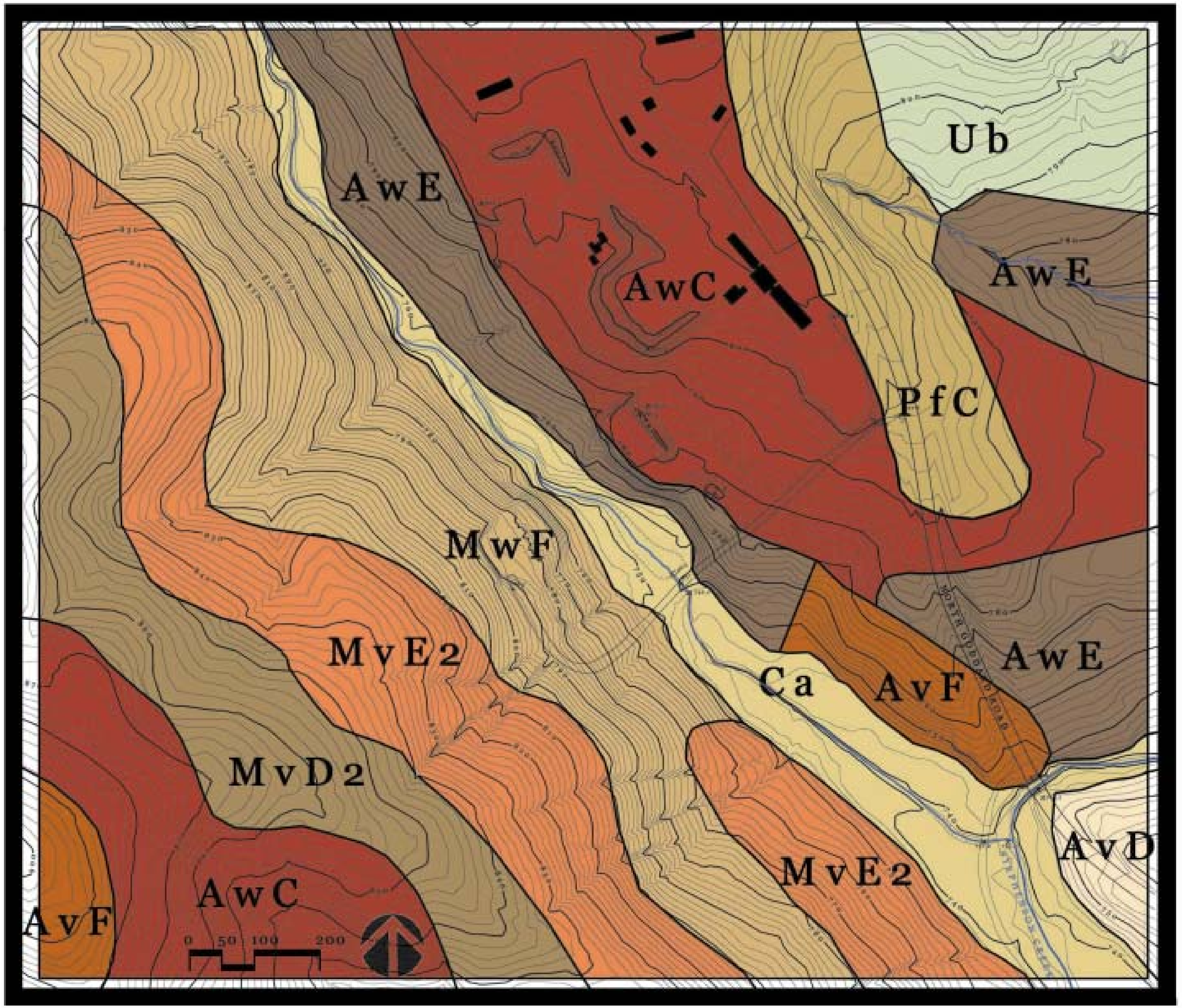


Figure 3.8 Soil Survey

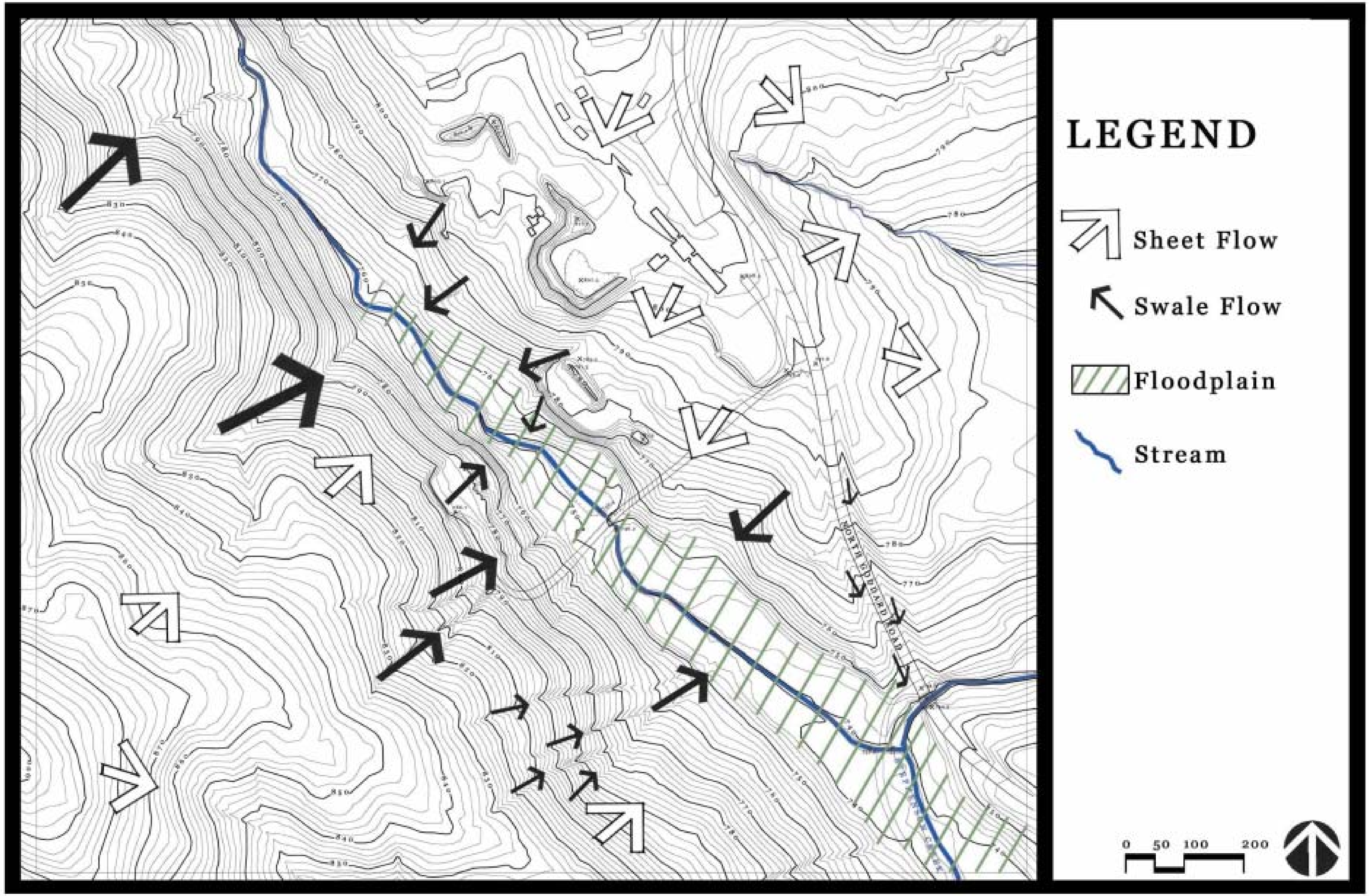


Figure 3.9 Hydrologic Flow

Figure 3.10 Vegetation

Soil and Water Testing:

Soil, sediment and surface water from the firing range were tested to determine the approximate levels of lead contamination on site. Lead sources include atmospheric deposition from the dust produced during firearm release and the breakdown of whole and fragmented bullets.

Soil Testing

The soil samples were collected along transect-lines at six of the seven target areas (Figure 3.13). Along each transect-line, stakes were installed at twenty-five foot intervals. Around each stake, an equilateral triangle was made from three one-meter lengths of wood. With a stainless steel trowel, soil from the top 5cm was collected at each of the triangles' corners, and then mixed together in a plastic bucket. This mixture was placed in a plastic bag and labeled.

A background sample of soil (BGD) was taken for comparative purposes upslope of the target areas at the north edge of the property line. Soil samples at Target Area A were collected at a diagonal along the surface water flow line. Samples could not be collected from Target Area B because the area up to the berm is paved in concrete. At Target Area C, C1 was collected at the top of the berm, C2 was collected at the base, then the line continued away from the berm. The transect line for Target Area D started in the depression behind the targets at the base of the berm, then extended towards the shooting pavilion. Due to the steep slope behind Target Area E, E1 and E2 were collected 25 feet apart along the transect line near the stream, then E3 and E4 were collected 25 feet from one another at the top of the slope, behind the impact berm. E5 and E6 were collected 25 feet to 50 feet from the gently sloping area in front the berm. The impact area for Target

Area F is actually the exposed cut away face of the hill. F1 was collected in the rubble at the base of the cut. F2 was taken immediately behind the targets, samples F3 and F4 were from the eroding soil in front of the targets. F5 and F6 were collected along the line in the floodplain. Target Area G is on very shallow soil, with bedrock exposed in some places. G1 was collected from the shallow, mostly humus layer that covered the bedrock. G2 was taken on the backside of the impact berm and G3 and G4 in front of the targets.

Figure 3.11 Targets and Backstop of Target Area F

Figure 3.12 Stakes Marking Collection Sites for S3 and W3

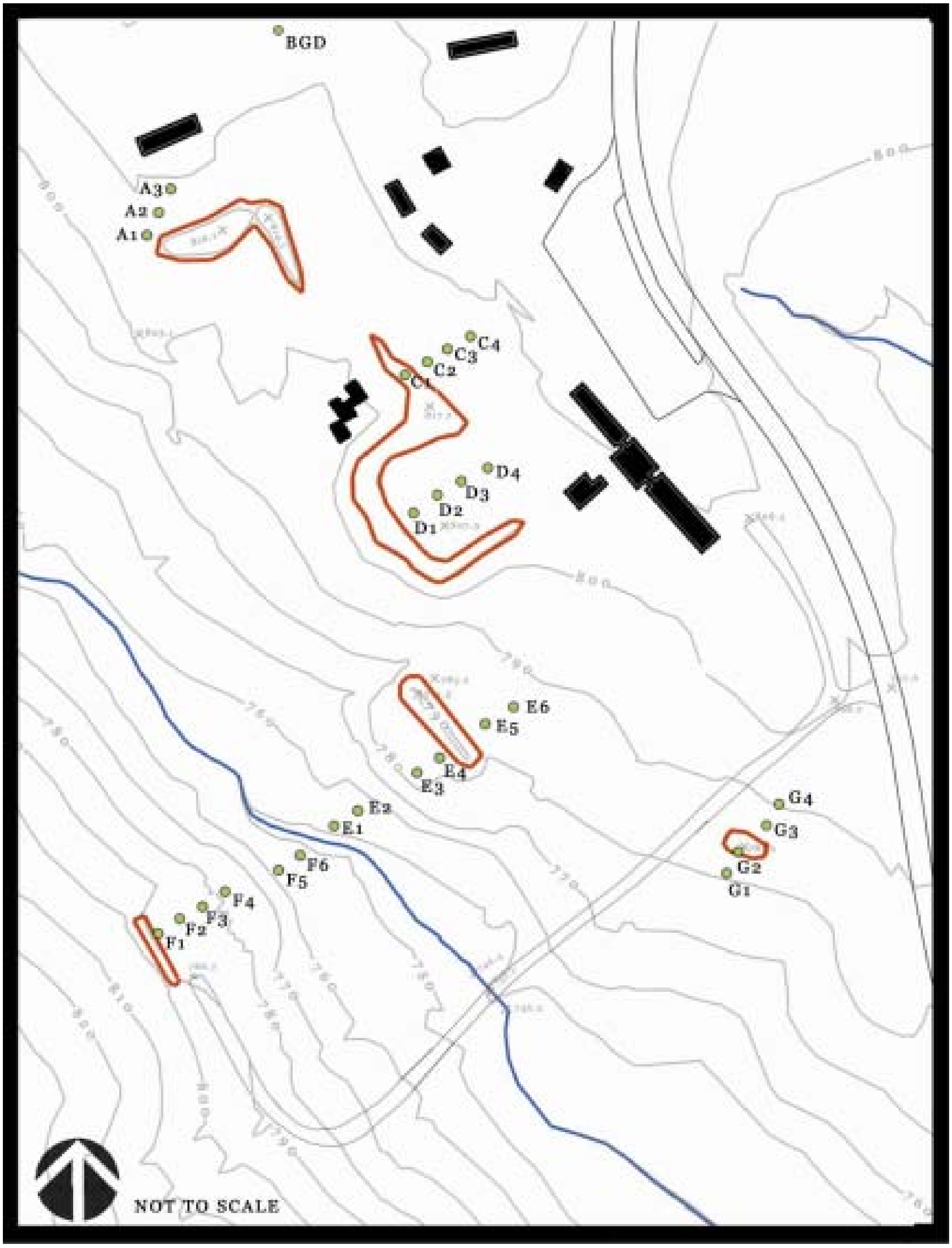


Figure 3.13 Soil Collection Sites

The following testing method used for the soil and sediment samples has been shown to extract 80% or more of the lead from soil. The samples were allowed to dry, mixed thoroughly, then individually sifted through a 2 mm sieve to remove large particles, including rocks, organic material, bullets and bullet fragments. The samples were prepared using USEPA Method 3050 (Amacher 1996). One gram of the sieved soil was placed into an Erlenmeyer flask. At random intervals, three flasks were prepared from the same sample source to determine the standard deviation. 10ml of nitric acid was added to each flask, a condenser was placed on top and the samples were heated for two to four hours on a hot plate until the lead was extracted into the solution. The samples were then removed from the heat and allowed to cool. Deionized water was added to each sample to bring the total solution to 100 ml. The solutions were filtered through Whatman 41 filter paper then analyzed on a Perkin-Elmer 5000 Atomic Absorption Spectrophotometer. From the absorption levels it was calculated how many parts per million lead was in the soil.

Soil Testing Results

Samples A1, A2, C4, D2, D3, D4, and E1 contained whole bullets, pellets and/or fragments larger than 2mm. Table 3.2 lists the results of the atomic absorption analysis. Of the twenty-eight soil samples taken, the analysis showed the lead content ranges from 25 to 12,200 ppm lead. The general trend was for the lowest levels of lead particles smaller than 2 mm to be found on the impact berm, while the highest were located within twenty-five feet of the base. At target areas E and F, the highest levels of lead were found at the base of berm, with lead levels decreasing down the slopes towards the stream until the floodplain, where the levels were high again. This indicates that the lead is moving rapidly down the steep sides of the bank towards the water. Based on the results and the rating system from the University of Massachusetts (Table 2.1), Figure 3.15 shows the levels of lead contamination found on the site.

Table 3.2 Results of Lead in Soil Analysis

Sample#	Lead (ppm)
BGD	91.1± 7.79[1]
A1	3,189±1,797
A2	1,460
A3	363
C1	114
C2	7,160
C3	688
C4	1063±639
D1	7,363
D2	4,800±2,855
D3	12,200
D4	3,190
E1	2,160
E2	586
E3	200
E4	557
E5	3,367±724
E6	550
F1	11,700
F2	4,480
F3	6,200
F4	6,743±2,440
F5	5,410
F6	6,140
G1	1,500
G2	25
G3	713
G4	157

[1] Mean ± Standard Deviation

Sediments

Stream sediment samples were collected from the bottom of the tributary streambed (see Figure 3.14). S1 was the baseline sample taken upstream from the target areas. S2 was taken from the stream between target areas E and F. S3 was collected immediately upstream from the culvert that runs under the gravel drive and S4 was taken immediately after it. S5 was collected immediately upstream from where the stream flows into Stephenson Creek. The last sample, S6 was taken in Stephenson Creek. This was just upstream from a beaver dam. The sediment samples were prepared and analyzed in the same manner as the soil samples.

Sediment Test Results

None of the sediment samples contained lead particles larger than 2 mm. Table 3.3 shows the highest level of lead was between target areas E and F. The level dropped significantly after the water passed through the culvert under the gravel road, and returned to low levels where the stream joins Stephenson Creek.

Table 3.3 Results of Lead in Sediment Analysis

Sample#	Lead (ppm)
S1	14.3
S2	4,310±905[1]
S3	1,160
S4	563
S5	143
S6	75±6.76

[1] Mean ± Standard Deviation

Water

The water samples were collected from the stream that runs from northwest to southeast through the center of the property, Stephenson Creek and puddles in the target areas (Figure 3.14). At the time of collection, it had been raining off and on for three hours, and surface run-off from the slopes was entering the stream. All water samples were collected with clean plastic bottles that were rinsed several times with the stream water at the sample sites. Sample W1 was taken up stream from all of the target areas to test the base level of lead in the stream. W2 was collected at a point behind target areas A-D. W3 was collected immediately before the culvert and W4 on the downstream side of the culvert. W5 was collected just before the stream joined Stephenson Creek. W6 was sampled from Stephenson Creek upstream from where the stream intersects, to determine the baseline level for the creek, and W7 was collected approximately 50 feet downstream from the intersection. WD1 and WD2 were taken from standing water behind the targets at Target Area D. The samples were filtered through a .45 micron nylon filter and analyzed for dissolved lead on a ICP spectrometer in accordance with EPA method 3005A 2.2.

Water Test Results

All water samples collected in the stream are within the natural concentrations of lead (0.6 to 120 ppb lead) in river waters (Table 3.4). This indicates that the dissolved lead brought into the water by the sediments is quickly precipitating once it is in the stream. The chance of contamination in the surface flow beyond the property is minimal.

Table 3.4 Results of Lead in Water Analysis

Sample #	Lead (ppb)
W1	28.45
W2	0.69
W3	3.17
W4	16.23
W5	15.50
W6	11.97
W7	1.90

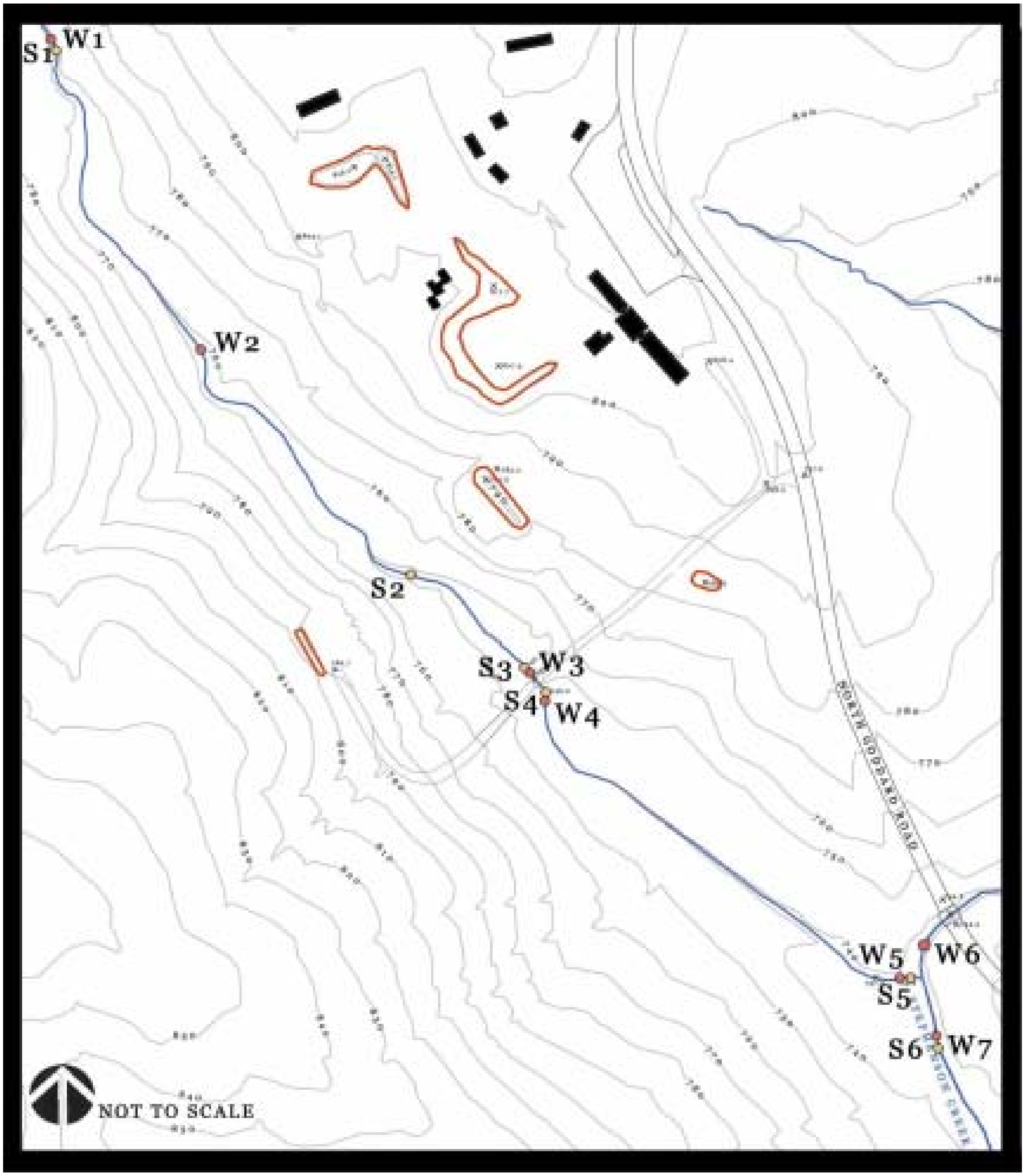


Figure 3.14 Sediment and Water Collection Sites

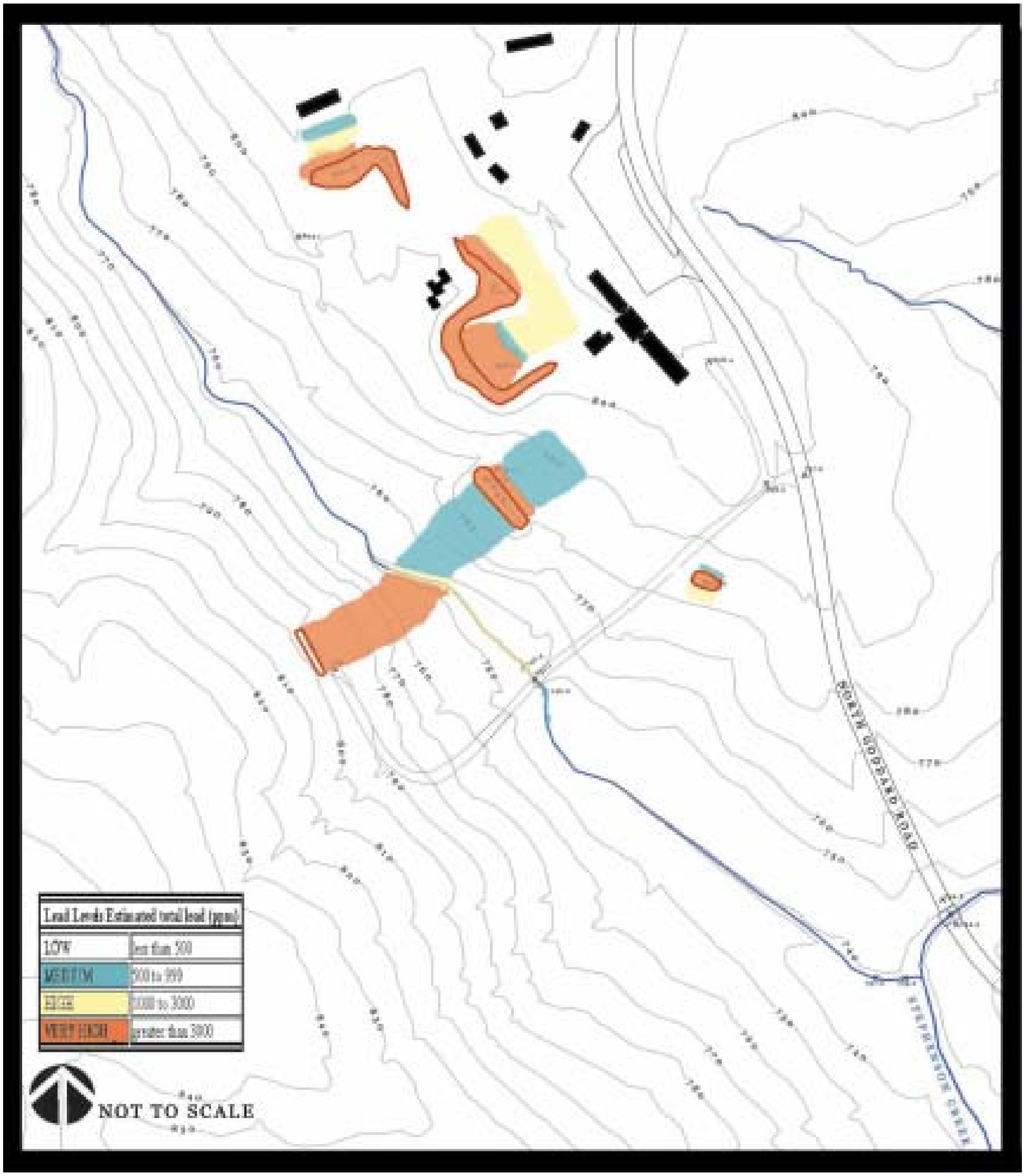


Figure 3.15 Lead Contamination Levels Based on Soil and Sediment Analysis

CHAPTER 4

CONCEPTUAL DESIGN FOR THE REMEDIATION OF LEAD CONTAMINATION AT DEKALB COUNTY FIRING RANGE

Conceptual Site Design

From the research conducted, it has been determined that immediate efforts should be made to contain the lead from migrating until it is removed from the site or stabilized. It is not feasible to house animals on the property as part of the wildlife rehabilitation center until the lead in the soil has been reduced to safe levels. Due to the amount of time it will take to fully plan and implement a remediation effort, it is advised that AWARE find another site to locate its animal housing facilities. As a result of these findings, a conceptual plan for the remediation of the site has been designed (Figure 4.1). The goals of the design include:

1. **Reducing further migration of lead into the waterways**. Although the high levels of lead contamination seem to be limited to the sediments immediately downslope from the firing ranges, there is still the possibility of lead fragments being carried down stream and off the property.
2. **Providing a cost effective method of reducing contamination on site**. The clean up of the site could potentially cost millions of dollars. Because the site is not under pressure for development, choosing remediation techniques that are less expensive but more time consuming could save the county a significant amount of money.

3. **Remediation of the lead in a manner that causes minimal adverse impact on the environment.** The firing range is slated to become part of the Davidson-Arabia Mountain Park, and included in the National Heritage Area. This dictates that the remediation is conducted in a manner that preserves the character and integrity of the environment. Methods that will cause a permanent alteration, such as solidification/stabilization, are not acceptable for large-scale remediation of the site. The processes chosen should impact the least amount of canopy trees possible.
4. **Providing an educational opportunity for the community to understand the hazards of lead and the processes used to remove it**. Community involvement in the remediation selection and implementation is essential to promoting an understanding of lead contamination and its removal. While the site may not be completely accessible during the remediation process, there should be opportunities for the community to witness and participate in the process.
5. **Let the land continue to heal once remediation efforts are complete, by allowing natural succession to return it to a forested state**. Because this property will be contained in the Davidson-Arabia Park, and part of the South River Corridor, the site should be allowed to succeed into forested land, to keep in character with the surrounding landscape.

Based on the literature review of the lead remediation methods, large scale landfilling, solidification/ stabilization and soil flushing were ruled out as alternatives due to the cost of these methods or the effects on the environment. Soil washing, phytoremediation, electrokinetics and a small area of solidification were chosen as the methods that fit the goals defined above.

The total process of remediation may take 10 to 20 years. A detailed plan for remediation must be established, treatability studies conducted, and a monitoring plan must be devised. The first step of the design is to install sediment barriers between the target areas and the stream. This will slow the velocity of the runoff and filter sediments. Install barrier according to Sd1 in the *Field Manual for Erosion and Sediment Control in Georgia* printed by the Georgia Soil and Water Conservation Commission (1997).

To remediate the impact berms A, B, C, D, E, and G, the depth of penetration by the bullets will need to be determined. The top few inches of soil in the target areas should be added to the berms for remediation. The bullets and fragments can be sieved out of the soil then sent to a smeltering facility for recycling. The *ex-situ* method of soil washing should be applied to the collected soil (Figure 4.1). Once this is accomplished the lead levels in the berms and collected surface soil should be reduced to low or medium concentrations. While this method is not cheap, it will significantly reduce the amount of lead in the soil in a short amount of time. It is also much less expensive than hauling the contaminated soil to the landfill. Some money may be recovered by recycling the lead, and the removal of the bullets and lead particles will reduce contamination levels to less than 500 ppm (Hlousek 2000). This immediate reduction of the potential for contamination migration will make the next phase, phytoremediation, more feasible.

The next step provides a relatively inexpensive method to further reduce the levels of lead in the soil, while creating research and educational opportunities. Experimental plots will be set up for phytoremediation (Figure 4.2). The plots are arranged in a rectilinear formation (Figure 4.3). Besides being convenient for maintenance, this configuration is a reminder that the site is not a natural landscape. As part of the National Heritage Area, the formation will represent the impacts we have had on the land, similar to the featured remains of granite quarrying operations nearby. A ten-foot chain-link fence should be installed around the phytoremediation site to prevent wildlife, such as deer, from contact with the plants. The treated soil and remaining berms should be tilled into the land in plots. Each plot should have a fine mesh netting over it to prevent wildlife such as birds from entering. A variety of plants should be tested for treatability before the large-scale application. This would be a good opportunity to involve horticultural students from the University of Georgia. Due to the mild climate of Georgia, it may be possible to do year round rotations of crops such as Indian mustard in the cool seasons and sunflowers in the warm seasons. Another possibility is to use perennial grama grasses to stabilize the soil. Fields left fallow will naturally grow crabgrass, which has also been tested for its remediation effects. All of these crops will have to be harvested on a regular basis and the lead they contain recycled or disposed of in the proper facility. Due to the slow recovery time of phytoremediation, the total process may last for ten to twenty years. Beyond the fence line of the plots, native vegetation should be allowed to grow to promote stabilization of the lead in the soils. Throughout this process, monitoring data should be collected. Climatic data, such as temperature, precipitation, relative humidity, and wind speed and direction will help determine maintenance requirements and evapotranspiration rates. The plants need to be monitored for signs of stress, insect or animal damage, tissue composition, transpiration rates and root density. To optimize vegetative growth and quantify contaminants, measurements of the soil's geochemical parameters (pH, nutrient concentrations, water concentrations, etc.) and contaminant levels must be taken. Groundwater should also be monitored for depth to groundwater, rate of flow and contaminant levels.

Berm F is experiencing rapid erosion of soil due to the bare earth. To stop the erosion and minimize the cost of repairing the hillside, it is suggested that the soil is stabilized with the formation of a visitor seating area (Figure 4.4). The seating area would serve as an overlook to the remediation processes being conducted below, allowing for educational opportunities. It would be constructed of concrete to solidify the contamination.

To remediate the lead in the stream sediments, treatability studies should be conducted using electrokinetics. If this method proves feasible, it would allow the least amount of disruption to the sensitive floodplain ecosystem.

As remediation efforts are underway, the community should be allowed to observe and participate. However, any involvement is contingent upon assurance that there is no unreasonable risk of human contact with contaminated soil or dust. Adopt-A-Stream volunteers can monitor the water quality of the stream and Stephenson Creek, for both chemical and biological aspects. AWARE may consider organizing research studies to monitor the lead levels in the wildlife on site. The existing building can be converted into an educational center that explains the remediation process. The center could also be used by AWARE as part of their outreach program to educate the public about the effects of environmental contaminants on wildlife. This can be a field site for the environmental magnet school, with field trips being conducted on site, and educational lectures being held on the seating area on the ridge.

Once remediation efforts are completed and the amount of lead in the soil has returned to safe levels, the fencing surrounding the phytoremediation plots should be removed, along with the sediment barriers. The land should be allowed to succeed into a mixed deciduous hardwood forest. However, the significance of the disturbance created by humans should not be lost. Even as the forest regenerates, the outline of the remediation plots will be apparent. The gravel road on sire can link with the PATH bikeway and South Corridor Trail as a scenic viewpoint. The educational center can remain, if there are funds to maintain it, otherwise, it can be removed from the site. If that is the case, then informational signs should be installed to continue to educate the public on the history of the site.

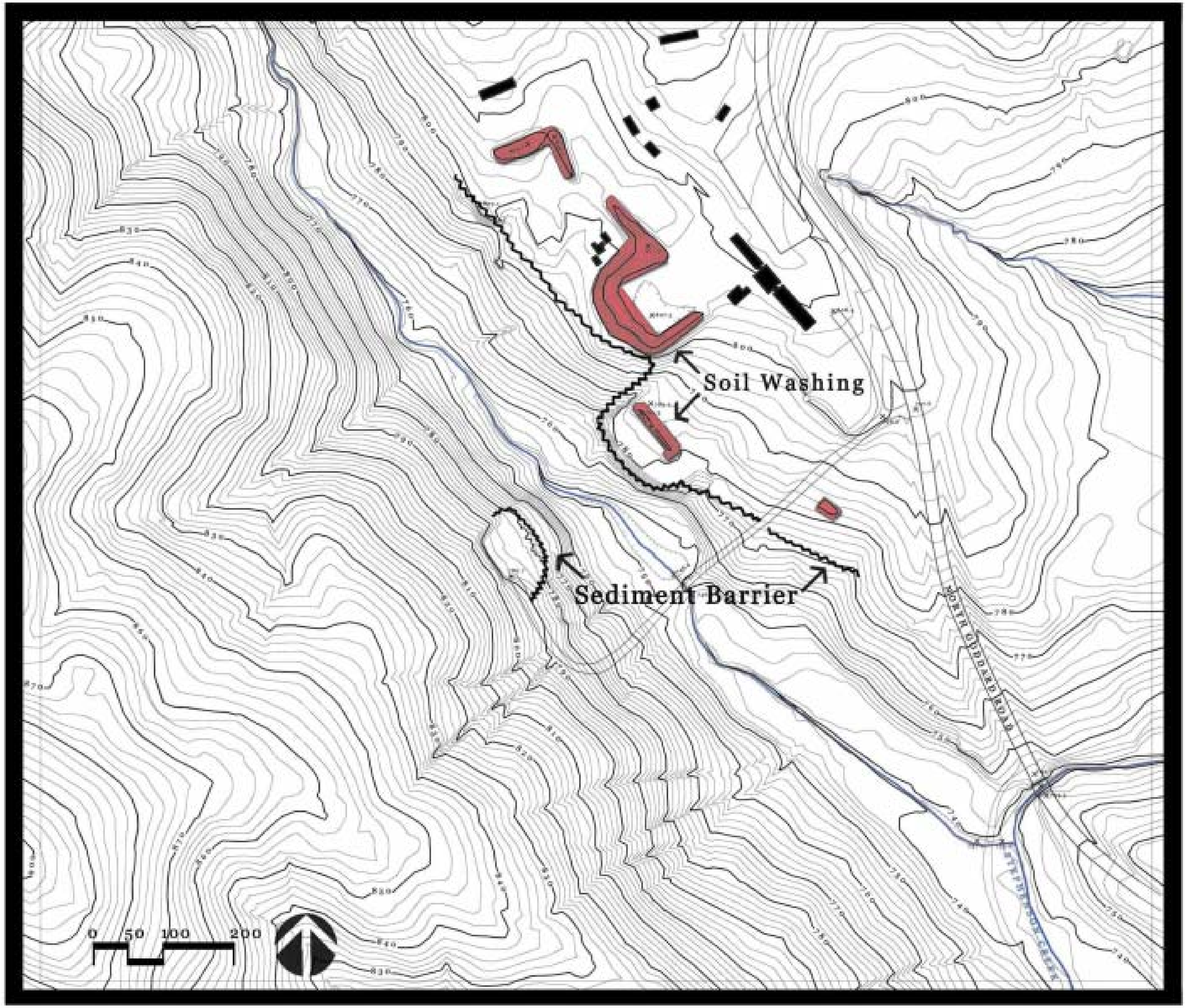


Figure 4.1 Soil Washing

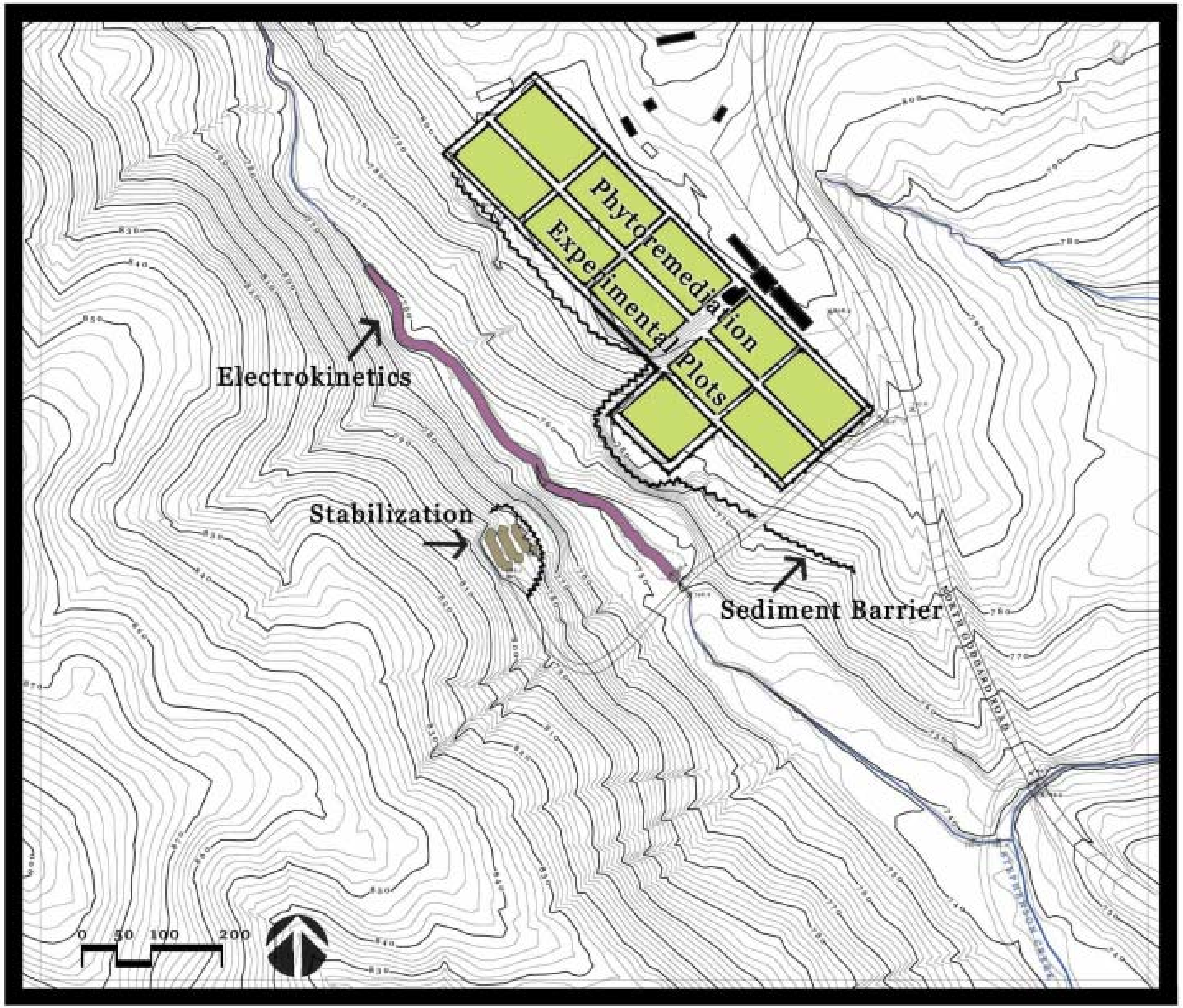


Figure 4.2 Experimental Phytoremediation Plots and Electrokinetics

Figure 4.3 Phytoremediation Plots

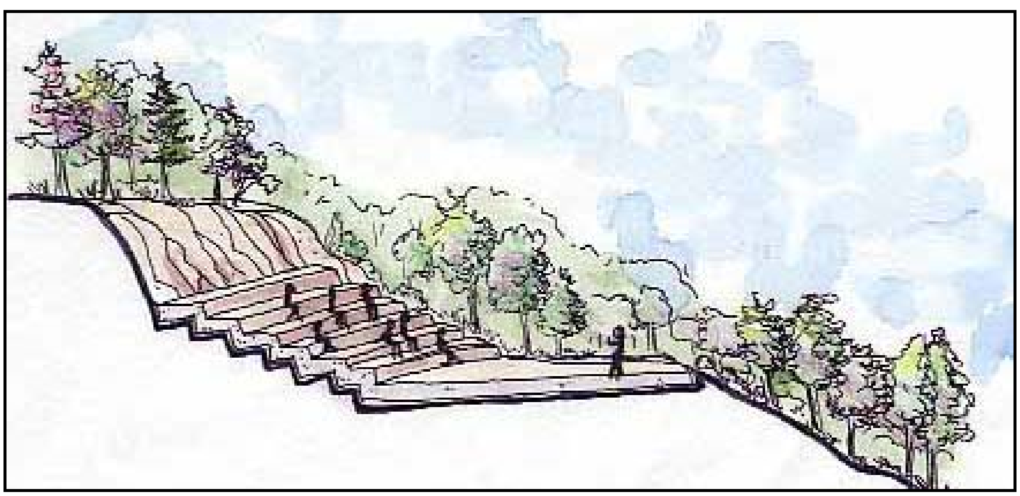


Figure 4.4 Stabilized Seating Area

CHAPTER 5

CONCLUSIONS

The major purpose of this thesis was to explore the application of environmentally sensitive practices and public education to the clean up of lead-contaminated sites. The major findings of this study included the potential for lead contamination to migrate through the environment and the ecological application of current technologies available for remediation. In the site-specific study, it was found that Dekalb Firing Range does contain significant levels of contamination on site through the analysis of the soil, sediment and water. It was determined from this analysis that the site was unsuitable for housing the animals of the AWARE wildlife rehabilitation center. As an alternative, a conceptual plan for the remediation and long-term use of the site was designed. The plan was designed to remove the contamination in an ecologically sensitive manner. A related benefit is the education of the public. The final use of the land allows the natural functions of the site to return, while providing continued educational opportunities for the public to understand the impacts humans have had on the landscape.

The remediation of lead contaminated firing ranges is still a new field of discovery. Remediation projects in the field, and carefully monitored experiments can yield much-needed information for future remediation efforts. Particularly with phytoremediation, there are still many questions that need to be answered. Research is needed to develop a better understanding of the physiological, biochemical, and genetic processes that allow for the adaptability and lead accumulation of the plants. More specific data are needed on the potential for plant species' use in extraction and stabilization. A standardization of field-test protocols needs to be developed. The site remediation could provide an opportunity for further development of this technology.

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