DISSERTATION

SIMULATION OF MUNITIONS EFFECTS ON ECOSYSTEM CONTAMINATION IN AN ARMY RANGE IMPACT AREA

Submitted by

Stephen T. Houston

Graduate Degree Program in Ecology

In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Summer 2002

UMI Number: 3063995

ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

COLORADO STATE UNIVERSITY

June 28, 2002

WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY STEPHEN T. HOUSTON ENTITLED SIMULATION OF MUNITIONS EFFECTS ON ECOSYSTEM CONTAMINATION IN AN ARMY RANGE IMPACT AREA BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

Committee on Graduate Work

Adviser

Department Head/Director

ABSTRACT OF DISSERTATION

SIMULATION OF MUNITIONS EFFECTS ON ECOSYSTEM CONTAMINATION IN AN ARMY RANGE IMPACT AREA

As a military service, the Army faces unique challenges in maintaining its warfighting readiness while practicing sound environmental stewardship of its training lands. The environmental implications of using firing ranges and impact areas are becoming more important. These include health and safety risks due to unexploded ordnance. Chemical contaminants such as Trinitrotoluene (TNT), Royal Demolition Explosive (RDX), and High Melting Explosive (HMX) are subject to environmental fate and transport processes congruent with the ecological setting in to which they are released.

An understanding and application of environmental and ecological science provides a vehicle for adequately addressing the impact area contamination problem. This dissertation demonstrates a methodology that integrates these disciplines into a problem solving approach that provides a foundation for effective resource management and future research.

An ecological framework for assessment of environmental risk is used to evaluate the relative resilience of eleven major Army impact areas to explosive residue contamination. It identifies ecosystem properties that directly influence the rates of environmental fate and transport processes in the natural system.

First approximations of munitions disturbance and contaminant loading are made and field data collected and analyzed from Fort Greely, Alaska. This yields a set of soil properties such as soil organic matter content that are related to an impact area's ability to attenuate contaminant fate and transport. Organic matter content of the soils proved to be a good predictor of cation exchange capacity and it also is a good descriptor of crater disturbance.

SOM dynamics provides an integrative link between environmental process and ecological setting resolving the complex problem of impact area contamination into one that is more understandable and manageable. CENTURY SOM dynamics simulation adequately predicted levels of primary production and soil carbon for the modeled ecotypes of Fort Greely, Alaska. Simulated SOM rates-of-change resulting from munitions use provided insight into ecological and environmental processes affecting munitions contamination, and the ability to quantify contaminant attenuation.

Finally, a geographic information system enables an integrated analysis that produces an environmentally and ecologically based measure of the system's ability to attenuate contamination for use in decision making.

Keyword: munitions contamination, fate and transport processes, soil organic matter dynamics, impact area, military impacts, U.S. Army

Stephen T. Houston
Graduate Degree Program in Ecology
Colorado State University
Fort Collins, CO 80523
Summer 2002

ACKNOWLEDGEMENTS

I owe a great deal of gratitude to Dr. Bob Shaw, Director of the Center for Environmental Management of Military Lands (CEMML) and Dr. Bill Doe, Associate Director for CEMML who supervised my studies mentoring me through the past two and a half years. Also, I wish to thank Dr. Ed Redente, Dr. Melinda Laituri and Dr. Neil Grigg for serving on my committee. Their guidance and encouragement made this experience very challenging and rewarding.

My research would not have been possible without the financial support provided by the Army Research Office and Dr. Russ Harmon. Also, I must thank Dr. Chuck Racine, Dr. Tom Jenkins, Mr. Charlie Collins and Mr. Tony Palazzo from the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory. Without their help in providing access to the Fort Greely impact areas, technical support, advice and encouragement, my fieldwork would not have been possible. Additionally, I want to thank Dr. Bill Parton and Ms. Cindy Keough of the Natural Resource and Ecology Laboratory for helping me through the demanding process of configuring, parameterizing and interpreting the results of my CENTURY simulations.

I am very grateful for the support and encouragement provided by the CEMML staff. They always welcomed me when I had questions or needed help and I could not have wished for a better environment in which to research and study.

I wish to thank the COL Chris King, COL Mike Kelley and COL Gene Palka from the Department of Geography and Environmental Engineering, United States Military Academy at West Point first for their support in allowing me to pursue this Ph.D. and for their review of portions of this dissertation.

Many friends in the community and the university have made our time here in Colorado very special. In particular I want to thank Dr.'s Bill and Sue Doe. They are life long friends and have been a joy to be with the past two and a half years.

Finally, and most of all I wish to thank my wife Laura for her love, support and patience through the challenging times of a Ph.D. program.

DEDICATION

This dissertation is dedicated

to the memory of

Taylor Anne Houston

June 17, 1999

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

Army Environmental Stewardship

The United States Army Trains as it Fights

The United States Army's purpose is to fight and win our nation's wars. It does so by serving as a powerful deterrent to any potential adversary, and by being the world's premier land force that can achieve sustained land dominance against an adversary should deterrence fail. For that reason, the Army must be able to close with and destroy enemy forces through the application of maneuver and lethally precise fires anywhere, anytime and under any conditions (FM1, 2001). This requires firing ranges and impact areas that provide soldiers and units with tough, realistic firing conditions that will help them learn to perform effectively under the stress of military operations. The bottom line for the Army is that it must train as it would fight because if it does not, it places the freedoms we enjoy and value as Americans in jeopardy.

Today, the Army faces unique challenges in maintaining its war fighting readiness while practicing sound environmental stewardship of its training lands. Yet the Army is prepared to meet these challenges it values and is committed to protect the training and testing lands that Americans have entrusted to its care. It understands that protecting our nation also means safeguarding the environment in which it trains. The Army has a long tradition of environmental stewardship that has evolved in step with our culture. The past is usually an indicator of the future, therefore a short review of the Army's environmental efforts provides evidence of the Army's commitment to the environmental security as it works protect or nation from its adversaries.

Army Environmental Stewardship

The Army's early environmental stewardship experiences began with expeditions of the western territories led by Army officers such as Lieutenant Zebulon Montgomery Pike in 1805 and by Major Stephen Long in 1820. During their explorations they described and documented the awesome natural and ecological resources of these pristine lands. In 1870, Army officer and explorer Lieutenant Gustavus C. Doane authored an official report that was so eloquent in it its description of the raw beauty and uniqueness of the Yellowstone region that it helped to inspired Congress to pass legislation designating Yellowstone as the country's first National Park (Hampton, 1971). Former General of the Army, President Grant, signed the bill into law in 1872. However, many began to exploit the Yellowstone Park and over the next 14 years the destruction of wildlife and vandalism of geysers gradually became intolerable to politicians in the east. The President ordered the Army to take charge of Yellowstone and in 1886 Troop M, First United States Cavalry, under the command of Captain Moses Harris, assumed responsibility for Yellowstone National Park. The U.S. Army would manage and protect Yellowstone, as well as other national parks, such as Yosemite and Sequoia, until just before World War I (Hampton, 1971).

This auspicious start for the Army's environmental program must be tempered. While its cadre of officers and soldiers had a great sense of environmentally sound practices because of their "field" experiences, there were instances where they contributed to the destruction of natural resources. During the Indian Wars for example, a common operational goal was to deprive the warring tribes of resources thereby forcing them to sue for peace. Consequently, much of the country's bison populations were indiscriminately eliminated to near extinction. However, this error was later recognized and contributed to the Army's support of the establishment and management of Yellowstone National Park (Hampton, 1971).

As the United States emerged as a world power during the two World Wars and throughout its subsequent Cold (and frequently hot) War struggles the U.S. Army's requirement for training and testing lands steadily increased (Doe et al., 1999). Reflecting America's cultural emphasis on growth and development at the expense of the environment, the Army paid relatively little regard to effective and proactive environmental stewardship, although the restricted access nature of training and testing lands had the side benefit of serving as island habitats for several endangered species.

It was not until the early 1960's that the Army, specifically the Corps of Engineers, began to take a deeper interest in environmental responsibility. According to Reuss (1983), the Secretary of the Army actively participated in the development and implementation of the Kennedy administration's 1962 initiative on water resource development and protection. This was one of the nation's first contemporary environmental initiatives. Later, the U.S. Army Corps of Engineers was instrumental in the implementation and enforcement of the River and Harbors Act of 1965. It created numerous regulations and guidelines between 1966 and 1970 designed to enhance environmental attentiveness during project planning. By 1970 the Corps of Engineers hired almost 300 environmental scientists and established the Institute for Water Resources, which made awareness of environmental quality one of its top priorities. Also, during this time the Corps of Engineers establishment of the Environmental Advisory Board that had as its chairman Roland Clement, ecologist and Vice president of the National Audubon Society (Reuss, 1983).

However, toward the end of the 1980's the Army, as well as other federal agencies, became increasingly and more publicly vulnerable to rule-based environmental laws related to restoration, compliance, and conservation. This created a public relations and environmental compliance challenge for the Army (Rubenson et al., 1994). The Army reacted by dramatically increasing its budgeting for environmental projects to address violations and in 1992, the Army spent over $2 billion dollars on environmental programs (Sullivan & Stone, 1992). The Army felt it was definitely better to obey the rules than to pay the fines. The inadequacy of this response was demonstrated in the early 1990's in the case of the Red Cockaded Woodpecker (RCW), which is found in significant numbers on the Fort Bragg Military Reservation in North Carolina. As a federally listed endangered species, the RCW required protection and effective management of its habitat. However, the Army failed to comprehend the urgency of the planning and conservation management requirements and was forced to shut down critical training areas to protect diminishing habitat. This had a negative impact on unit training and readiness (Rubenson et al., 1992).

The Army quickly realized that responsible environmental actions meant more than avoiding fines. It meant developing a vision and a plan that reflected the country's environmental values, that could be internalized by its members, and that enabled it to maintain readiness in an environmentally sensitive manner.

In the face of increasing subjugation to environmental laws and the increasing loss of training lands due to post-Cold War Department of Defense (DOD) downsizing, the Army reformulated and improved its environmental stewardship philosophy. In 1992, the Secretary of the Army and the Army Chief of Staff issued the *US Army Environmental Strategy into the 21st Century* (Sullivan and Stone, 1992). This innovative initiative outlined the Army's:

1. Vision – "The Army will be a national leader in environmental and natural resource stewardship for present and future generations as an integral part of all Army missions" (Sullivan and Stone, 1992, p. 1);
2. Goals – Compliance, Restoration, Prevention, and Conservation;
3. Objectives – Leadership driven incremental steps toward meeting goals;
4. Plan – Which includes the components of People, Resources, Communication, Management and Organization; and the
5. Foundation of shared values between the Army and the Nation it serves.

Further buttressing the Army's initiative was the 1994 Undersecretary for Defense (Environmental Security) mandate that the services will use a goal-driven ecosystem management approach to restoring and sustaining healthy ecosystems and their functions and values (DUSDES, 1994). This is very significant given the fact that the Army has the largest requirement for training lands and is the largest land manager in the DOD with over one hundred installations that sustains Army readiness (Shaw et al., 2000). Clearly, the notion of environmental responsibility had changed and the Army was determined to be the leader in environmental stewardship within the federal government.

Today, the depth of the Army's environmental stewardship ethic can be found in the following initiatives:

1. Full implementation of the ecosystem management oriented Integrated Training Area Management Program with its four functional areas of Land Condition Trend Analysis, Land Rehabilitation and Maintenance, Environmental Awareness, and Training Requirements Integration, at over 100 Army installations (Doe et al, 1999);

2. Establishment of a comprehensive leader and soldier environmental stewardship education program and publication of the Unit Leader's Handbook for Environmental Stewardship (TC 5-400, 1994);

3. Extensive reliance on scientific research on the part of activities such as the Army Environmental Center, the Strategic Environmental Research and Development Program (Ecosystem Management Program) (SERDP, 1995, 1998a, 1998b, 2000).

4. The US Army Construction and Engineering Laboratory - Successional Dynamics Modeling effort (McLendon et al., 1998);

5. Budgeted annual funding with over one billion dollars directed toward Environmental Programs (USAPAO, 1999).

Finally, the Army recognizes that environmental stewardship has become inseparable from international environmental security or the protection of regional natural resources for the sake of avoiding conflict. The Army's missions in

Somalia and Haiti have shown that without an environmental ethic, nations can find themselves in conflicts that threaten global security and American interests (King, 2000).

All of these accomplishments reflect a philosophy of responsible environmental stewardship of a vital component of military readiness – Army training lands, and of natural resources the nation has intrusted to its care. One can conclude from them that the U.S. Army has internalized a credible environmental ethic and is committed to ecological sustainment of military lands through its environmental stewardship strategy.

Impact Area Contamination

It is against this backdrop that I address impact area contamination. As population densities increase near installations, the environmental implications of using firing ranges and impact areas are becoming more apparent. These include health and safety risks due to unexploded ordnance (UXO) and environmental contamination from explosive constituents of fired munitions and UXO. Many environmental groups, communities, and state and federal agencies are pressing for "emissions" controls and cleanup of UXO. For example, the Commonwealth of Massachusetts and the Environmental Protection Agency (EPA) have restricted weapons firing due to groundwater contamination from explosives chemical contamination on the Massachusetts Military Reservation impact area (EPA, 2000a).

Impact area contamination is a complex problem. Much of what is known about munitions contamination fate and transport comes from laboratory studies of national defense cleanup sites (Larson et al., 1998a and 1998b; Myers et al, 1998; Pennington, 1988; Pennington et al., 1999a, 1999b and 1999c; Price et al., 1998). However, there is great variability in the way munitions fail and the way in which their contaminants move through the environment. Unlike the controlled environments described above, munitions contamination occurs in highly restricted and sometimes-inaccessible impact areas and accounting for all of the variables associated with contaminant release, fate and transport is nearly impossible.

This dissertation is about assessing and addressing the problem of munitions contamination in Army impact areas. It integrates several environmental disciplines into a problem solving approach that may provide the foundation for resource management and future research.

Overview and Purpose of Chapters

Each chapter represents a major problem-solving component and each succeeding chapter builds upon the findings of its predecessor. Table 1-1 shows the focus and objectives of each chapter.

Chapter 2 is a macro-level analysis of munitions contamination. It develops an ecological framework for environmental risk assessment of Army impact areas based on environmental processes that affect the mobilization, fate and transport of munitions contamination. From this framework a set of

Table 1-1

Overview of Dissertation Chapter Titles, Objectives and Topics. Horizontal flow arrows indicate contaminant fate and transport linkages.

Chapter	**1**	**2**	**3**	**4**	**5**
Title	Introduction Army Environmental Stewardship	Environmental Risk of Army Ranges and Impact Areas	Munitions Use in an Army Impact Area	Using Century to Assess the Effects of Munitions Use	Conclusion Integrated Data Analysis Using GIS
Objective	Army Environmental Stewardship and Impact Area Contamination	Derive and Evaluate Macro Level Ecological Metrics for Risk Assessment	Derive a Micro Level Ecologically Based Response Metric	Evaluate a Micro Level Ecologically Based Response Metric	Integrated GIS Approach For Impact Area Management
Topic	Army Environmental Stewardship	Risk Assessment Framework for FORSCOM Impact Areas	First Approximations for Munitions Disturbance	Computer Simulation of Soil Organic Matter Dynamics	Remote Sensing for Site Evaluation
		Explosive Contaminants	Retardation Factor	Munitions Use and Soil Organic Matter Stocks	
			Cation Exchange Capacity	Soil Organic Matter and Contaminant Retardation	Retardation Factor and Munitions Use in GIS
	Impact Area Contamination	Contaminant Fate and Transport			
			Crater Disturbance	Soil Organic Matter and Contaminant Biodegradation	
		Ecological Settings	Ecotype Discrimination	Munitions Use and Ecotypes	
	Management Challenges Impact Area Contamination	Strategic Vision for Impact Area Management	Management Implications	Management Implications	Training Readiness and Environmental Stewardship
	Overview and Purpose of Each Chapter				

ecological metrics are derived that are then used to evaluate a population of Army impact areas located in the continental United States. This macro-level assessment framework would remain the same for micro-level assessments such as for a specific portion of an installation's impact area.

Chapter 3 develops a micro-level ecologically base response metric. First approximations of munitions disturbance and contaminant loading are made and field data collected from Fort Greely, Alaska analyzed. An analysis of this data yielded a set of soil properties such as soil organic matter content that are related to an impact area's ability to attenuate contaminant fate and transport.

Chapter 4 focuses on evaluating soil organic matter dynamics using computer simulation. Four different ecological settings from Fort Greely were simulated to evaluate soil organic matter response to munitions use. Simulated soil organic matter rates-of-change resulting from munitions use provided insight into ecological and environmental processes affecting munitions contamination, and the ability to quantify contaminant attenuation.

Chapter 5 concludes the dissertation by demonstrating how a geographic information system can be used to integrate the problem-solving components described above for use in decision-making. This involves describing a method for analyzing remotely sensed data for efficient and effective site evaluations and the coupling of simulation output and transport modeling into a decision making tool.

As our ecological understanding increases, new environmental problems are identified and the complexity of current environmental problems becomes more apparent, but our ability to adapt our environmental management practices also increases. The Army will continue to maintain the trust of the nation they serve by being good stewards of the lands and resources Americans cherish. This dissertation provides a measure of knowledge to the Army as it accomplishes its missions.

CHAPTER 2

Environmental Risk of Army Ranges and Impact Areas:

An Ecological Framework for Assessment

Introduction

For nearly 100 years the United States has maintained a substantial modern military force with which it has fought five major wars, many smaller-scale conflicts and numerous military operations other than war. Military training and testing lands, including weapons firing ranges and munitions impact areas, have been and will remain a key element in the successful preparation for all of these operations. The Army's warfighting strategy continues to stress the need for live fire training as a cornerstone of readiness.

Since the end of the Cold War the U.S. has reduced its force and installation structure. Concurrently, the operational tempo (OPTEMPO) of our military forces has increased dramatically due to regional threats and events in less stable countries. These trends challenge military land managers in two ways. First, the high OPTEMPO of today's military forces combined with a decrease in available training space have increased the use and the potential for environmental impacts on the remaining training lands. Secondly, the technological advances in weapons systems have changed tactical doctrine. As weapons systems become more sophisticated in terms of range, precision of delivery of munitions and digital connectivity, tactics and operations become highly decentralized. Concomitantly there is an increase in the requirement for larger and more versatile training areas, ranges and impact areas (Doe et al, 1999). These circumstances have placed overwhelming demands on military ranges and impact areas with potentially negative implications for both the readiness of warfighting units and the environment.

Many researchers have described the effects of military maneuver on the environment. Their findings support the conclusion that these maneuver effects are persistent and significant (Milchunas et al., 2000; Demarais et al., 1999; Shaw and Diersing, 1990). From an ecological and land stewardship standpoint, the training stress placed on these ecosystems is negatively manifested in physical, chemical and biological strain in the environment. Natural resources can become polluted with contaminants associated with munitions. Areas subject to intense and prolonged disturbance by both inert and explosive munitions can negatively impact the ecosystem (Demarais et al., 1999).

The management balance between high demand and ecosystem sustainability on ranges and impact areas is complex. There has been little research on ecosystem response to munitions use within impact areas where the effects can be more dramatic and deleterious to both the environment and training readiness. Vegetative responses can lead to a noticeably barren landscape reducing gunnery training value for combat crews. Invariably, threatened or endangered species (TES) can be found residing within range and impact areas. Blast, heat, and noise effects can impact TES resulting in the cancellation or delay of training activities. Understanding an ecosystem's resistance and resilience is key to mitigating or avoiding negative environmental outcomes associated with range and impact area use (Doe et al., 1999).

Sustainable Range and Impact Area Management

An important component of sustainable use and management of ranges and impact areas involves the management of the unexploded ordnance and constituents (UXO(C)) associated with these areas. Brannon et al., (1999) defined UXO as "military munitions that have been prepared for action, fired, dropped, or buried, and remain undetonated, posing hazard to operations, personnel, or material." Constituents of UXO are the pyrotechnic, explosive and propellant fillers of a munition that remain potentially hazardous. Each military service is required by Department of Defense Directive to "establish and implement procedures to assess the environmental impacts of munitions use on DoD ranges" (DODD 1999). Additionally, the Office of the Deputy Chief of Staff for Operations and Plans has identified recent policy and regulatory efforts to manage UXO(C) as hazardous waste subject to the Resource Conservation and Recovery Act of 1976 (as amended through 1992), and Comprehensive Environmental Response, Compensation and Liability Act of 1980 (as amended through 1986). This regulatory trend translates into a critical need to characterize and predict the effects of munitions use (VanDervort, 1999).

There are obvious safety issues surrounding UXO on active, inactive, former and closed/transferred/or transferring (CTT) ranges (e.g., injuries and deaths from UXO detonations). There are also more subtle yet socially charged environmental contamination and pollution concerns associated with the constituents. Many environmental groups, communities, and state and federal agencies are pressing for "emissions" controls and cleanup of UXO(C). For example, the Commonwealth of Massachusetts and the Environmental Protection Agency (EPA) have restricted weapons firing due to groundwater contamination from explosives chemical contamination on the Massachusetts Military Reservation impact area (EPA, 2000a). Currently, the Army is inventorying all ranges to comply with the EPA's concerns of UXO(C) accountability across all of the Army's active/inactive and CTT ranges (EPA, 2000b).

Impact Area Resilience Assessment Framework

Doe, et al. (1999) developed an ecological framework for evaluating Army training and testing land resilience in the face of maneuver effects. The foundation of this framework was the concept of training land resiliency defined as "the inherent capability of the land to support intensive military training and testing activities while sustaining the existing ecological system." Applying this general definition more specifically to impact areas, a resilient ecosystem is one characterized by biotic and abiotic environmental processes that enhance an ecosystem's ability to attenuate UXO(C) contamination. Environmental processes that influence attenuation include dissolution, adsorption, advection, and biodegradation. These processes directly affect the fate and transport of contaminants within and through an ecosystem.

The functional and structural components of an ecosystem, such as the hydrologic cycle, soil forming processes, climatic regime, and species composition determine which environmental processes are dominant for a particular setting. Therefore, ecological settings can be a key element in determining local/region ecosystem resilience and can be useful in defining an impact area's ability to attenuate contamination.

Impact Area Ecoregional Descriptions

Eleven U.S. Army, Forces Command (FORSCOM) installations and their impact areas within the contiguous United States were considered in this analysis. They represent a cross-section of the country's ecological regions found in the United States. Bailey's *Ecoregions of the United States* (USFS, 1994) was used to identify climatic zones and sub-zones in which these impact areas are located as well as to describe the landscape elements such as soil taxa, vegetation, surface water characteristics, disturbance regimes, and land use. Figure 2-1 depicts the locations of these installations. Table 2-1 shows the eleven installation impact areas and their hierarchical ecoregional characterizations using Bailey's system (Bailey, 1998).

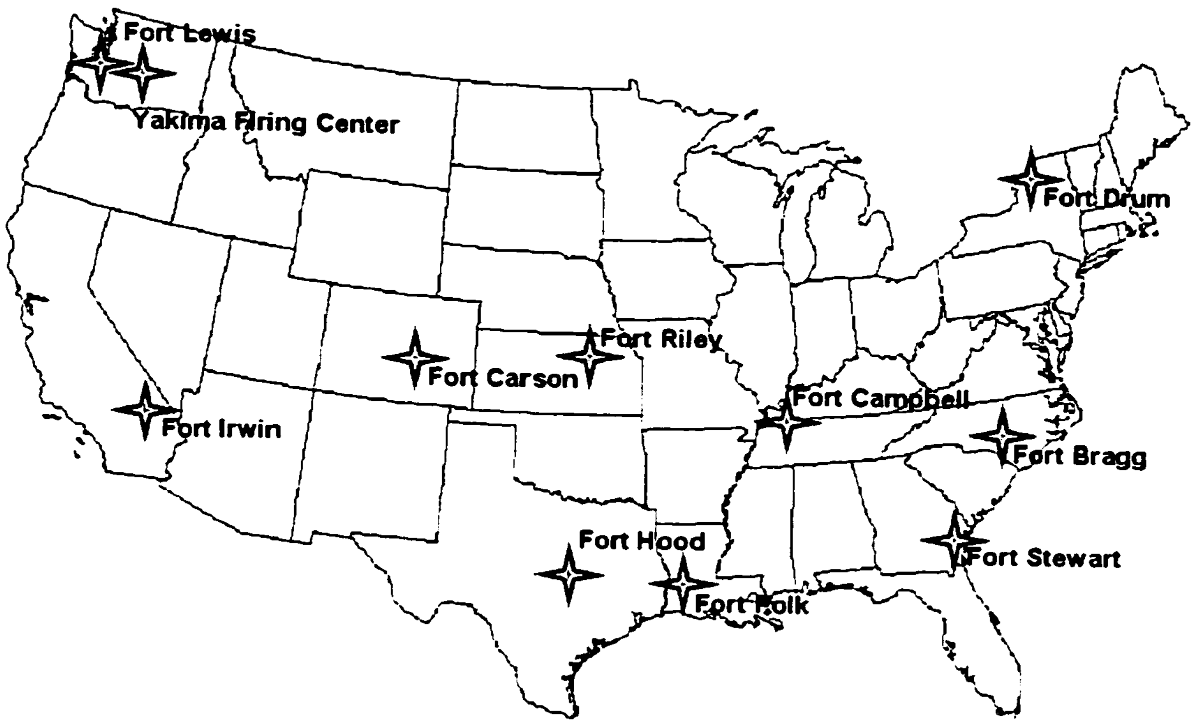


Figure 2-1. Locations of U.S. Army installations considered for impact area assessment.

Table 2-1

The Hierarchical Ecological Subregion Characterization of FORSCOM Impact Areas

	Bailey Ecoregion Classification					Soil Characteristics		Moisture Region	Effective Growing Season	Maneuver Resiliency Rating
INSTALLATION	**DOMAIN**	**DIVISION**	**PROVINCE**	**SECTION DESCRIPTION**	**SOIL ORDER(S) Present**	**CEC (cmol/kg)**	**SOC (mg/ha)**	**Type, (Index), Climate**	**(Days)**	**1 (low) to 5 (high)**
FT BRAGG, North Carolina	Humid Temperate	Subtropical	Southeastern Mixed Forest	Coastal Plains and Flatwoods, Lower	Ultisols Entisols	3.5 11.6	93 99	Humid (20) Moist Climate	240	3
FT CAMPBELL, Kentucky	Humid Temperate	Hot Continental	Eastern Broadleaf Forest	Interior Low Plateau, Highland Rim	Ultisols Alfisols	3.5 9	93 69	Humid (40) Moist Climate	205	3
FT CARSON, Colorado	Dry	Temperate Steppe	Great Plains Palouse Dry Steppe	Arkansas Tablelands	Entisols Aridisols Mollisols	11.6 15.2 18.7	99 35 131	Semiarid (-40) Dry Climate	150	2
FT DRUM, New York	Humid Temperate	Hot Continental	Eastern Broadleaf Forest	Erie and Ontario Lake Plain	Alfisols Inceptisols	9 14.6	69 163	Humid (60) Moist Climate	150	3
FT HOOD, Texas	Dry	Tropical Subtropical Steppe	Southwest Plateau and Plains Dry Steppe and Shrub	Edwards Plateau	Mollisols	18.7	131	Dry subhumid (-20) Dry Climate	225	2
FT IRWIN, California	Dry	Tropical Subtropical Desert	American Semi-desert and Desert	Mojave Desert	Aridisols Entisols	15.2 11.6	35 99	Arid (-60) Dry Climate	30	1
FT LEWIS, Washington	Humid Temperate	Marine	Pacific Lowland Mixed Forest	Willametta Valley and Puget Trough	Inceptisols	14.6	163	Humid (80) Moist Climate	160	4
FT POLK, Louisiana	Humid Temperate	Subtropical	Outer Coastal Plain Mixed Forest	Coastal Plains and Flatwoods, Western Gulf	Ultisols	3.5	93	Humid (20) Moist Climate	270	2
FT RILEY, Kansas	Humid Temperate	Prairie	Prairie Parkland	Flint Hills	Mollisols	18.7	131	Moist subhumid (0) Dry Climate	190	4
FT STEWART, Georgia	Humid Temperate	Subtropical	Outer Coastal Plain Mixed Forest	Atlantic Coastal Flatlands	Ultisols Spodosols	3.5 9.3	93 146	Humid (20) Moist Climate	220	2
YAKIMA FIRING CENTER, Washington	Dry	Temperate Desert	Intermountain Semi-desert	Columbian Basin	Aridisols Mollisols	15.2 18.7	35 131	Semiarid (-40) Dry Climate	60	1

Bailey Ecoregion Classification (Bailey, 1998); Soil Characteristics of soil orders and associated cation exchange capacity (CEC) and organic carbon (SOC) content (Brady and Weil, 1999); Moisture Region Index (Espenshade and Hudson, 1995); Effective Growing Season days (Diersing et al., 1990); and Maneuver Resiliency Ratings (Doe et al., 1999).

Contaminant Threat Analysis

This study focuses on three high explosives used in munitions: Trinitrotoluene (TNT), Royal Demolition Explosive (RDX), and High Melting Explosive (HMX). Yinon (1999) and EPA (2000b) describe the uses for these explosives. Artillery, rocket, mortar and grenade munitions use TNT and RDX as their high explosives. TNT has been the most widely used military explosive since WWI. RDX has been used since WWII, and also has been used in combination with TNT. HMX has been used in a variety of propellants and warheads (e.g., Dragon Anti-tank warheads and Light Anti-tank Weapons Systems). Also, HMX is present in RDX as a manufacturing impurity. Table 2-2 shows some typical munitions uses and their explosive compositions: TNT, RDX, and HMX (CEMML, 1999).

Table 2-2

A Selection of Standard Munitions and Their Explosives Compositions Consisting of Mixtures of Trinitrotoluene (TNT), Royal Demolition Explosive (RDX), and High Melting Explosive (HMX).

	Filler Material		
Munitions	TNT	RDX	HMX
20mm (Cartridge)		X	
30mm (Cartridge)			X
40mm (Grenade)		X	
60mm (Mortar)	X	X	
81mm (Mortar)	X	X	
105mm (Projectile)	X	X	
4.2" (Mortar)	X	X	
120mm (Mortar)		X	
155mm (Projectile)	X	X	
84mm (AT4)	X		X
66mm (LAW)	X		X
Fragmentation Grenade	X	X	
2.75" Rocket HE warhead	X	X	
C-4		X	
TOW Missile warhead	X		X
Hellfire Missile warhead			X
Dragon Missile warhead			X
Stinger Missile warhead	X		X
Volcano Mine		X	
M15 AT Mine	X	X	
M16A1 AP Mine	X		
M19 AT Mine	X	X	
Claymore Mine		X	

These explosive constituents also have some significant physical and chemical properties that determine their fate and transport through the environment. They are all organic chemicals that undergo volatilization, are soluble in water, and partition to soils.

The EPA has established Lifetime Health Advisories for TNT, RDX and HMX (EPA, 2000a). These advisories establish "the concentration of a chemical in drinking water that is not expected to cause any adverse non-carcinogenic effect over a lifetime of exposure" (EPA, 2000a; and NIOSH, 1994). Lifetime Health Advisories for TNT and RDX are 2ppb and 400ppb for HMX. The EPA has classified TNT and RDX as possible human carcinogens (EPA, 2000a). Yinon (1999) relates toxicity hazards associated with their production. Of note, he stated that there were 17,000 TNT poisonings resulting in 475 deaths at US munitions factories in the first 7½ months of WWI. Exposure routes consist of inhalation, absorption through the skin and/or eye, and ingestion. Little is known about the human toxicity of HMX (Yinon, 1999); however, animal studies indicate that HMX can cause toxic effects in the liver and central nervous system when ingested or absorbed through the skin.

Munitions that malfunction (UXO) and residual components from munitions that functioned improperly (UXO(C)) are major sources of potential contamination of groundwater in impact areas (EPA, 2000b). Additionally, the distribution of surface and subsurface residual contaminant concentrations from munitions (that either malfunctioned or functioned properly) strongly correlate with the targetry type and locations used in an impact area as well as munition type (Jenkins et al., 1998). They found high concentrations of HMX in the vicinity of anti-tank target arrays and correlated these high concentrations to large quantities of Light Anti-tank Weapon (LAW) rocket derbies and the high percentage of warheads that failed to detonate. They also found that the highest concentrations of explosive compounds are greatest in the top 15 cm of the soil matrix and that this concentration declined with increasing depth.

Finally, the type of weapons system will determine the spatial distribution of UXO. Brannon et al. (1999) reported that direct fire systems such as tank main gun and anti-tank rocket weapons systems will deposit high concentrations of explosive residue on the surface because warheads tend to shear upon impact resulting in less than complete detonation of explosive filler. Indirect fire systems, and in particular artillery munitions, have stronger casings and strike the ground at higher angles of attack. This results in a UXO distribution to greater depths and, depending on the integrity of the delivery system following impact, results in varying concentrations of explosive residue.

UXO loading rates into an impact area are a function of munitions expenditure rates and of munitions failure rates. Little information is available for estimates of exposed UXO constituents, but Brannon et al. (1999) suggest work is being done to statistically characterize soil concentrations around target arrays. A conservative figure for munitions failure rate is 10% (EPA, 2000b). A simple approximation for loading rates can be made using ammunition expenditure data and failure rate combined with known target locations. This approach does not provide information such as the amount of free product exposed to moisture or the vertical distribution of UXO in the subsurface. For the purposes of this macro analysis, UXO is assumed to be uniformly present in all of the impact areas under consideration. Lastly, UXO constituent releases occur in all three phases (solid, liquid, and gas), and can be considered a controlled continuous point source emission. The only phase considered in this analysis is the liquid phase release process, consisting of leachates derived from dissolution of free product on or below the surface, and from seepage from UXO (Brannon et al., 1999).

Fate and Transport Characteristics of TNT, RDX, and HMX

TNT, RDX, and HMX contaminants have different biotic and abiotic mobilization, immobilization, and transformation characteristics. Brannon et al. (1999) reported the dissolution fluxes for free solid to liquid phase. Their model considers dissolution flux critical for quantifying contaminant-loading rates. TNT has the highest rate at 4,164 $\mu g\ cm^{-2}\ hr^{-1}$; HMX has a rate of 454 $\mu g\ cm^{-2}\ hr^{-1}$, and RDX's has the lowest dissolution rate at 360 $\mu g\ cm^{-2}\ hr^{-1}$. Adsorption of TNT to soil has been documented and considered to be very important in immobilizing TNT and its transformation products (Comfort et al., 1995; Larson et al., 1998b; Myers et al., 1998; Pennington et al., 1999c; Weissmahr et al., 1998) and in particular to humic soils (Hundal et al., 1997). TNT adsorption has been positively correlated with cation exchange capacity (CEC) (Brannon et al., 1999; Pennington, 1988). TNT can undergo both aerobic and anaerobic degradation (Brannon et al., 1999; Larson et al., 1998a; Pennington et al., 1999a) provided there are sufficient carbon and energy sources (Pennington et al., 1999b). RDX has been shown to sorb at lower rates than TNT (Price et al., 1998; Singh et al., 1998) and also can be positively correlated with soil CEC characteristics (Brannon et al., 1999). While HMX adsorption occurs, little is known about the solute-sorbent process to enable the prediction of adsorption coefficients for HMX (Brannon et al., 1999). RDX and HMX undergo biodegradation only under anaerobic conditions (Comfort et al., 1995 as reported by Larson et al., 1998a; Price et al., 1998). Vegetation also can act as a sink for explosive contaminants by root uptake (Larson et al., 1998a). All of the explosives, as with any solute, can be transported by groundwater advection. These UXO fate and transport characterizations serve as the conceptual foundation for the development of a framework for the ecological assessment of impact area resilience.

Development of a Framework for Ecological Resiliency Assessment – Environmental Processes and Ecological Settings

Fate and transport processes are continuously at work within the environment. Brannon et al. (1999) developed a conceptual model for fate and transport of UXO that provides a basis for a qualitative evaluation of the key processes at work in the environment. Their model outlined representations for soil, sediment, and water environments, described source term considerations, and developed descriptor formulations of key processes resulting in explosive contaminant mobilization, retardation, and transformation effects. With modifications, these key processes are *dissolution,* the initiating release mechanism; *adsorption* to soils, considered to be an important retardation mechanism; and biotic transformation, or for the purposes of this paper *biological action*, consisting of metabolism by microorganisms and uptake by plants. Biological action is regarded as an important transformation mechanism.

Reformulating this conceptual model into an ecological framework for assessment involves relating process and effect to relevant ecosystem components and their governing ecological setting. For example, dissolution is the process by which TNT, RDX and HMX are dissolved by a solvent from free product to solutes. In this case, the solvent is water that is provided via the hydrologic cycle. The hydrologic cycle is an ecological component that determines the availability of water, and its relative importance is governed by the ecological setting of the region in which UXO is located.

Adsorption is the process by which solutes move to and bind with a sorbent. This processes is reversible and is dependent on the partitioning affinity of the solute for either the solute or sorbent (LaGrega et al., 1994). For this macro analysis, the process is the movement or partitioning of dissolved TNT, RDX, and HMX to soil colloidal surfaces. Generally, soil colloidal surfaces, composed of clays and humic matter, are negatively charged. In the subsurface, adsorption is primarily a process of positively charged organic chemicals accumulating at these colloidal soil surfaces of which naturally occurring humic matter in soil plays a significant role (LaGrega et al., 1994). Therefore, the notable parameter for adsorption is colloidal content of soil as determined by the ecological component of soil forming processes. Colloid content can be measured via a soil's CEC, which in turn is used to define a partitioning coefficient for contaminant to soil adsorption. In terms of the influence of ecological setting on the adsorption process, one can evaluate the soil order present and its average CEC to obtain an idea of the relative retardation potential of the region in which UXO is found.

Biological action consists of the mechanisms of biodegradation and bio-uptake of contaminants. Biodegradation involves the oxidation and reduction of organic contaminants and bio-uptake involves plant root uptake by vegetation. Both depend on the ecological components of soil, the hydrologic process, and temperature. Microorganisms responsible for the biodegradation process obtain energy and carbon from the soil as well as the contaminants they metabolize. Vegetation requires soil for structural support, for a source of oxygen for root respiration, and for a source of macro and micro-nutrients. Soil microorganisms and plants both require water and each require a temperature regime conducive for growth – a function of climate. Soil quality has been described by soil organic matter (SOM) content since SOM greatly influences several biological, physical and chemical characteristics of soil such as:

1. Nutrient and energy source for soil biota
2. Improves soil structure by strengthening soil aggregates
3. Increases water retention and available water capacity
4. Promotes infiltration and reduces erosion
5. Increases cation exchange capacity
6. Chelates metals
7. Influences the fate of pesticides (NRC, 2000)

Soil organic carbon (SOC) content is used regularly as a measure of SOM. Climate in terms of effective growing season (EGS) is a good indicator of conditions favorable for microbial and plant activity. SOC and EGS can provide a relative measure of the transformation potential of the region in which UXO is found.

Ecological Settings as Resiliency Metrics (Metric Formulation)

Resiliency metrics provide an effective measure of the influence of ecological settings on fate and transport processes. Table 2-3 summarizes the relationships between fate and transport process and effect, ecosystem components, their governing ecological settings and metrics.

Table 2-3

Relationships Between Fate and Transport Process and Effect, Ecosystem Components, Their Governing Ecological Settings and Metrics.

Fate and Transport Process	Fate and Transport Effect	Ecosystem Component	Ecological Setting	Resiliency Metric
Dissolution	Mobilize	Hydrologic Cycle Atmosphere and Near Subsurface	Moisture Conditions	*Thornwaite Moisture Regions*
Adsorption	Retard	Soil Processes Colloid Fraction Clay & Humus	Soil Conditions (Cation Exchange Capacity)	Average CEC for each Soil Order
Biological Action	Transform	Hydrologic Cycle and Climate Near Subsurface	Growing Conditions (Temperature and Precipitation)	Effective Growing Season
Biological Action	Transform	Soil Processes Carbon and Energy Source	Soil Conditions (Organic Matter)	Average Soil Organic Carbon for each Soil Order

Note: Since microbial populations require a multifaceted set of ecological conditions in order to perform their transformation role, both Effective Growing Season and Average Soil Organic Carbon resiliency metrics are used to describe Biological Action.

The first resiliency metric used in this study is that of *Moisture Region*. The amount of atmospheric and near subsurface available moisture is a good indicator of the dissolution potential. The less moisture, the lower the potential for dissolution by virtue of less solvent and decreased contact time between solvent and free product. This condition would be favorable for a resilient impact area ecosystem because it limits release. The Thornthwait moisture region classification (Espenshade and Hudson, 1995) provides a moisture index value for each region of the United States (Table 2-1).

Effective Growing Season (EGS) serves as a metric that indicates biological action potential. An impact area that has a longer effective growing season has a higher potential for biodegradation and biouptake of contaminant. Based on United States Army Construction Engineering Research Laboratory (USACERL) method (Diersing et al., 1990), climatic diagrams were constructed for each impact area using 30-year NOAA data from the nearest reporting station. The climatic diagram indicated the number of days above 10°C and the number of days, if any, of moisture deficit. The difference of these two values, Number of Days above 10°C – Number of Days with Moisture deficit = Effective Growing Season, provided the EGS for each impact area.

Regional *Soil Conditions* provides two measures of resiliency. The first measure is SOM content with respect to soil order. SOM can be estimated by the average soil SOC content (Brady and Weil, 1999). Impact areas with higher SOM conditions have a greater potential for contaminant transformation through biological action. The second measure is soil order average CEC. Impact areas with higher CEC conditions have a higher potential for contaminant to soil adsorption. Brady and Weil (1999) provide average estimates of SOC and CEC values for soil orders. Each of the impact areas is evaluated against these values. In cases where an impact area has two or more soil orders associated with it, the values are averaged.

With metric values for an impact area established, the group of impact areas were sorted and assigned their ranked score between zero to ten. The higher the number the better the resiliency score. Rank scores are summed for total score and the impact area with the highest score is the area with the highest relative resilience.

Resiliency Rankings

Figure 2-2 shows the total scores of the impact areas in this macro analysis. Fort Hood, Fort Riley, Fort Carson, and Yakima Firing Center impact areas ranked best for relative impact area resilience. Fort Irwin, Fort Bragg, Fort Polk, and Fort Stewart tended to have moderate levels of relative resilience, while Fort Lewis, Fort Drum and Fort Campbell ranked lowest in relative resilience.

Although Fort Irwin scores best in its dissolution attenuation, it lacks significant biological action potential relative to other installations due to a lack of moisture. EGS assessment shows that Fort Polk has the best climatic driven biological action potential. However, when evaluated for its soil properties Fort Polk ranks lowest in terms of adsorption potential. Overall, installations that ranked best had moderate to high individual rankings for all three metrics. Those that had lower combined potentials were deficient in one or more metrics.

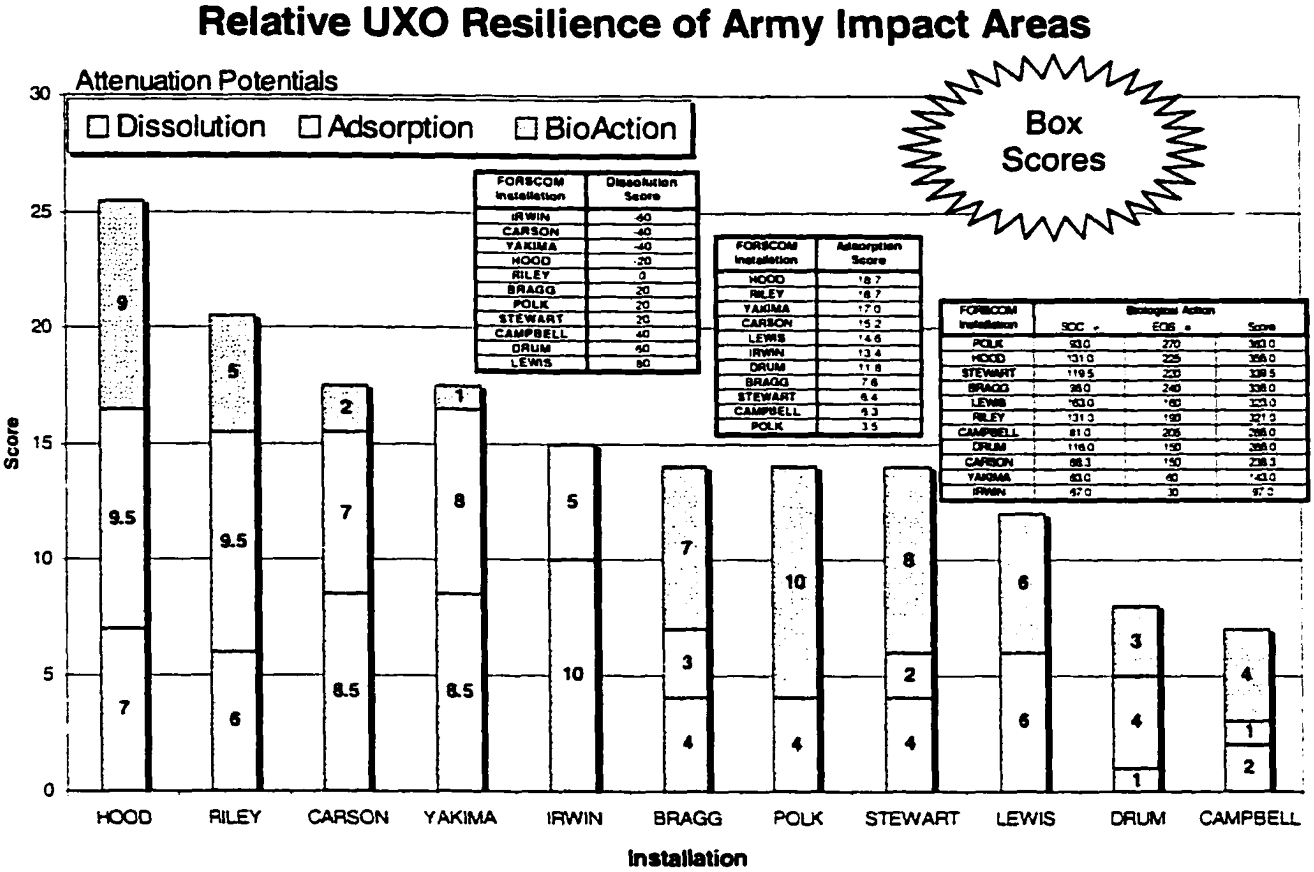


Figure 2-2. UXO Resiliency Ranking. Boxes show metric scores. Each Box Score is sorted in descending order from highest to lowest attenuation potential. Installations received individual relative rankings (10 is highest and zero is lowest) based on their box score order. Bar graph indicates overall relative ranking with individual relative rankings shown within each bar. Highest score (e.g., Fort Hood = 25.5) indicates highest relative resilience.

Analysis

Coarse Resolution Analysis

Generally, high resilience impact areas achieve their relative high score because they occur in drier climates, which limit dissolution. Also, they have higher adsorption potentials and are generally classified as tropical/subtropical steppe, temperate steppe or temperate desert divisions within dry domains. Low resilience impact areas are ones that have a higher dissolution potential due to higher moisture conditions, a lower adsorption and biological action potential due to soil conditions. They are generally classified as hot continental or marine divisions within humid temperate domains. However, these comparisons are based on the uniform presence of UXO across all of the assessed impact areas, and are based on generalized environmental processes that affect fate and transport. An assessment that accounted for usage and/or concentration differences will yield different results. For example, an impact area characterized by low dissolution rates and low EGS potential that also has high usage rates might, as a result, have high contaminant concentrations that negate any relative resilience advantage due to the toxic impacts on biological action (King, 2000).

When compared to maneuver resilience assessment made by Doe et al. (1999) we find a negative correlation between impact area resilience and maneuver area resilience (Figure 2-3). This can be explained primarily in terms of moisture region and EGS characteristics, because maneuver resiliency is based largely on vegetative regeneration. The rapid regeneration of vegetation on affected maneuver areas is moisture and temperature dependent. The more moisture the greater the vegetative growth potential. However, as described earlier, high moisture conditions increase the dissolution potential resulting in more contaminant solute entering the system. The implications for training area and impact area land management are complex. Within impact areas, land managers may have to manage for soil condition and munitions load distribution rather than vegetative response.

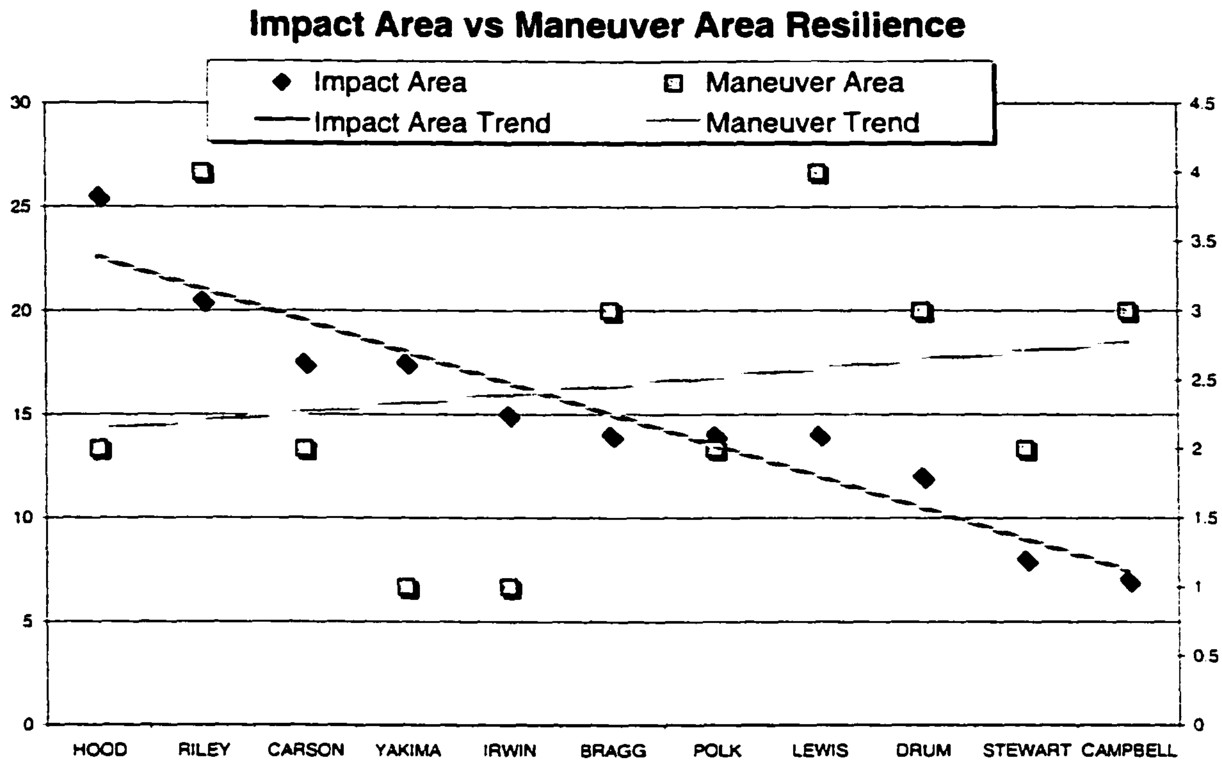


Figure 2-3. Comparison of Impact Area Resilience vs Maneuver Area Resilience.

Fine Resolution Analysis

This analysis focused on macro level metrics to provide an assessment of relative resilience. For an assessment that provides a finer resolution of impact area attenuation potential and resilience one must consider a more comprehensive set of fate and transport processes as well as the local variations in ecological setting. Fate processes such as filtration, hydrolysis, dissolution, volatilization and ionization operate at rates specific to local conditions. For example, a location's water chemical characteristics and temperature regime will greatly influence dissolution rates. Rain shadow, slope and aspect, site history, composition and distribution of specific soil types, are just a few of the innumerable local ecological settings that influence local resilience. Transport process such as advection, dispersion and diffusion are all dependent on local subsurface geologic conditions. The extent of the vadose zone, depth to groundwater, hydraulic conductivity heterogeneity, and other aquifer/aquitard characteristics are critical for accurate characterization of contaminant plume migration and attenuation. Additionally, one or more fate and transport processes and ecological settings will certainly prove to be an influential variable requiring a more sophisticated resilience calculus. As the level of assessment moves to finer resolutions, ecological setting and environmental process complexity increases dramatically, but the assessment framework remains the same. One must relate fate and transport processes to their relevant ecological components, relate these components to their ecological setting, then use ecological setting based resiliency metrics to describe resilience.

Strategic Insight

An understanding of the ecological conditions for a particular impact area helps Army range operations personnel and land managers balance training and land management strategies. High moisture climates which result in high dissolution rates near groundwater recharge areas with high advection capability might require a management scheme that focuses on locating targetry in areas that can be isolated from potential contaminant leaching. Isolation might be achieved by taking advantage of geologic structures that segregate high and low recharge areas or by selecting an area based on favorable local or even microclimatic conditions such as rain shadow areas. Target areas over soils that have a high attenuating capacity are better than areas that have lower capacities. Soil management techniques that reduce erosion and sustain or even build on soil organic matter content thereby improving adsorption and bio-action rates would be effective in enhancing resilience and are desirable management schemes. This might entail encouraging the growth of vegetation that can serve both as a slope-stabilizing agent and as a prolific organic matter source. For low moisture regimes, where the dissolution rates are nearly insignificant, management requirements may focus on the identification and tracking of UXO. Soil conservation practices would be desirable but not as aggressively pursued as in a high moisture region. Also, management may focus on encouraging growth of vegetation that maintains soil moisture conditions conducive for microbial action and which may serve in a phyto-remediation role.

Other improvements for range sustainability include enhancing propulsion, ballistic and detonation reliability of munitions. These can have both environmentally beneficial effects as well as improving lethality of weapon systems. A good example is the development and use of green ammunition (i.e. non-polluting), that greatly reduces the amount of lead contamination on small arms ranges. The civilian community has made this adjustment in its regulation of ammunition use by hunters who can no longer use lead shot when hunting waterfowl.

Using munitions tagging techniques that enable remote detection of fired munitions that function incorrectly, would not only improve battle damage assessment (i.e., determining the combat effectiveness of a friendly weapon system against enemy weapons systems - a critical warfighting task), but also enable land managers to identify UXO locations and densities for either subsequent removal or for tracking contaminant load rates.

Less sophisticated weapons systems such as mortars and the grenade machine gun still rely on "iron-sight" technology for their employment. This means for example, that UXO tracking on a grenade launcher range and impact area will still be challenging. However, the current trend toward digitization of the battlefield comes with an added benefit in terms of UXO tracking. More sophisticated systems are capable of identifying their firing position and the point of impact to within a few meters through the use of GPS enhanced digital targeting systems. Additionally, these systems require some form of synthetic target creation to interface with the crew employing the system when used in a training environment. For example, the AH-64D Longbow Apache's targeting and fire control radar system will not recognize a plywood silhouette as a threat vehicle. A Longbow ground station with a desktop size computer system that acts as a radar equipped attack helicopter can provide a synthetically derived targeting picture that serves as the radar signature of a threat vehicle. When this signature is transposed over the plywood silhouette, the aircrew now has a viable and more realistic target engagement scenario. This technique can be used to both the trainer's and the land manager's advantage. No longer are missile or artillery ranges restricted to a few over-used targets. Instead, targetry can be synthetically manipulated to provide more realistic engagement scenarios as well as to manage munitions use within a particular area. When these technological advances in targeting are combined with a sound knowledge of the environmental processes that effect range contamination, Army trainers and land managers can realize a more enlightened management approach for long-term range sustainability and military readiness.

CHAPTER 3

Munitions Use in an Army Impact Area

Introduction

Munitions use is a significant disturbance gradient in Army impact areas. Demarais et al. (1999) described a wide array of spatial and temporal disturbance regimes and agents of disturbance associated with military training. They summarized the limited body of knowledge related to live-fire training and its physical, chemical and biological effects on the environment. However, little is known about impact area ecosystem response to munitions disturbance. High explosive munitions explode on or near the soil surface and therefore have the potential for creating a crater and damaging vegetation. In addition to the inherent kinetic and blast destructive effects of munitions, there is a contaminant effect associated with munitions that fail to function properly. These dud and low order detonation munitions, which are also called unexploded ordnance (UXO), have the potential for environmental contamination by leaching of their explosive fillers. Soil properties, in particular cation exchange capacity (CEC) and soil organic matter (SOM), have the ability to influence the fate and transport of these contaminants through an ecosystem. Soil formation processes also are dynamically linked to the vegetation (i.e., ecotype) with which they are associated. If one can characterize the soils related with impact areas and ascribe measures of their attenuation potential, then the implications for adaptive ecosystem management in the face of evolving contaminant threats may be significant. Munitions use in the Washington Impact area at Fort Greely, Alaska provides an opportunity to examine the effects of munitions use in an ecosystem. The objectives of this study are to determine the:

1. Approximate area disturbed by munitions use per year and the maximum theoretical contaminant loading in this area.
2. Soil properties that best predict the soil cation exchange capacity.
3. Soil properties that best discriminate vegetation cover types.
4. Soil properties that best describe crater disturbance.

An analysis of the spatial extent of munitions disturbance, associated contaminant loading and soil component influence on movement of contaminants through the soil addresses objective 1 and provides the foundation for addressing objective 2. This analysis is based on range and impact area requirements, munitions use data, and munitions characteristics and effects. Objectives 2, 3 and 4 are addressed through a soil property investigation involving the collection of soil samples from Fort Greely and subsequent mathematical modeling and statistical analysis of soil laboratory results. Prior to this analysis a description of the Fort Greely, Alaska study area and discussion of how impact areas are designed is provided for background information.

Background

Study and Control Area Descriptions

Fort Greely Military Installation is located in central Alaska approximately 160 km southeast of Fairbanks, near the town of Delta Junction. The installation covers approximately 267,900 ha and consists of the cantonment area, West Training Area, and East Training Area. Fort Greely is a US Army training and testing installation with approximately 34,400 ha of high hazard impact areas. The Washington impact area is the subject of this study and is used for a variety of weapons testing and training involving mortar and artillery firing exercises, tank gunnery, and aerial bombing. Washington impact area is set in a floodplain and encompasses approximately 800 ha within the Delta River floodplain (Walsh et al., 2001). At the south boundary of the impact area is a portion of the Washington Range (i.e., an area from which weapons systems are fired into the impact area). This area extends approximately 2.5 kms to the south, is very similar to the impact area and is a control area for the study. It is called the Washington Range control area (Figure 3-1).

The second control area, Jarvis Creek, is approximately 15 km to the east-north-east of the Washington impact area and is used for maneuver training. It is named for Jarvis Creek that runs along the training area's western boundary. Jarvis Creek is similar to Delta River in terms of direction of water flow, elevation, geomorphic units and ecotypes (Jorgenson et al., 2001).

The climate of Fort Greely as described by Bailey (1998) is Boreal Subarctic, characterized by a great seasonal range in temperatures. While its climate is moist all year, Fort Greely has relatively small annual amounts of precipitation that is concentrated in warm months. Winter is the dominant season with short cool summers. Weather data covering 63 years from Big Delta FAA/AMOS AP, AK (2001) indicates that January is the coldest month with an average maximum temperature of -16.1C and average minimum temperature of

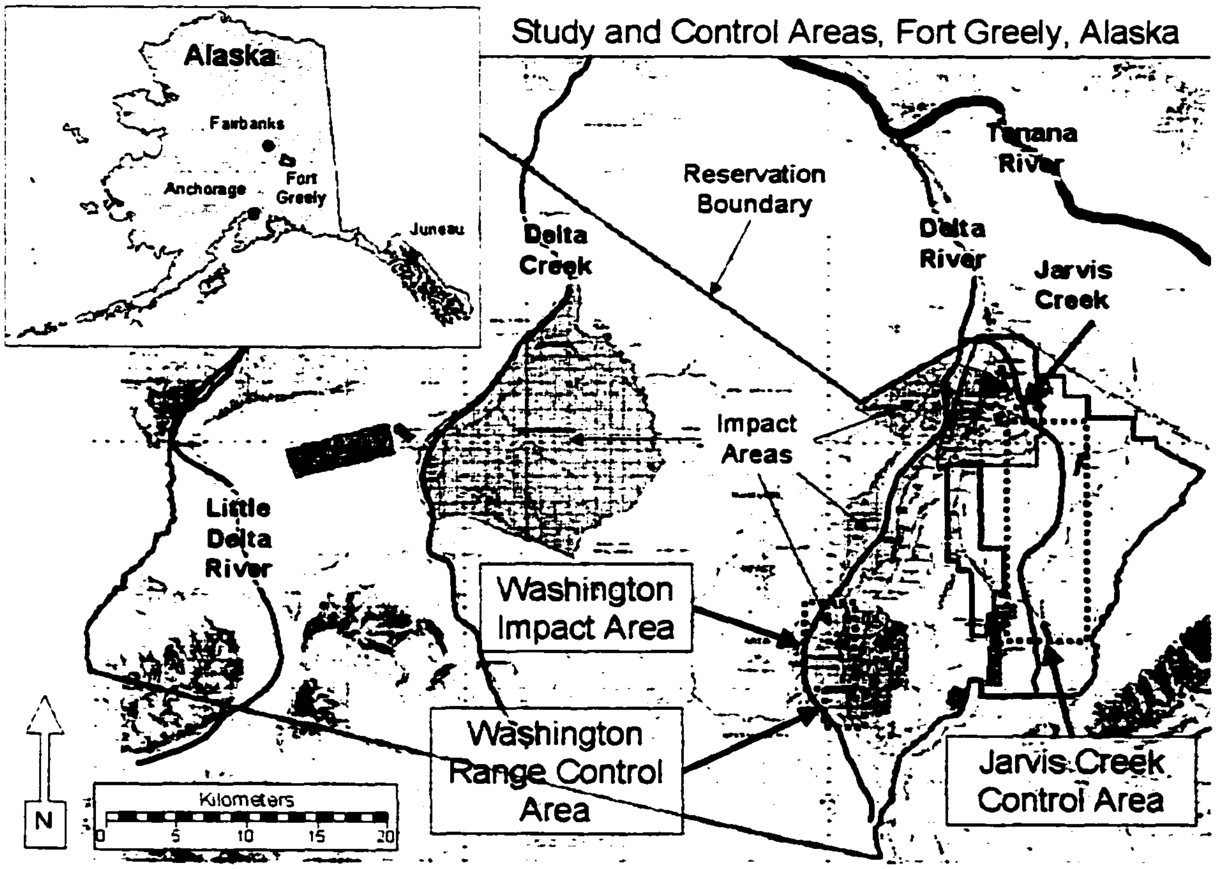


Figure 3-1. Map of the Fort Greely Reservation depicting the Washington impact area and the Jarvis Creek and Washington Range control areas outlined with dashed lines. Also, major watercourses are shown. Two of these watercourses, the Delta Creek and Delta River, flow through impact areas. Inset shows the State of Alaska with the exception of the western most Aleutian Islands.

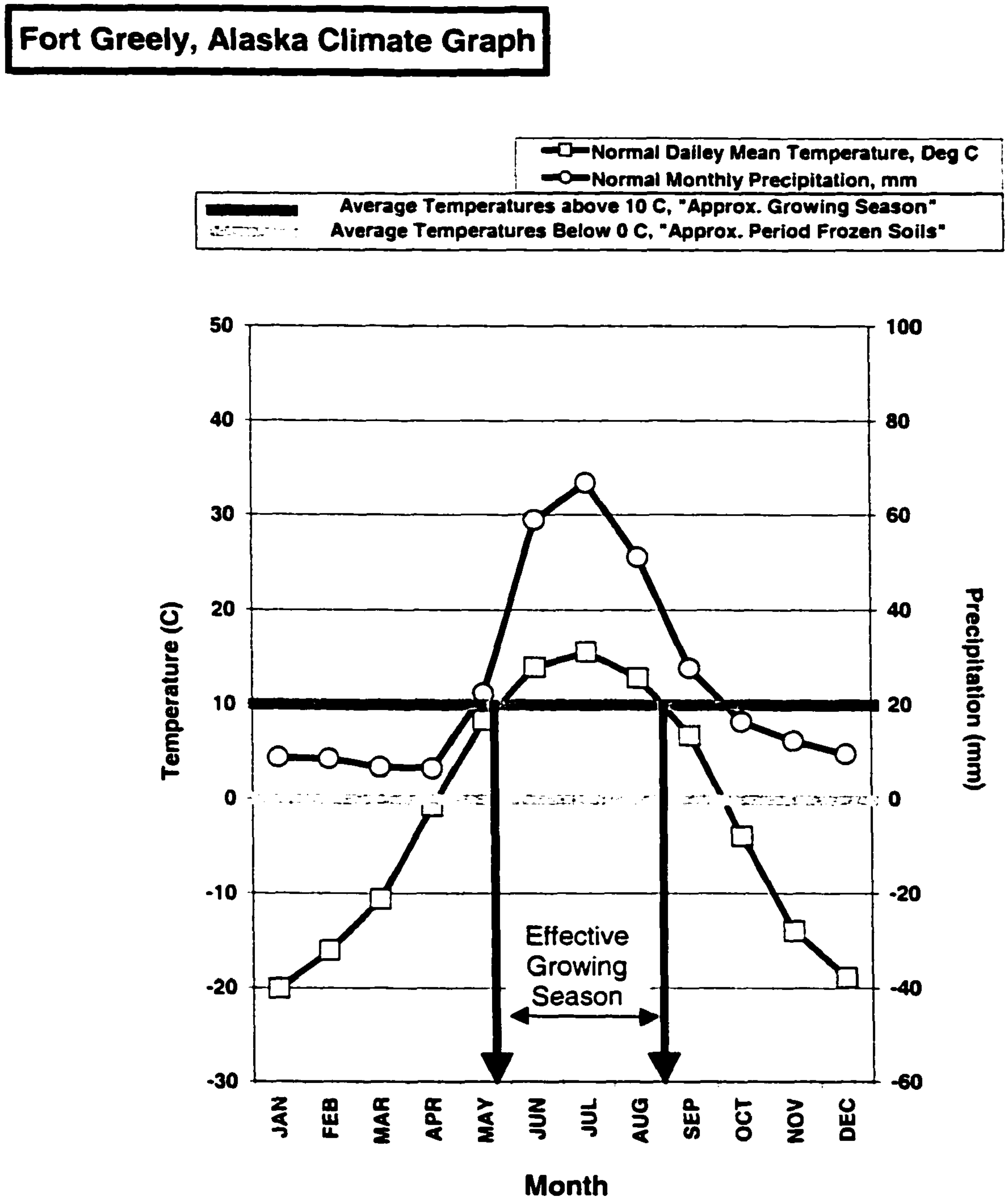


Figure 3-2. Climate graph for Fort Greely, Alaska depicting effective growing season (Diersing et al., 1990). Climate data obtained from Big Delta FAA/AMOS AP, AK (2001).

-24.1 °C. July is the warmest month with an average maximum temperature of 20.8 °C and average minimum temperature 10.3 °C. Total average annual precipitation is 29.5 cm with July having the highest monthly average of 6.7 cm. Total average annual snowfall amounts to 111.3 cm with October having highest monthly average snowfall of 23.4 cm. Average snow depth during winter is 10.2 cm with the month of February having the highest monthly average depth of 25.4 cm. Using the USACERL methodology (Diersing et al., 1990), Fort Greely's effective growing season is 25 May – 31 August (Figure 3-2).

The region's physiography is described as the Tanana-Kuskokwim Lowlands (CEMML, 1999). It consists of a broad depression north of the Alaska Range on top of coalescing outwash fans that spread northward. The area is generally underlain by permafrost, however areas over deep gravels and/or on south facing slopes are relatively free of permafrost. Alluvium consists of porous gravel sands. The dominant geomorphic feature associated with the impact area and control areas is glaciofluvial sediment deposits from the past Delta Glaciation and from modern glaciers (CEMML, 1999). Flooding events are infrequent, as these areas are located primarily on inactive glacial-fluvial outwash deposits or in inactive floodplains of meandering and headwater streams. Soils are Inceptisols, underdeveloped Entisols and Histosols. Both stream systems physiographies are classified as riverine and flat (Jorgenson et al., 2001).

The hydrology of both areas is similar and characterized by braided glacial streams over glacial outwash fans. Both the Delta River and Jarvis Creek flow generally northward from Alaska Range to Tanana River. Delta River, which runs through Washington Impact Area and Fort Greely, drains 4,305 km^2 and is 130 km long. Its primary source is glacial melt water from the Alaska Range and is entrenched up to 60 m into an alluvial fan. The Jarvis Creek, which runs through control area and Fort Greely, drains 96 square kilometers, is 65 km long and is entrenched into the same alluvial fan. It is an influent stream that is dry during the winter, and has high water during spring melt and summer rains (CEMML, 1999). Delta River and Jarvis Creek are perched above a single aquifer with varying local confinement. Both streams lose some flow to the aquifer in winter. The groundwater table is less than 10 m below Delta River and flows to the northeast (CEMML, 1999). Finally, the natural disturbance component for both areas consist primarily of fluvial and fire processes and wind erosion (Jorgenson et al., 2001).

Ecotype Descriptions

Jorgenson et al. (2001) is the primary source for ecological description of Fort Greely. They utilize a hierarchical classification scheme to present three levels of ecosystem organization and descriptions for the Fort Greely installation, which are:

1. *Ecodistrict* – (1:500,000 scale) Middle Tanana Floodplain Common Regional Ecosystem with the Delta River Floodplain, Jarvis Creek Floodplain sub districts.

2. *Ecosection* – (1:100,000 scale) Glacial Fluvial Outwash - Active-riverbed Deposit, Inactive-riverbed Deposit, Abandoned Riverbed, and Inactive Cover Deposit.

3. *Ecotype* – (1:25,000 – 50,000 scale) areas within Fort Greely with homogeneous topography, terrain, soil, surface form, hydrology and vegetation.

Their ecotype descriptions are based primarily on physiography and vegetation structures with the vegetation type or successional stage the differentiating characteristics. While this is not the common definition of ecotype (Redente, personal communication), they argued that this approach is effective at differentiating soil characteristics and vegetation composition and that the integration of these characteristics is useful in discriminating ecotypes that "may have different sensitivities to disturbance" (Jorgenson et al., 2001).

The physiography for both areas described above are classified as riverine. There are five riverine ecotypes associated with the study and control areas. These are differentiated by their vegetative cover and consist of scrub, broadleaf forest, mixed forest and needleleaf forest ecotypes and are described below.

The *scrub ecotype* is what Jorgenson et al. (2001) described as Riverine Dwarf, Low, and Tall Scrub. Vegetation consists of a range of early successional scrub species that are highly variable and frequently includes: *Dryas drummondii*, *Populus balsamifera* saplings, *Shepherdia canadensis*, *Fragaria virginiana*, *Oxytopis campestris*, *Elaeagnus commutata*, *Potentilla multifida*, *P. fruticosa*, *Salix alaxensis*, *Alnus tenuifolia*, *Salix planifolia*, *Betula nana*, and *Calamagrostis canadensis*. Soil profiles range from stratified to massive gravel with occasional thin and sandy layers that lack organics to interbedded silts and sands with thin surface organic layers. Soils are generally well drained (i.e., moist) to excessively drained (i.e., dry) and exhibit activities that range from slightly alkaline to slightly acidic.

The *broadleaf forest ecotype* is what Jorgenson et al. (2001) described as Riverine Broadleaf Forest. Vegetation consists of a range of early to mid successional broadleaf species. Open to closed canopies are composed of *Populus balsamifera* occasionally mixed with *P. tremuloides*, and *Picea glauca*. Understories consists of *S. canadensis, P. fruticosa, D. drummondii, F. virginiana, Ceratodon purpureus, Astragalus* spp., *Geocaulon lividum* and *Linnaea borealis*. Soil profiles range from interbedded gravel, sand and silt, lacking in organics to interbedded silts and sands with thin surface organic layers. Soils are generally well drained (i.e., moist) to excessively drained (i.e., dry) and exhibit activities that range from neutral to slightly acidic.

The *mixed forest ecotype* is what Jorgenson et al. (2001) described as Riverine Moist Mixed Forest. Vegetation consists of a range of intermediate successional broadleaf and needleleaf species. Closed canopies are composed of *P. balsamifera, P. glauca*, and/or *Betula papyrifera*. Understories consist of *S. canadensis, D. drummondii, F. virginiana, C. purpureus, A. tenuifolia, Rosa acicularis, G. lividum, L. borealis* and *Hylocomium splendens*. Mixed ecotype soils are similar to those of the broadleaf ecotype described above.

The *needleleaf forest ecotype* is what Jorgenson et al. (2001) described as Riverine Gravelly Needleleaf Forest and Moist Needleleaf Forest. Vegetation consists of a range of late successional needleleaf species. Open to closed canopies is composed of *P. glauca*. Understories consist of *S. canadensis, Solidago canadensis, G. lividum* and *H. splendens, R. acicularis, Ledum groenlandicum* and *C. canadensis*. Soil profiles exhibit interbedded gravel, sand

and silt layers, with thin surface organics. Soils are generally well drained (i.e., moist) to excessively drained (i.e., dry) and exhibit activities that are slightly acidic.

Impact Area Design

Impact areas are the ground and airspace within a training complex used to contain fired, dropped or launched munitions and any resulting fragments, debris, and components (CEMML, 1999). The Army's Readiness Program requires that impact areas provide effective individual, crew, and unit live fire and maneuver proficiency training using the Army's latest generation weapons systems (AR 210-21, 1997). Therefore, impact areas reflect a mission-oriented design that is continually being updated to accommodate technological and doctrinal changes.

Impact area lands are more effectively utilized by grouping firing ranges so that safety danger zones (i.e., the three-dimensional space along a line from the gun to the target to include areas around the gun and target) associated with individual weapons systems overlap. This not only reduces the area required for live fire training, but also minimizes the area contaminated by UXO. Additionally, impact areas are segregated from surrounding maneuver areas and from public and private lands to avoid unintentional contact with UXO. They are intended for indefinite use (AR 210-21, 1997) because of the challenges and uncertainties associated with clearing UXO. As such, they represent a potential source of environmental contamination either from UXO residues or from sediment pollution caused by normal cratering effects. Current impact area design and management of older impact areas, incorporates extensive environmental planning that includes pollution prevention, and natural and cultural resource management considerations (TC 25-1, 1991).

Combat readiness is a measure of a unit's ability to accomplish its assigned wartime mission. Many of the readiness measures relate to soldiers' and combat crews' employment of their individual and crew served weapon systems. Therefore, Army range objectives are tailored to provide ranges and associated impact areas to ensure combat readiness of the tactical units assigned to the installation (Table 3-1). Ranges are generally designed for direct or indirect fire weapon systems or for a combination of system types. Based on these range requirements, one can determine an approximate target and target array area requirements within an impact area for a given set of ranges. Direct fire weapon systems such as tanks and anti-tank systems are those that fire to a point target such as an enemy tank or fighting position. They require a series of single targets each of which occupy a relatively small area of approximately a quarter hectare. Indirect fire weapons systems are those employed against area targets such as a group of enemy vehicles or soldiers. They require groupings of targets or target arrays that occupy a somewhat larger area on the order of one hectare. Typically, division sized range facilities and impact areas require approximately one or two thousand targets and target arrays occupying many hundreds of hectares within impact areas.

Table 3-1

Notional Range Requirements for US Army Installations (TC 25-8). Target and target array calculations are based on ranges descriptions in TC 25-8. Highlighted ranges use high explosive munitions.

Notional Range Requirements, Modified from Table 3-8, TC 25-8

					Division**			Modified	
Range No*	Range Type	Firing Unit Size	Maximum Position Points or Lanes per Range	Army Range Objectives	Armor	Mech	Inf	No Targets or Target Arrays per Point or Lane	No Targets or Target Arrays per Range
6-1	CPOC/MPFQC	CO	15	Required	1	1	1	7	105
6-2	Multipurpose Indoor Range	CO	Throughput Dependent	Optional					
6-3	Basic 25 meter Zero	CO	110	Required	2	2	2	1	110
6-4	Automated Field Fire	CO	32	See Note	***	***	***	3	96
6-5	Automated Record Fire	CO	16	See Note	***	***	***	7	112
6-6	Modified Record Fire	CO	16	See Note	2	2	2	9	144
6-7	Sniper Field Fire	PLT	4	Optional	1	1	1	12	48
6-8	Night Fire (Small Arms)	CO	35	Optional	1	1	1	2	70
6-9	Known Distance	CO	55	Optional	2	2	2	1	55
6-10	Machine Gun 10 meter	CO	20	Required	2	2	2	1	20
6-11	Multipurpose Machine Gun Transition	CO	10	Required	1	1	1	12	120
6-12	Multipurose Gunnery Range	CO	6	TBD	1	1	1	7	42
6-13	Hand Grenade Familiarization Course	CO	4	Required	1	1	1	4	16
6-14	Hand Grenade Qualification Course	CO	6	Required	1	1	1	7	42
6-15	Genade Launcher	CO	4	Required	1	1	1	7	28
6-16	Recoilless Rifle	CO	8	Optional	1	1	1	7	56
6-17	Light Antitank Weapon	CO	8	Optional	1	1	1	1	8
6-18	Scaled Range (1 30/1 60)	CO	4	Optional	1	1	1	10	40
6-19	Scaled Gunnery Range (1 5/1 10)	CO	4	Optional	1	1	1	10	40
6-20	Stationary Gunnery	CO	14	Optional	2	2	1	1	14
6-21	Antiarmour Tracking and Live Fire	CO	20	Required	1	1	1	0.5	10
6-22	Light Demolition	CO		Required	1	1	1	6	6
6-23	Infiltration Course	CO	2	Optional	1	1	1	0	0
6-24	Bayonet Assault Course	CO	4	Optional	1	1	1	10	40
6-25	Target Detection (Non-firing)	CO	50	Optional	1	1	1	0.2	10
6-26	MOUT Assault Course (MAC)	CO	8	Required	1	1	1	1	8
6-27	Gunship Harmonization	CO	1	Optional	1	1	1	1	1
6-28	Flame Operations Range	CO		Optional	1	1	1	6	6
6-29	Mortar, Scaled	CO	6	Optional	1	1	1	2	12
6-30	Motar	CO	6	Required	1	1	1	5	30
6-31	Field Artillery, 1 10 Scaled	BTRY	Optional	Optional	1	1	1	5	30
6-32	Field Artillery Indirect Fire	BTRY	Optional	Required	1	1	1	5	30
6-33	Multipurpose Training Range	CO	2 Trails	Required	2	2	1	20	40
6-34	Combat Engineer Vehicle	CO		Required				22	22
6-35	Air Defense Firing	BTRY		Optional	0	0	0	2	12
6-36	Helicopter Gunnery	CO	8	Required	1	1	1	3	24
6-37	Fire and Movement	CO	Throughput Dependent	Optional	1	1	1	6	24
6-38	Squad Defense Range	CO	5	Optional	1	1	1	6	30
6-39	Infantry Squad Battle Course	SQUAD		Required	1	1	1	20	20
6-40	Infantry Platoon Battle Course	PLT		Optional	1	1	1	60	60
6-41	MPRC-H+	PLT		Required	1	1		60	60
6-42	MPRC-L+	PLT		Required			1	60	60
6-43	Platoon Defense Against Aircraft	BTRY		Optional	0	0	0	NA	NA
6-44	MOUT CTF++	CO/BN	16/32	Required	1	1	1	NA	NA
									1701

* Range numbers correspond to those in Chapter 6, TC 25-8
** Notional quantities by range type depend on annual training frequency. The most current DA PAM 350-38 prescribes training frequency
*** AFFs and AFRs are recommended for TRADOC school installations. MFRs are recommended at unit-based installations to conserve resources.
+ Type and configuration of MPRC selected depend on which units are supported (armour/mechanized division = MPRC-H, LID, air assault division = MPRC-L).
++ AC division installations typically need a MOUT complex consisting of a 32-building CTF with MOUT assault course to meet throughout METL training requirements. AC separate brigade, semiactive installations supporting RC annual training and weekend training typically need a MOUT complex consisting of a 16-building CTF with MOUT assault course.

The subject of this study is the high hazard impact area at Fort Greely located in Alaska. Fort Greely has been an active Army installation for over fifty years. Its impact area was designed to support a division-sized unit, although today only one brigade (approximately 25% of a standard division) trains at Fort Greely at any one time.

Spatial Extent of Munitions Disturbance, Contaminant Loading Approximations and Contaminant Movement through the Soil

Munitions Disturbance

An examination of the types of munitions used in an impact area, the quantities expended, and an approximation of the magnitude of potential contaminant loading provides a measure of the problem under consideration. High explosive munitions are the focus of this study because they have both a destructive and contaminant effect in the environment. High explosive munitions are those that explode on or near the soil surface and therefore have the potential for creating a crater and damaging vegetation. Other munitions include smoke projectiles, illumination projectiles, and small arms and inert projectiles (CEMML, 1999). These munitions have the potential for creating craters and damaging vegetation, but this potential is relatively small compared to high explosive munitions.

The spatial extent of the physical disturbance occurring within Fort Greely impact areas can be approximated by an evaluation of munition expenditure data. Ideally, historical firing records indicating the number and type of munitions fired at particular targets would be used to account for the area exposed to high explosive munitions. Since, this information has not been well documented, an approximation of the surface area of target arrays can be estimated using the training doctrine guidance for Army ranges and munitions expenditure data. Fort Greely's high hazard impact areas had approximately 185,846 high explosive munitions fired, launched or dropped into its impact areas over a six year period – approximately 30,974 munitions per year (CEMML, 1999). This area could encompass up to 975 ha exposed to munitions disturbance, or about 2.75% of the total impact area (Figure 3-3). Determining the approximate annual cratered surface area refines this estimate of disturbance. Using the CEMML (1999) data set and assuming a crater radius for each type of munition, approximately 10.25 ha were disturbed annually during this period. This represents approximately 1.08% of the lands exposed to munitions or less than 0.03% of the total high hazard impact areas.

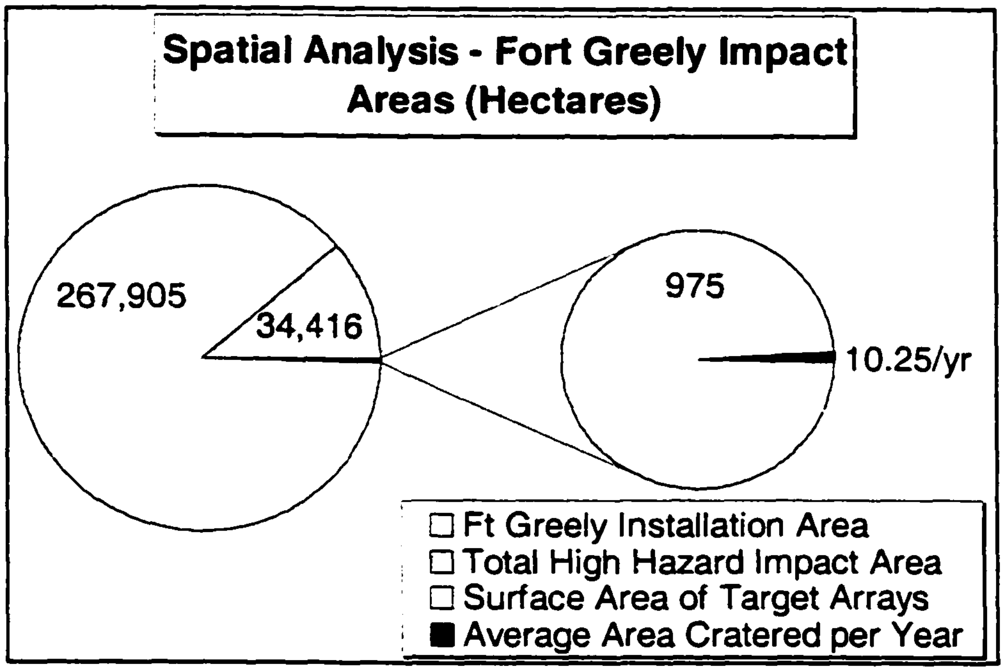


Figure 3-3. Spatial analysis of the area affected by munitions use at Fort Greely, Alaska indicates that munitions disturbance is confined to a relatively small area.

Contaminant Loading

In addition to the inherent kinetic and blast destructive effects of munitions, there is a contaminant effect associated with munitions that fail to function properly. There are two modes of munition failure – dud and low order detonation. A dud is a round that completely fails to function after it is fired, while a low order detonation is a round that only partially functions leaving part of the high explosive filler exposed in the target area (USATCES, 2000). Dud rounds retain their explosive filler inside the delivery body of the munition and are relatively isolated from the environment. However, during impact the delivery body can become fractured and over time small amounts of explosive filler may be mobilized through dissolution with water. Low order detonations can result in significant amounts of explosive filler available for dissolution and subsequent movement into the environment (Brannon et al., 1999). Therefore, both dud and low order detonation munitions have the potential for environmental contamination by leached explosive filler.

Explosive fillers such as Trinitrotoluene (TNT), Royal Demolition Explosive (RDX), and High Melting Explosive (HMX) are subject to environmental fate and transport congruent with the ecological setting in to which they are released. Release is contingent on dissolution rates and on the amount of free product exposed to water. Brannon et al. (1999) reported the dissolution fluxes for free solid to liquid phase. Their model considers dissolution flux critical for quantifying contaminant loading rates. They reported TNT has the highest rate at 4,164 μg cm^{-2} hr^{-1}; HMX has a rate of 454 μg cm^{-2} hr^{-1}, and RDX's has the lowest dissolution rate at 360 μg cm^{-2} hr^{-1}. Lynch et al, (2001) report higher rates of 604,800 μg cm^{-2} hr^{1}, 25,056 μg cm^{-2} hr^{-1}, and 8,294 μg cm^{-2} hr^{-1} for TNT, HMX and RDX, respectively. They used weapons grade explosives and subjected samples to mixing, which may be more similar to free product exposed to surface water flow. Since dissolution is a function of interfacial surface area, temperature, and energy input (i.e. degree of fluid motion), these higher rates may be due to relatively large energy input. Also, dissolution rates of pure explosive will differ from the rates of mixtures of explosives used in munitions (e.g., an artillery munition may have a mixture of TNT and RDX). Mixing of fillers occurs because most manufacturing processes result in one explosive encapsulated within another explosive, or within compounds that serve as explosive binders. For example, "certain formulations include binders made of insoluble wax; explosives almost entirely encapsulated in wax would persist for extended periods of time yet yield comparably lower concentrations." (Lynch, 2001, personal communication).

The amount of free product available for dissolution can be approximated by an evaluation of munition failure rates. Using failure rates published by USATCES (2000) and assuming the same failure rates are applicable to Air Force munitions, analysis indicates that there could be approximately 1,271 dud and 95 low order munitions failures per year on Fort Greely impact areas (Table 3-2). Loading rates could be derived from this data, but the highly variable nature of the state of explosive fillers available for mobilization (e.g., fully contained in a dud delivery body, partially contained in a low order delivery body and/or scattered by a low order detonation) coupled with varying solubility and dissolution fluxes resulting from manufacturing creates uncertainty. The most conservative approach is to assume that all of the explosive filler from dud and low order munitions failures is available for dissolution. Assuming optimum

Table 3-2

Munitions Expenditure Data For The Period 1992-1996 at Fort Greely, Alaska (CEMML, 1999). Expenditure data combined with mass of explosive filler, and munitions failure rates allows a first approximation of contaminant loading rates. Crater size approximations are not shown. Loading rates are based on target array and crater area approximations shown in Figure 3-3.

US Army Munition	Type	Total rds	Average rounds per year	Mass of Filler per round (kg)	*DUD %	*LO %	Average DUD (rds/yr)	Average LO (rds/yr)	Ave.Mass of Filler DUD (kg/yr)	Ave. Mass of Filler LO (kg/yr)	Total Filler DUD + LO	Source Remarks (see notes)
20mm	HE	11752.00	1958.67	0.01	*3.45*	*0.28*	67.57	5.48	0.68	0.05	0.73	1
40mm	HE	489.00	81.50	0.04	1.32	0.15	1.08	0.12	0.04	0.00	0.05	1,2
60mm	HE	3025.00	504.17	0.36	2.48	0.00	12.50	0.00	4.50	0.00	4.50	1,2
81mm	HE	1724.00	287.33	0.95	2.28	0.08	6.55	0.23	6.24	0.22	6.46	1,2
105mm	HE	11080.00	1846.67	2.63	4.95	0.09	91.41	1.66	240.41	4.37	244.78	1,2
120mm	HE	120.00	20.00	2.99	*3.45*	*0.28*	0.69	0.06	2.06	0.17	2.23	1
84mm	HE	143.00	23.83	0.44	0.00	0.15	0.00	0.04	0.00	0.02	0.02	2,3
Frag Genade	HE	530.00	88.33	0.18	*3.45*	*0.28*	3.05	0.25	0.55	0.04	0.59	3
2.75 Rkt	HE	744.00	124.00	2.18	8.16	0.00	10.12	0.00	22.06	0.00	22.06	3
TOW	HE AT	224.00	37.33	3.10	*3.45*	*0.28*	1.29	0.10	3.99	0.32	4.32	3
Hellfire	HE AT	18.00	3.00	2.50	*3.45*	*0.28*	0.10	0.01	0.26	0.02	0.28	4
Dragon	HE AT	62.00	10.33	2.50	3.45	*0.28*	0.36	0.03	0.89	0.07	0.96	5
4.2 in	HE	385.00	64.17	3.73	6.92	0.08	4.44	0.05	16.56	0.19	16.75	1,2
155mm	HE	16.00	2.67	11.50	2.25	0.01	0.06	0.00	0.69	0.00	0.69	1,2
30mm	HE	520.00	86.67	0.03	*3.45*	*0.28*	2.99	0.24	0.07	0.01	0.08	1
66mm	HE AT	16.00	2.67	0.50	4.52	0.04	0.12	0.00	0.06	0.00	0.06	2
USAF Munition											0.00	
20mm	HE	23912.00	4782.40	0.01	*3.45*	*0.28*	164.99	13.39	1.65	0.13	1.78	5
30mm	HE	126230.00	25246.00	0.03	*3.45*	*0.28*	870.99	70.69	21.77	1.77	23.54	6
2.75 Rkt	HE	2652.00	530.40	2.18	*3.45*	*0.28*	18.30	1.49	39.89	3.24	43.13	3
Mavenck	HE	19.00	3.80	36.30	3.45	*0.28*	0.13	0.01	4.76	0.39	5.15	3
Mk82	HE 500lb	1477.00	295.40	89.00	*3.45*	*0.28*	10.19	0.83	907.03	73.61	980.64	3
Mk83	HE 1000lb	229.00	45.80	202.00	3.45	*0.28*	1.58	0.13	319.18	25.90	345.08	3
Mk84	HE 2000lb	391.00	78.20	945.00	*3.45*	*0.28*	2.70	0.22	2549.52	206.92	2756.43	3
Totals or Averages		185758.00	30959.67				1271.21	95.02	4142.87	317.46	4460.32	

Theoretical Contaminant Loading

Total Mass of Explosive Filler (DUD + LO)	4460 kg/yr
Theo. Max. Explosive Loading Rate TGT Arrays	0.46 g/m2/yr
Theo. Max. Explosive Loading Rate Crater Area	43.52 g/m2/yr

Theoretical Contaminant Concentrations in the Top 10 cm of the Soil with a bulk density of 1.5 g/cm3

Total Mass of Explosive Filler (DUD + LO)	4460 kg/yr
Theo. Max. Explosive Concentration TGT Arrays	3.05 ug/gm/yr
Theo. Max. Explosive Concentration Crater Area	290.15 ug/gm/yr

* Estimated DUD and LO Rates are italicized.

Notes:

1. Jane's, 2000
2. USATCES, 2000
3. FAS, 2001
4. No data. Assumed same as TOW
5. No data. Assumed same as Army 20mm
6. No data. Assumed avg. Army 20 & 40mm

dissolution conditions, this results in a potential maximum annual average of 4,460 kg of high explosive materials available for dissolution and translates into a maximum theoretical loading rate within the target array area exposed to high explosive munitions of about 0.46 gm m^{-2} yr^{-1}. Alternatively, assuming that this maximum potential annual average of high explosive materials is deposited in cratered areas, the maximum theoretical loading rate could be as high as 43,52 gm m^{-2} yr^{-1} (Table 3-2). Soil concentrations can be approximated by assuming the contaminant load resides in the top 10 cm of the soil profile with a soil bulk density of 2.0 Mg m^{-3}. If no transformations take place, this equates to potential concentrations ranging from 3.05 μg g^{-1} for target areas to 290.15 μg g^{-1} for craters for a given year. These approximated concentrations are comparable to those reported by Walsh et al. (2001) for Washington impact area soils directly associated with low-order detonations which were 130, 340, and 40 μg g^{-1} for TNT, RDX and HMX respectively. Additionally, these approximated concentrations are comparable to EPA Region III Risk-based industrial concentrations, which are 52 μg g^{-1} for RDX, 190 μg g^{-1} for TNT and 10,000 μg g^{-1} for HMX. These risk-based concentrations are used by the EPA for chemical screening during baseline risk assessment (EPA, 2002; Walsh et al., 2001).

Contaminant Movement through the Soil

Chapter 2 described a modified conceptual model initially developed by Brannon et al. (1999) for fate and transport of UXO that provides a basis for a qualitative evaluation of the key processes at work in the environment. Applying this conceptual model to an Alaskan ecological framework involves relating process and effect to relevant ecosystem components and their governing ecological setting. For example, dissolution is the process by which TNT, RDX and HMX are dissolved by water from free product to solutes. At Fort Greely, water is available in an unfrozen form for relatively short but intense time frames. Therefore, one would expect that mobilization through dissolution to the soil component occurs primarily during spring snowmelt and the summer rainy season, each of which is about one month long.

Adsorption is the process by which TNT, RDX, and HMX solutes move to and bind with soil colloidal surfaces. These sorbents are composed of clay and naturally occurring humic matter (LaGrega et al., 1994). Colloid content can be measured via a soil's cation exchange capacity (CEC) which in turn is used to define a partitioning coefficient for contaminant to soil adsorption. For that reason, CEC may provide an indication of the relative retardation potential of the area in which UXO is found. Generally, Alaskan soils are not as weathered as soils in more temperate regions and have less clay fraction. Therefore, humus should be the dominant contributor to CEC in this setting.

Adsorption of TNT to soil has been documented and considered to be very important in immobilizing TNT and its transformation products (Comfort et al., 1995; Larson et al., 1998b; Myers et al., 1998; Pennington et al., 1999c; Weissmahr et al., 1998) and in particular to humic soils (Hundal et al., 1997). This process has been described by Freeze and Cherry (1979), LaGrega et al. (1994), Myers et al. (1998) and Roberts et al. (1982), who describe a retardation factor based on a one-dimensional saturated flow contaminant transport equation shown below:

$$R\frac{\delta C}{\delta t} = D\frac{\delta^{\theta} C}{\delta x^{\theta}} - v\frac{\delta C}{\delta x} - \mu C \quad \text{where,}$$

$\frac{\delta C}{\delta t}$ is the partial derivative of a unit change in concentration C per unit time t,

R is the retardation factor,

D is the combined diffusion and dispersion coefficient ,

v is the advection term based on average pore water velocity, and

μ is the solution and solid phase disappearance coefficient

The retardation factor equation is,

$$R = [1 + (\rho_b K_d / \varepsilon)] = u^{-1}{}_r, \qquad \text{where,}$$

R is the retardation factor or relative residence time (dimensionless),

$u^{-1}{}_r$ is the relative velocity of movement of a concentration front of sorbing solute divided by the velocity of movement of a front of conservative tracer (dimensionless),

ρ_b is bulk density of the flow matrix (kg-solids/l),

K_d is the distribution coefficient (i.e., solute to sorbent in l/kg), and

ε is the flow matrix porosity (cm^3/cm^3).

The distribution coefficient K_d is a function of the fraction of organic carbon, f_{oc} in the soil (g organic carbon/ g dry soil) and the hydrophobicity of the solute as measured by its octanol:water partitioning coefficient K_{ow}. K_d is given by the equation,

$$K_d = f_{oc}(6.3 \times 10^{-7})(K_{ow})$$

K_{ow} for each contaminant can be estimated by various approaches or found in the literature. For example the TNT $K_{ow} = 10^{2.25}$ (Verschueren, 1996). Brannon et al. (1999) describes another approach, which utilizes soil column testing to determine K_d for a soil. They found that K_d for a specific contaminant to a soil is highly correlated to the CEC of a soil. For example, they found that for a set of soils TNT, K_d can be estimated by the equation, $TNT\ K_d = 0.055\ (CEC) + 1.26$, and that the K_d for RDX can be estimated by the equation, $RDX\ K_d = 0.056\ (CEC) + 0.15$. While HMX adsorption occurs, little is known about the solute-sorbent process to enable the prediction of adsorption coefficients for HMX (Brannon et al., 1999). Using either method for estimating K_d and assuming that the velocity of a front of conservative tracer is similar for soils in a similar setting allows the use of the retardation factor approach to determining the relative risk for organic contaminants releases to the soils at Fort Greely. Soils with higher fractions of organic carbon and/or higher CECs should inhibit movement of these contaminants and provide time for some measure of transformation to take place before groundwater resources are impacted.

Transformation of explosive compounds, either though biotic or abiotic processes, have been described using disappearance coefficients that are based on first order reaction kinetics (Brannon and Myers, 1997; Myers et al., 1998;

Brannon et al., 1999). Myers et al. (1998) reports while transformation of TNT, RDX and HMX is not well understood it is more important than sorption processes for the soils they studied. Biotic transformation processes are biodegradation and bio-uptake of contaminants and appear to be important in TNT and RDX transformations (Myers et al., 1998). Biodegradation involves the oxidation and reduction of organic contaminants and bio-uptake of organic and inorganic contaminants involves plant root uptake by vegetation. Soil organic carbon (SOC) content and climate in terms of effective growing season (EGS) are good indicators of conditions favorable for microbial and plant activity. SOC and EGS can provide a relative measure of the transformation potential of the region in which UXO is found. For soils located in Fort Greely, Alaska impact areas, SOC percentages should be relatively low and growing seasons are relatively short so biological activity will not be as great as in more temperate regions.

Soil Property Investigations

Field Methods

Soil samples were collected from sixty plots for soil characterization analysis (i.e., objectives 2 and 3 on page 37) and from five craters for crater disturbance descriptions (i.e., objective 4 on page 37).

Plot sampling: In order to determine sampling locations for the Jarvis Creek control area a supervised land cover classification was performed using a Landsat 7 Enhanced Thematic Mapper scene (10 September 1999, path 67, row

15), provided by the U.S. Army Corps of Engineers, Topographic Engineering Center. This generated thematic maps of the Tanana watershed in the vicinity of Fort Greely and the Jarvis Creek control area. Classification of the Washington Range and Impact areas was not possible due to cloud cover over these areas. General informational categories of interest were scrub, broadleaf forested, needleleaf forested, mixed forested ecotypes associated with riverine settings (Figure 3-4). Thirty-six plots were located in the Jarvis Creek control area, twelve per scrub, broadleaf and mixed forest ecotypes. These were designated Jarvis Creek scrub (JS), Jarvis Creek Broadleaf (JB) and Jarvis Creek Mixed leaf (JM). Another twenty-four plots were located within the Washington impact area and control area. Twelve of these plots were inside the impact area co-located with an array of previously established plots that had been cleared by ordnance disposal teams. These comprised the Washington impact area scrub (WIS). The other twelve plots were located on an array located just south of the impact. These comprised the Washington Range scrub (WS).

Sampling plots were located and marked using a Garmin III+ GPS receiver. Each sample consisted of fifty randomly collected 40 gm incremental samples that were composited into one 2 kg soil sample for that particular plot. Samples were collected from the interface of the organic and mineral stratums of the soil profile (i.e., the "O" and "A" layers respectively) within a 55-meter radius

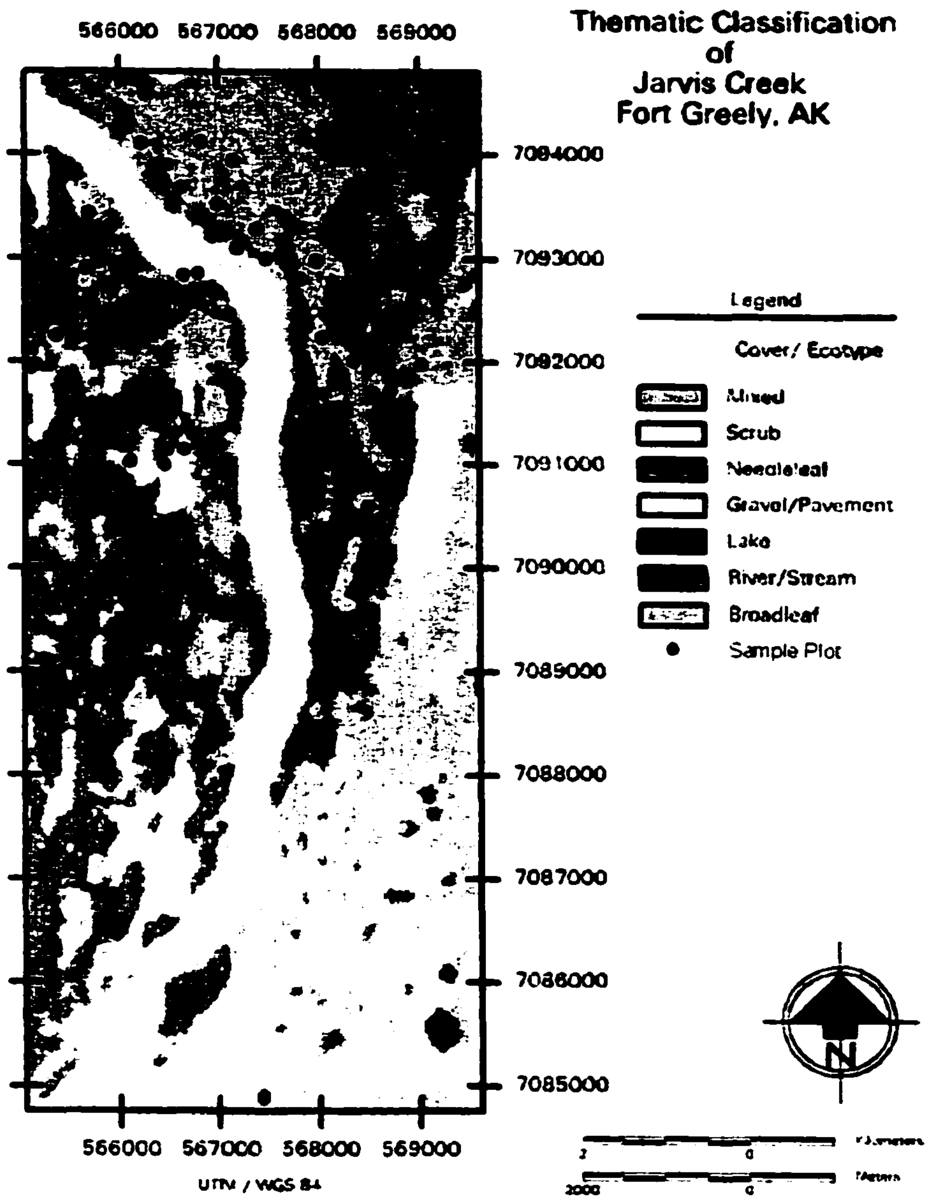


Figure 3-4. Thematic classification of the Jarvis Creek Control Area at Fort Greely, Alaska. Twelve plots per scrub, broadleaf and mixed leaf ecotype were identified and sampled from this area.

of the marked point (Figure 3-5). At each sampling plot the depth of the cumulative organic matter (CumO) was determined by digging a small trench to the depth of the lowest organic horizon or 40 cm which ever was deeper. Additionally, elevation, slope and aspect, and vegetative cover descriptions were noted for each plot. Finally, plot sampling replications were made on five randomly selected plots.

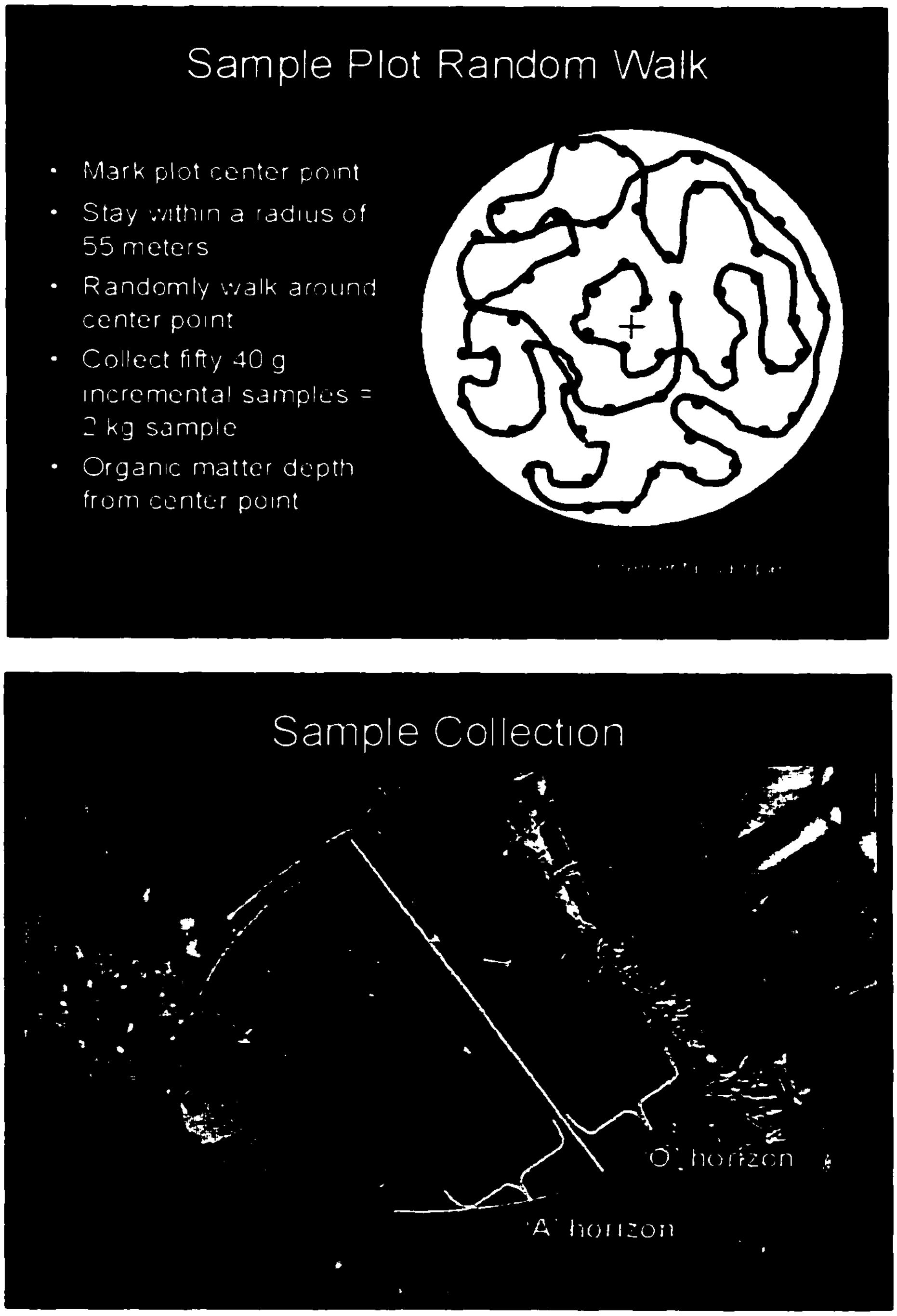


Figure 3-5. **Top - A depiction of hectare plot sampling method using random walk collecting 50 incremental samples for one composite sample at Fort Greely, Alaska. Bottom - An example of 'O' and 'A' horizon interface from which soil samples were collected.**

Crater sampling: Five craters of various ages ranging 2-11 years were selected based on accessibility and for the flat terrain on which they were located. Also, every effort was made to select craters that were not associated with other forms of disturbance (i.e., erosion or overlapping craters). Sampling for each crater consisted of five concentric rings radiating outward from the center of the target (Figure 3-6). The incremental distance (*I*) from the target array was determined by dividing the diameter (*D*) of the observed disturbed area by five (i.e., $I = D/5$) creating five concentric rings. Within each of these rings, three replicates of twenty 40 gm incremental samples were collected from the top 2 cm of the soil surface. These sixty incremental samples were composited into one 2.4-kg soil sample for that particular sample ring. The approximate age of older craters was determined by counting the growth rings of *P. balsamifera* shrubs growing in the center of the craters. The exception to this procedure was crater number 7, which had no vegetation at its center. Explosive ordnance specialists determined that this crater was no older than 2 years.

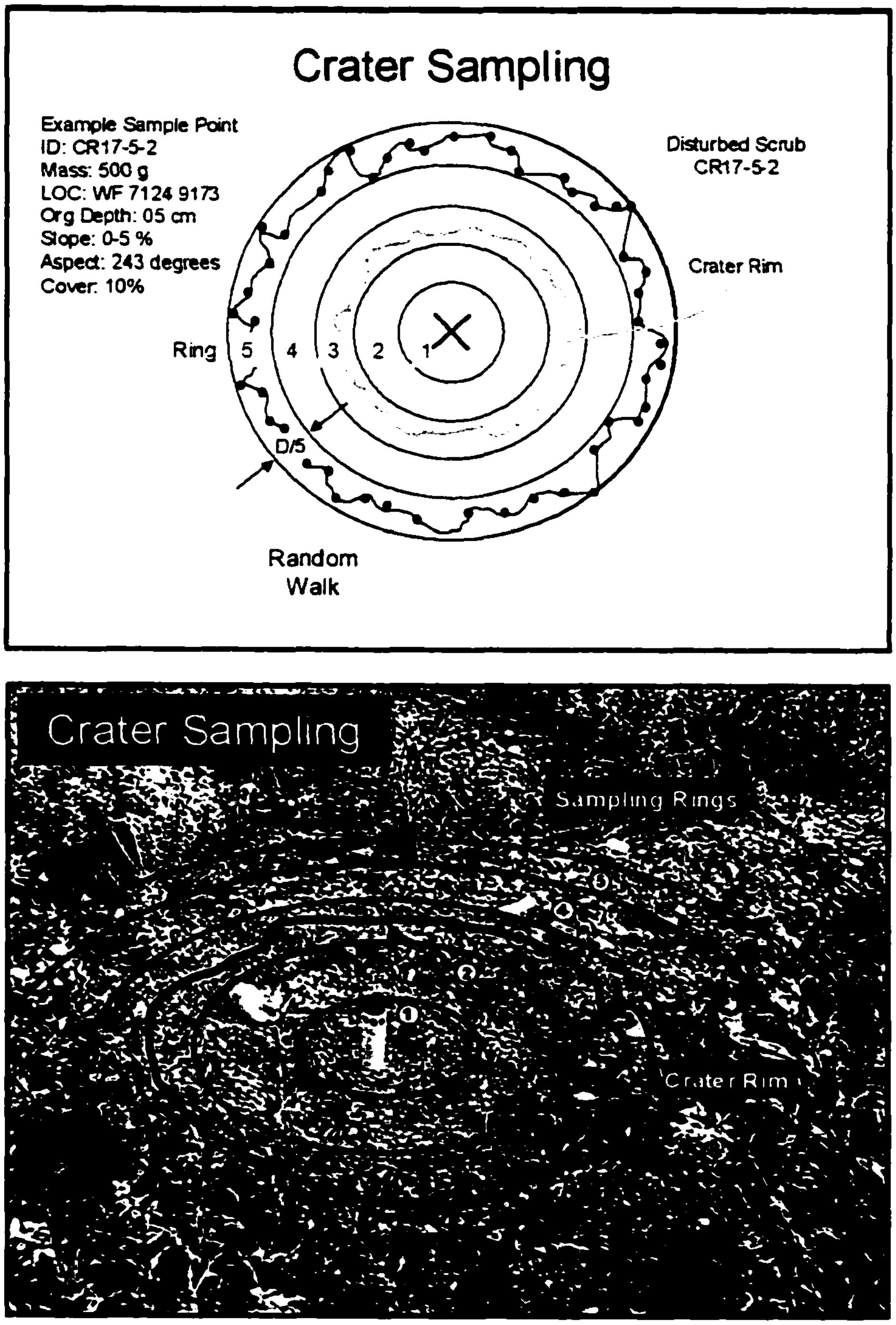


Figure 3-6. Top - Depiction of crater sampling method using random walk collecting 20 incremental samples for one composite ring sample. Bottom - Actual layout of crater sampling during fieldwork at Washington impact area, Fort Greely, Alaska. This is Crater 7, which is estimated to be a 1- to 2-year-old 105mm crater.

Analysis

All soil samples were air dried, sieved through a 4 mm mesh, mixed well, double sealed in plastic bags and submitted to the Colorado State University Soils Laboratory. Soil samples were analyzed using standard methods for the twenty-three soil properties listed in Table 3-3. Table 3-4 provides a summary of the laboratory results by ecotype (complete soil data is at Appendix A).

Plot Samples: Using the data from all sixty plot samples, a optimal model selection approach using "best fitting subset" (Ott, 1993) selection based on Mallows' C_p statistic for each model selected. This involved a multiple linear regression of all soil properties with CEC as the response variable. Subsequent transformations were based on residual plots with the intent to maintain original unbiased scales as much as possible. Forward, backward and stepwise model selection methods also were analyzed to determine relative importance of variables such as percent organic matter (PrcOM).

For ecotype soil characteristics, a stepwise discriminant analysis was performed to select a subset of the quantitative variables for use in discriminating among the ecotype classes. Selection criteria for variables to enter and stay were both conservatively set at *alpha=0.01*. Ecotypes were then plotted against the two most significant predictors to obtain a visual understanding of their relationship to ecotypes. These predictors also were used in Ryan-Einot-Gabriel-Welsch (REGWQ) multiple range tests on main effect means across ecotypes.

Crater Samples: Crater rings were initially evaluated using a two-way ANOVA for a ring to age interaction using both PrcOM and CEC as the response

Table 3-3

Description of Data Used in the Analysis. The number of ecotype and crater samples is shown as well as the soil property tests and methods performed by the Colorado State University Soil Laboratory.

Abbreviation:	*Ecotypes:*	Samples:
JS	*Jarvis Creek Scrub*	12
JBL	Jarvis Broadleaf Forest	12
JML	Jarvis Mixed Leaf Forest	12
WS	Washington Range Scrub	12
WIS	Washington Impact Area Scrub	12
	Total	60

Crater #:	Age (years)	Type:	Rings:	Reps:	Samples:
7	2	105mm Artillery	5	3	15
15	5	MK82 500lb Bomb	5	3	15
17	8	MK82 500lb Bomb	5	3	15
16	8	MK82 500lb Bomb	5	3	15
9	11	MK82 500lb Bomb	5	3	15
				Total	75

Soil properties:	Abbreviation:	Methods:	Reference:
pH	pH	Soil to water ratio of 1:1	2, p.487
pH Buffer	BpH	SMP Buffer	2, pp.502-505
Conductivity	EC	Soil to water ratio of 1:1	2, pp.420-427
Cation Exchange	CEC	Measure Na; account for entrained Na with nitrite.	2, pp.1201-1230
Texture	Sand Silt Clay	Hydrometer	1, method 15-4
% Organic Carbon	PrcC	Modified Walkely-Black	2, pp.995-996
% Organic Matter	PrcOM	1.724 x % Organic Carbon	
Soil Nutrients:			
Nitrogen as ammonia Nitrogen as nitrate	NH4 NO3	2M potassium chloride extract, automated phenate method by FIA	2, pp.1146-1162
Total N	PrcN	CHN furnace	2, pp.1085-1122
Total C	PrcC	CHN furnace	2, pp.967-977
Phosphorous	P	Mehlich 3 Extract	2, pp.893-894
Potassium	K	Mehlich 3 Extract	2, pp.893-894
Calcium	Ca	Mehlich 3 Extract	2, pp.893-894
Magnesium	Mg	Mehlich 3 Extract	2, pp.893-894
Extractable Metals:			
Cadmium	Cd	Mehlich 3 Extract	2, pp.893-894
Chromium	Cr	Mehlich 3 Extract	2, pp.893-894
Copper	Cu	Mehlich 3 Extract	2, pp.893-894
Lead	Pb	Mehlich 3 Extract	2, pp.893-894
Zinc	Zn	Mehlich 3 Extract	2, pp.893-894

1. Klute, 1986.
2. Spark, 1996.

Table 3-4

Soil Properties for Sampled Areas at Fort Greely, Alaska.

Soil Property	Washington Control Scrub WS n=12		Wash. Impact Area Scrub WIS n=12		Jarvis Scrub JS n=12		Jarvis Broadleaf JB n=12		Jarvis Mixed Leaf JN n=12	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
pH	7.46	0.17	7.27	0.30	6.21	0.99	5.98	0.85	5.65	0.74
EC 1:1 (mmhos/cm)	0.23	0.10	0.35	0.12	0.12	0.04	0.12	0.04	0.13	0.05
Ca (ppm)	4019.50	887.75	2775.92	777.47	3795.50	3260.92	4316.33	1385.09	3692.17	1560.23
Mg (ppm)	264.19	52.42	209.24	99.55	478.85	263.46	603.97	139.00	616.13	211.48
P (ppm)	3.98	0.70	3.74	2.55	4.59	2.01	7.75	6.45	7.00	6.64
K (ppm)	62.43	11.22	82.84	21.63	87.12	53.26	129.51	32.41	166.26	118.86
Zn (ppm)	8.05	0.83	8.12	2.85	9.53	8.57	13.53	6.66	10.96	7.79
Fe (ppm)	428.20	32.28	274.61	62.04	379.73	61.58	433.18	22.46	462.67	37.24
Mn (ppm)	113.12	9.46	68.12	26.08	111.97	56.27	134.87	19.43	149.07	52.46
Cu (ppm)	7.14	0.92	4.40	1.28	3.33	1.50	2.52	0.49	3.77	2.48
Cr (ppm)	0.17	0.00	0.09	0.04	0.20	0.06	0.17	0.01	0.17	0.01
Pb (ppm)	3.08	1.08	1.28	0.94	2.68	1.99	1.51	0.36	1.51	0.41
CEC (meq/100g)	9.17	4.17	11.98	4.94	27.08	23.12	31.69	12.50	33.97	16.37
% Sand	53.08	9.93	61.67	7.33	55.08	17.95	38.58	13.69	45.58	8.61
% Silt	43.08	9.67	34.50	6.99	33.67	12.93	50.42	11.47	45.17	8.05
% Clay	3.83	0.58	3.83	1.03	11.25	7.84	11.00	6.00	9.25	2.80
NH4-N (mg/kg)	3.53	2.16	3.48	1.99	6.63	5.05	10.78	10.97	9.79	7.28
NO3-N (mg/kg)	18.27	14.36	42.00	31.75	7.72	8.05	7.06	7.25	4.30	5.09
Total % N	0.12	0.05	0.15	0.09	0.39	0.32	0.36	0.08	0.31	0.15
Total % C	1.74	0.71	2.08	1.25	6.03	4.43	6.51	1.98	6.65	3.51
% calc OM	3.00	1.22	3.59	2.15	10.39	7.64	11.22	3.41	11.47	6.06
Buffer pH	7.50	0.00	7.43	0.10	7.23	0.27	7.26	0.23	7.30	0.11

variables. The intent was to be able to average each ring over the crater age to determine trends in soil properties across rings. However, there is a significant interaction between crater rings and age so this approach would not be appropriate since there are no replicates of craters by age class. Therefore, a ring analysis was made for each crater using REGWQ multiple range tests on main effect means of crater rings. Results were then evaluated for notable trends from one crater age class to the next.

Results

Table 3-4 shows the means and standard deviations soil property for each ecotype. Multiple linear regression generated a model with nine independent variables (PrcOM, BpH, CumO, Clay, Mg, Fe, Mn, Cu and Pb) with an R^2=0.9199. The selected model required a transformation based on its residual plot. Therefore, a weighted regression with original parameter estimates was used in order to maintain original unbiased scales yielding the final model with weighted parameter estimates shown below:

$$CEC = 154.6 + 1.6998(PrcOM) - 20.0151(BpH) + 0.0887(CumO) - 0.7421(Clay) + 0.0228(Mg) - 0.0188(Fe) + 0.0365(Mn) + 0.7993(Cu) - 1.7706(Pb)$$

Evaluation of parameter estimates indicate that two variables (i.e., CumO and Fe) are, or are nearly, non-significant and could be eliminated one at a time in future weighted regression modeling. A studentized residual plot of this transformed model is at Figure 3-7. Finally, PrcOM explains a large portion (i.e., R^2=0.8431) of the variability of CEC response (Figure 3-8) and is the most significant variable for all model selection processes (Table 3-5).

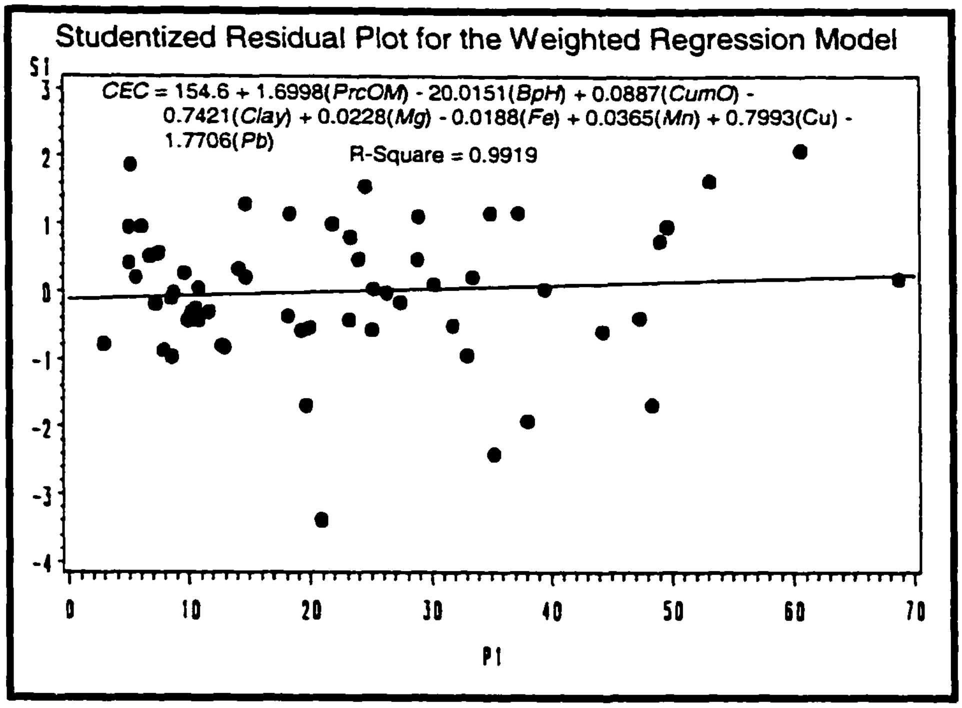


Figure 3-7. Residual plot for the weighted regression model indicates homogeneity of variance for this transformed model. S1 is the Studentized Residual and P1 is the Predicted Value.

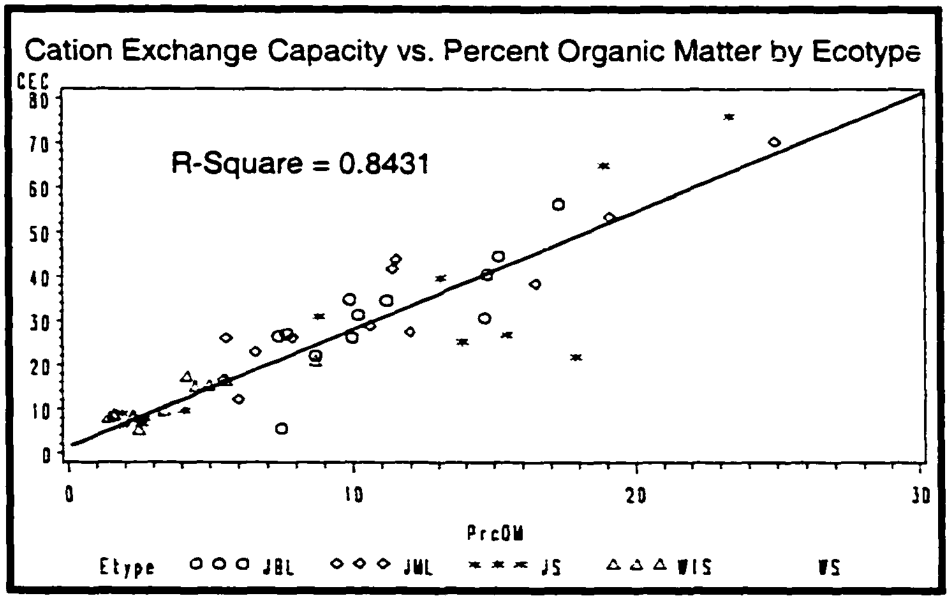


Figure 3-8. Initial plot of CEC verses PrcOM for the various ecotypes. Note that Washington Impact Area Scrub (WIS) and Washington Range Scrub (WS) responses appear to be different than the Jarvis Creek Broadleaf (JBL), Mixed Leaf (JML) and Scrub (JS) ecotypes.

Table 3-5

Mallows' C_p Model Selection Results. The top five models are in the top portion of the table. In the bottom portion of the table is a summary of other model selection processes indicating organic matter is the most important variable.

Number in Model	C(p)	Adj R-Square	R-Square	MSE	Variables in the model
9	4.625	0.9199	0.9055	27.7269	PrcOM BpH CumO Clay Mg Fe Mn Cu Pb
10	4.630	0.9235	0.9078	27.0281	PrcC BpH CumO Clay Ca Mg Fe Mn Cu Pb
10	4.631	0.9235	0.9078	27.0290	PrcOM BpH CumO Clay Ca Mg Fe Mn Cu Pb
10	5.464	0.9220	0.9060	27.5570	K PrcOM BpH CumO Clay Mg Fe Mn Cu Pb
10	5.471	0.9219	0.9060	27.5616	PrcN PrcOM BpH CumO Clay Mg Fe Mn Cu Pb
10	5.483	0.9219	0.9060	27.5690	PrcC K BpH CumO Clay Mg Fe Mn Cu Pb

Method*	Variable	F value and Pr > F	F value relative to other variables	Remarks
Forward Selection	PrcOM	233.44 <.0001	Largest	First to Enter
Backward Elimination	PrcC	30.29 <.0001	Largest	PrcC = PrcOM/1.74
Stepwise Selection	PrcOM	233.44 <.0001	Largest	First to Enter

*All model selection methods use a significance level of 0.05

Stepwise discrimination analysis to determine the best set of independent variables that could discriminate between ecotypes yielded seven variables (Fe, Cu, Cr, pH, BpH, NO3 and Pb) with Fe and Cu being the most useful. A plot of Fe verses Cu for ecotypes (Figure 3-9) shows that each ecotype can be distinguish from each other based on Fe, Cu or combination of Fe and Cu values. This discrimination is further supported by REGWQ multiple range tests for Fe and Cu by ecotypes (Table 3-6). PrcOM proved less reliable in discriminating among ecotypes, however there were significant differences between the Jarvis Creek control area and the Washington impact area and control areas.

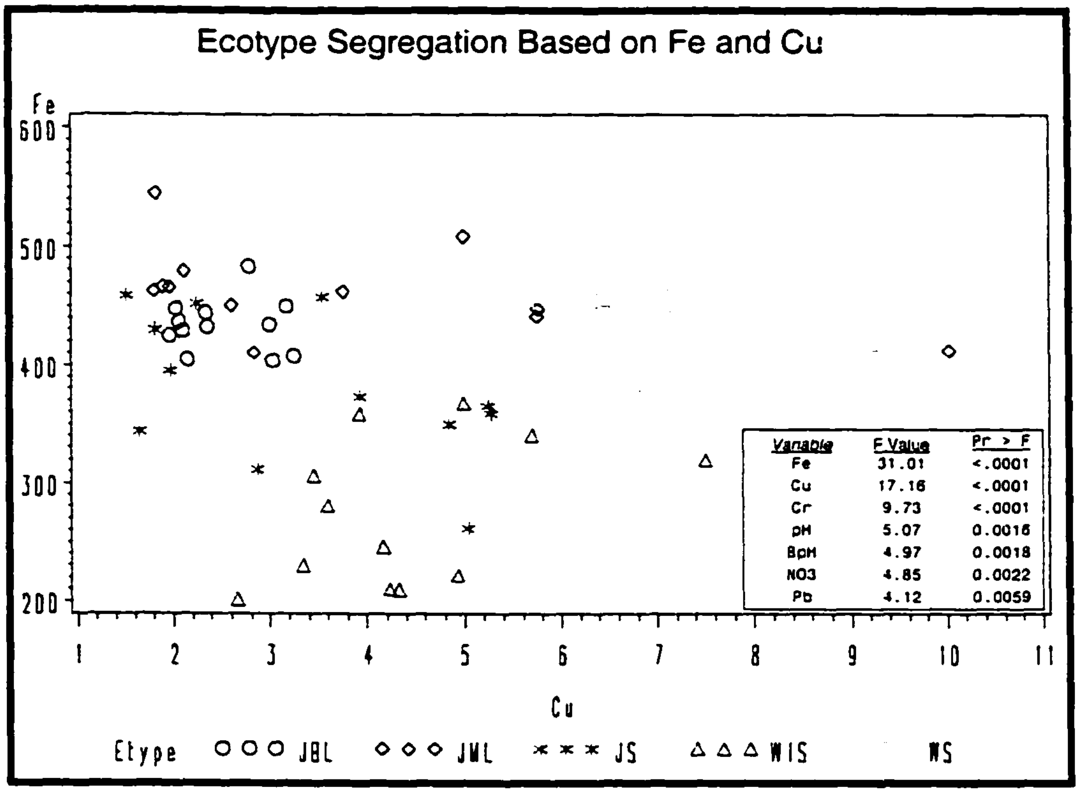


Figure 3-9. Plot showing ecotype segregation using Fe and Cu variables derived from a stepwise discrimination analysis. Inset shows a summary of the stepwise selection method, which determined Fe and Cu were the most important variables.

Table 3-6

Multiple Means Comparisons by Ecotype for Fe and Cu Independent Variables Selected by Stepwise Discrimination Analysis. Fe and Cu proved to be the best two variables for segregating ecotypes. A plot of Fe vs Cu by ecotype is at Figure 3-9.

Ryan-Einot-Gabriel-Welsch Multiple Range Test for Fe

REGWQ Grouping	Mean	N	Etype
A	462.67	12	JML
A			
A	433.18	12	JBL
A			
A	428.2	12	WS
B	379.73	12	JS
C	274.61	12	WIS
Means with the same letter are not significantly different at alpha = 0.05.			

Ryan-Einot-Gabriel-Welsch Multiple Range Test for Cu

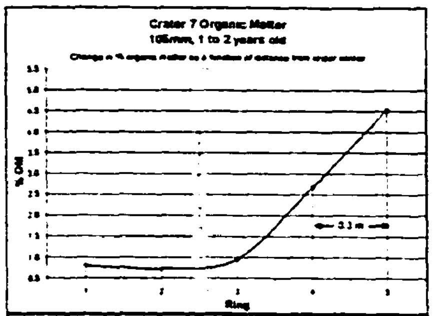
REGWQ Grouping		Mean	N	Etype
	A	7.1406	12	WS
	B	4.3986	12	WIS
	B			
C	B	3.7723	12	JML
C	B			
C	B	3.3272	12	JS
C				
C		2.5201	12	JBL
Means with the same letter are not significantly different at alpha = 0.05.				

REGWQ multiple range tests on main effect means of crater rings show significant differences (*alpha=0.15*) in PrcOM between rings for younger craters (i.e., < 5 years old) and for the oldest crater, which is estimated to be approximately 11 years old (Figure 3-10). Graphical evaluation of PrcOM response of the five craters yielded two notable trends. First in the 2 year-old crater, the center of the crater is nearly devoid of organic matter and there is a steep gradient of increasing organic matter percentages as measures move toward the outer rings. Second, the older craters illustrate that after a period of time the center of the crater tends to increase in PrcOM while the rings associated with the crater rim tend to remain low in percent organic matter. However, means comparisons and trend analysis should be viewed with caution due to small sample size (i.e., no replications of craters).

Discussion

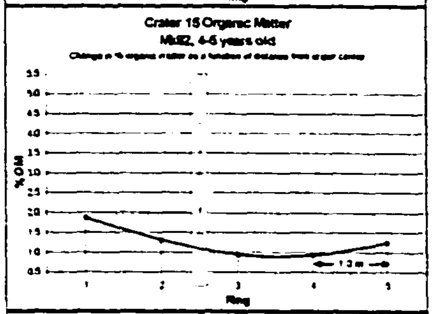
Cation Exchange Capacity

PrcOM appears to be the most important predictor of CEC response indicating that organic matter dynamics should be useful in assessing contaminant fate and transport potential for this study area. Therefore, any significant change in organic matter stocks should directly affect CEC and in turn the soil's retardation factor. Using soil organic carbon content to determine retardation factors provides an indication of the capacity of Washington impact area and Jarvis Creek control area soils to hold a contaminant in place. This is



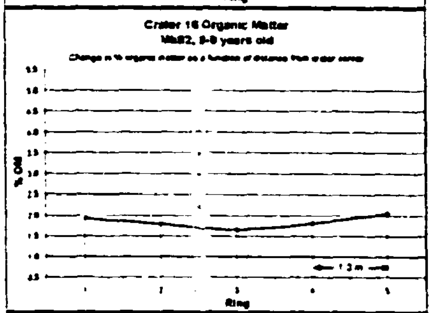
REGWQ Grouping	Mean	N	Ring
A	4.5667	3	5
B	2.7	3	4
C	0.9667	3	3
C			
C	0.7667	3	1
C			
C	0.7333	3	2

Means with the same letter are not significantly different at alpha = 0.15



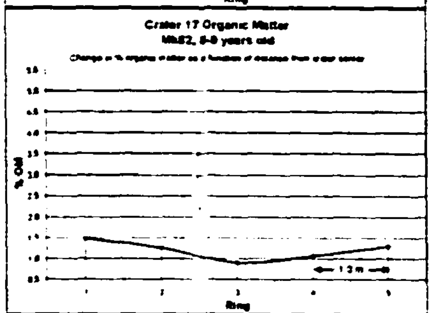
REGWQ Grouping		Mean	N	Ring
	A	1.8667	3	1
	B	1.3333	3	2
	B			
C	B	1.2333	3	5
C	B			
C	B	0.966	3	3
C				
C		0.9333	3	4

Means with the same letter are not significantly different at alpha = 0.15



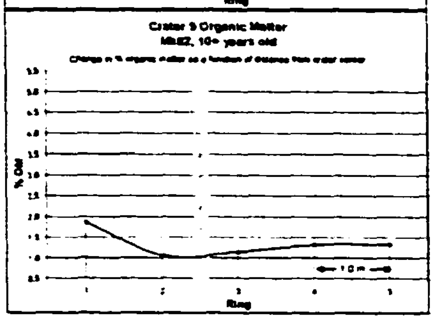
REGWQ Grouping	Mean	N	Ring
A	2.0667	3	5
A			
A	1.9333	3	1
A			
A	1.8333	3	4
A			
A	1.7667	3	2
A			
A	1.6333	3	3

Means with the same letter are not significantly different at alpha = 0.15.



REGWQ Grouping	Mean	N	Ring
A	1.4667	3	1
A			
A	1.3	3	5
A			
A	1.2333	3	2
A			
A	1.0333	3	4
A			
A	0.9	3	3

Means with the same letter are not significantly different at alpha = 0.15.



REGWQ Grouping	Mean	N	Ring
A	1.8667	3	1
B	1.3333	3	4
B			
B	1.3	3	5
B			
B	1.1333	3	3
B			
B	1.0667	3	2

Means with the same letter are not significantly different at alpha = 0.15.

Figure 3-10. Crater ring comparisons for five craters of various ages from the Washington impact area. The youngest crater is at the top and the oldest is at the bottom. REGWQ multiple range tests are at the right of their respective craters. Crater rim is indicated by the vertical rectangle between rings 2 and 3.

illustrated in Figure 3-11, which shows that small amounts of organic carbon provide significant adsorption capacity. As a result, contaminant transformation opportunity increases the longer a contaminant is held in place by the soil.

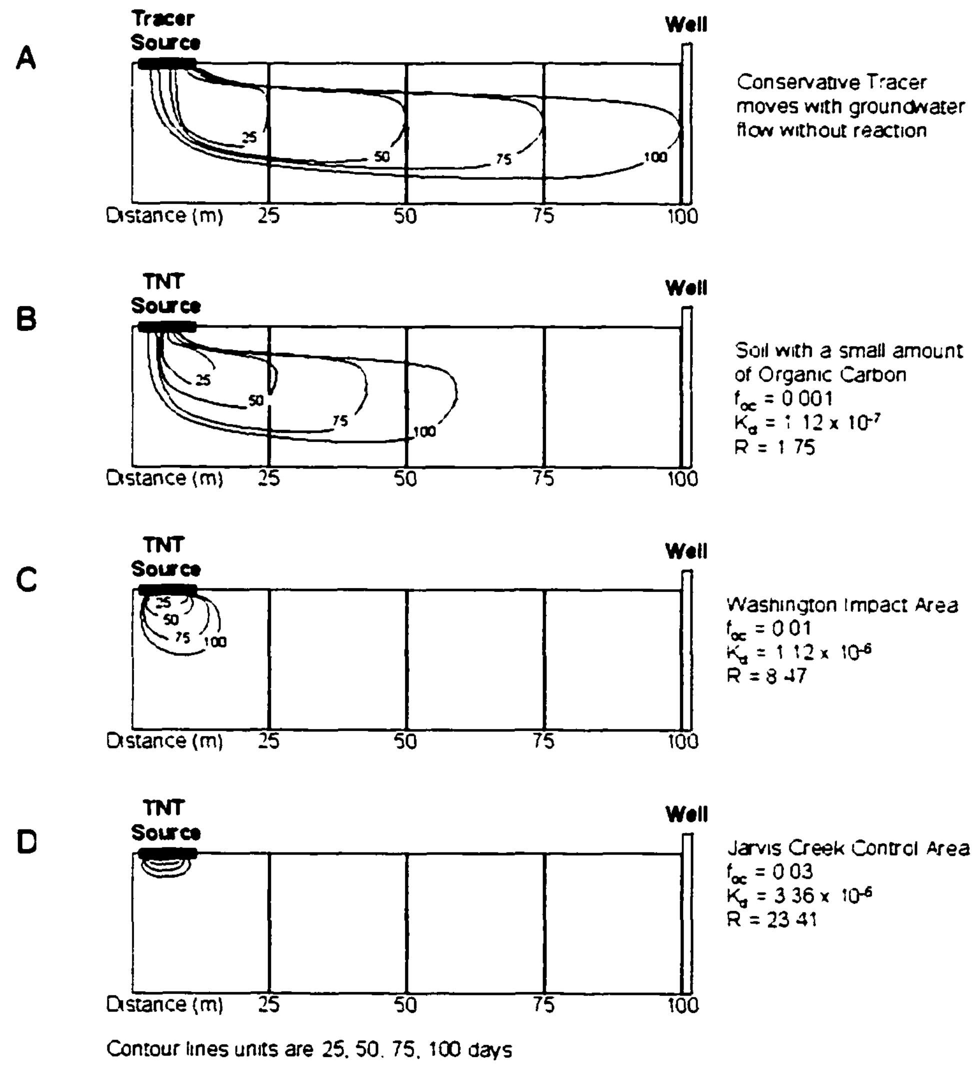


Figure 3-11. **Based on retardation factor modeling (Freeze and Cherry, 1979) the fraction of organic carbon f_{oc} affects the rate of TNT contaminant movement through a soil. Diagram A shows a conservative tracer that moves with groundwater. Diagram B shows the retardation effect with a very small amount of organic carbon present. Diagrams C and D show rates of TNT movement for soils in the study area. K_d is the distribution coefficient and R is the retardation factor.**

Ecotype Soil Characteristics

Statistical analysis of the Jarvis Creek control area ecotypes showed no evidence that PrcOM was different among these ecotypes. However, there were two soil quality variables (i.e., Fe and Cu) that may be used to detect significant differences between ecotypes. Results indicate there is a significant difference in the soil characteristics of the Jarvis Creek control area ecotypes and Washington Range control area scrub ecotype. However, the results may have been different if the Washington range and impact areas were included in the classification process. Washington range and impact areas were not mapped due to cloud cover in the Landsat scene and these two areas were considered to be the same ecotype. Additionally, a level 3 classification may have resulted in better discrimination between different vegetative forms within ecotypes (e.g., differentiating between a scrub ecotype dominated by *D. drummondii* and one dominated by *P. balsamifera* saplings), which may then be correlated with soil characteristics. Soil property differences between these forms may then be more pronounced. Overall, this analysis demonstrated that ecotypes could be effectively segregated based on soil properties and that there is potential for the ability to infer soil properties based on ecotype.

Crater Disturbance

Comparison of undisturbed Washington Range control area scrub to the Washington Impact area scrub showed no significant differences in PrcOM. There was a considerable difference between PrcOM of the 2-year old crater and sampled plots within the impact area. The center of the crater is nearly devoid of organic matter and there is a steep gradient of increasing organic matter percentages as measures move toward the outer rings, which indicates that the degree of the cratering disturbance is significant (Figure 3-5). If the frequency and intensity of this physical disturbance exceeds the capacity of the system to recover, the system may lose the capacity for contaminant attenuation. Whether the disturbance regime has or will reach such a critical threshold can be evaluated by comparing crater age. Older craters illustrate that after a period of time the center of the crater tends to increase in percent organic matter while the rings associated with the crater rim tend to remain low in percent organic matter. Relatively higher concentrations of organic matter were found in the center of craters that were four years old or older. This is a reasonable finding given the nature of the soil forming processes at work in the Washington impact area. Craters provide a depression that can capture wind blown leaves, silts and finer organic particulates, as well as seeds. They may also capture snow and serve as a moisture source for plant establishment. It appears that the physical disturbance and displacement of soil material eventually serves as a catalyst for organic matter additions assisting recovery. Also, the PrcOM of the surface soil appears to recover as shown by the flattening of the gradient curve on older craters. However, means comparisons and trend analysis should be viewed with caution due to small sample size (i.e., no replications of craters).

Conclusion

Approximations of area disturbed by munitions use per year and the maximum theoretical contaminant loading in this area show good correlation to measured contaminant concentrations. This highlights the possibility of using munitions expenditure data and failure rates for risk assessments. However, this analysis did not use actual firing data. Current munitions use tracking procedures account for types of munitions used for a particular range (USAEC, 2000). This evolving data set may provide greater resolution of the area disturbed and contaminant loading when combined with expenditure and failure rate data, but it still does not account for targetry locations. Firing data, or the number and type of munitions fired and the target areas into which they were fired, would provide the resolution required to adequately calculate munitions disturbance and contamination effects. Given the digital sophistication of the Army's weapons systems this level of resolution is within reach.

Organic matter content of the soils in this study proved to be a good predictor of CEC and it also is a good descriptor of crater disturbance. CEC should allow the use of the retardation factor approach to determining the relative risk for organic contaminants releases to the soils at Fort Greely. Soils with higher fractions of organic carbon and/or higher CECs should inhibit movement of these contaminants and provide time for some measure of transformation to take place before groundwater resources are impacted. Since SOM has an influence on contaminant fate and transport through the environment, range and impact area managers should be concerned with its dynamics and its condition in the soil. In the case of munitions use in impact areas, expected soil organic matter responses might be recovery from cratering through organic matter inputs, and the assimilation and transformation of explosive compound contamination within the soil matrix. These responses should be intimately tied to biomass inputs, and to processes that influence biological activity within the soil component all of which can be described by soil organic matter dynamics.

CHAPTER 4

Using CENTURY to Assess the Effects of Munitions Use

Introduction

Soil Organic Matter Dynamics in Agricultural Systems

Many agricultural researchers have investigated the effects of management practices on soils in an effort to identify a soil quality index and soil organic matter (SOM) dynamics frequently emerges as an indicator of soil quality. Cultivation practices have been shown to affect SOM dynamics and soil properties. Needelman et al. (1999) examined the interaction of tillage and soil texture and found that overall, no till practices resulted in an increase of particulate organic matter and soil carbon in the upper 5 cm of the soil profile as compared to conventional till practices for fine textured soils. They ultimately argued that SOM decomposition rates may increase with sand content and that particulate organic matter is a sensitive indicator of tillage-based depth effects. Hao et al. (2001) found that minimum tillage practices resulted in significantly higher organic carbon than found in conventional tillage practices. They also reasoned that differences in SOM dynamics in minimum tillage systems such as increased soil surface plant residue, reduced rate of plant matter decomposition and soil erosion, resulted in higher soil quality for minimum tillage soils verses conventionally tilled soils. Additionally, tillage practices affect soil organisms, their environment and functions, which in turn directly impacts SOM dynamics. Microbial activity has been shown to be higher in no till verses conventional till systems due to greater availability of soil moisture and more stable soil temperatures (Kladivko, 2001). Others have found that microbial biomass is higher in no till soils than in conventional till soils (Alvarez and Alvarez, 2000; Aon et al., 2001). They contend that this is a result of changes in soil structure (i.e., physical habitat) as a consequence of SOM loss and physical disturbance associated with conventional till practices. As such, tillage practices have been universally recognized as anthropogenic disturbances of varying degrees affecting ecosystem productivity and SOM is central to understanding the effects of these practices.

The agricultural scenarios described above can be adapted toward range and impact area management. From observation, munitions use creates craters, which affects soil structure and the degree to which plant residue is exposed to decomposition processes; it cuts and damages vegetation, which results in short term organic matter inputs; and causes fires, which releases nutrients. Craters can be equated to tillage practices, and plant damage and cutting can be equated to increased crop residue inputs or to phenomena such as tree blow down events. Since SOM influences contaminant fate and transport through the environment through microbial degradation and contaminant adsorption to soils with high fractions of organic carbon, range and impact area managers should be concerned with its dynamics and its condition in the soil and even consider SOM as a contaminant attenuation metric. In the case of munitions use in impact areas, expected SOM responses might be recovery from cratering through organic matter inputs, and the assimilation and transformation of explosive compound contamination within the soil matrix. These responses should be intimately tied to biomass inputs, and to processes that influence biological activity within the soil component all of which can be described by SOM dynamics.

A Simulation Approach to Investigate Munitions Disturbance

The investigation of anthropogenic disturbance within ecosystems is challenging both from an integrative systems analysis (i.e., highly complex) and cost (e.g., time and resources) perspective. The study of agricultural ecosystems, or agroecosystems, provides an effective approach in dealing with this challenge. Metherell (1992) described the agroecosystem as an interactive group of biotic and abiotic components that is complex due to relationships between socio-economic and ecological processes. He further argued that agroecosystems exploit a natural resource (i.e., soil component) using timed disturbances such as cultivation, fertilization, pesticide use and irrigation practices to obtain agricultural products. The effects of these disturbances are manifested by changes in ecological processes and properties such as soil organic matter dynamics. The analogy as it relates to Army ranges and impact areas is that military ecosystems also represent an interactive group of biotic and abiotic components that is complex due to relationships between the need for military training and ecological processes. The military exploits areas that provide realistic training environments in order to obtain combat readiness and in doing so exploit natural resources (Figure 4-1). Forms of disturbance associated with military training take the form of maneuver (e.g., soil compaction or damage to vegetation) and munitions use (e.g., cratering, damage to vegetation and/or increase fire frequency). Finally, sustainability is a critical requirement for both agricultural and military ecosystems. For military and agricultural lands, sustainability also means preventing contamination of water, air and soil components.

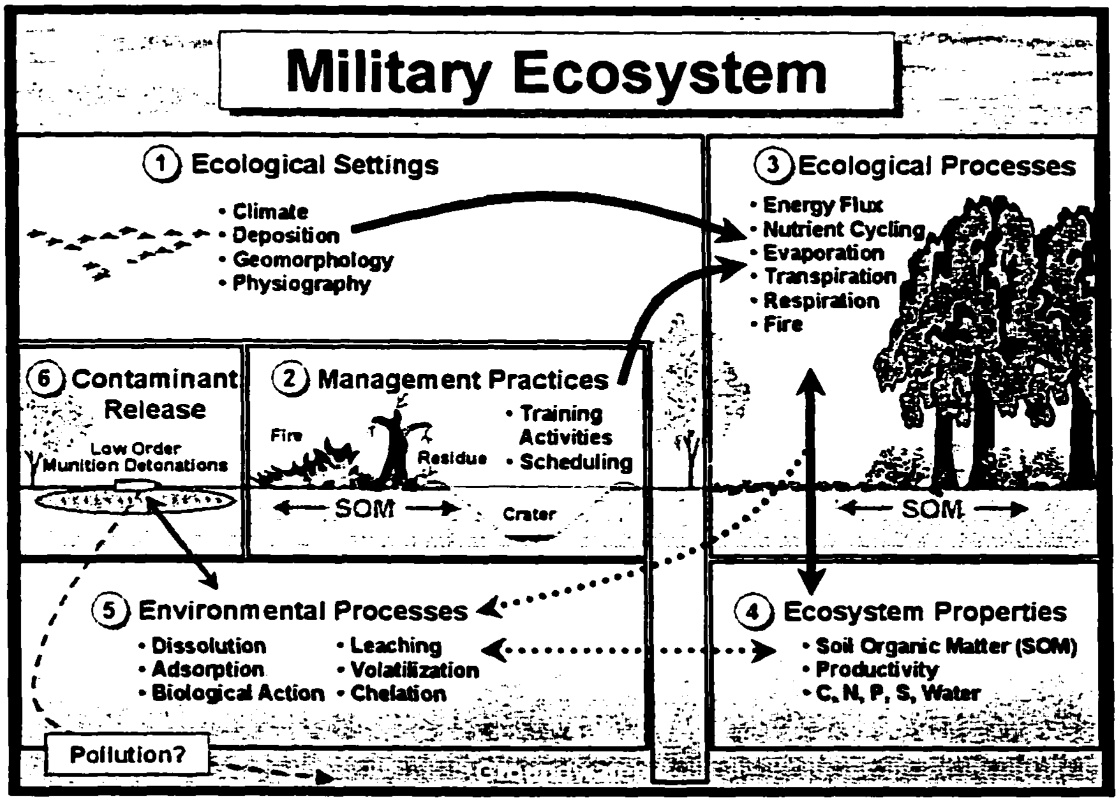


Figure 4-1. The Military Ecosystem (adapted from Metherell, 1992). Ecological setting (1) and management practices such as munitions use (2) combine to influence ecological processes (3). Ecological processes (3) help determine and are influenced by ecosystem properties (4). Also, ecological processes (3) in combination with ecosystem properties (4) help determine and are influence by environmental processes (5). The fate and transport of contaminants such as explosive compounds released into the environment (6) is determined by environmental processes (5).

Adding an additional dimension of military-ecosystem complexity is the issue of unexploded ordnance (UXO) associated with ranges and impact areas. Because of this hazard, access to impact areas is very limited making direct observation and study extremely challenging. Therefore, computer simulation is one of the few tools an investigator has to explore the relationships between ecological processes and human exploitation of natural resources in complex military ecosystems. Ecosystem scientists have effectively employed computer simulation of SOM dynamics (Ågren et al., 1991) to describe many complex systems such as hurricane disturbance (Sanford et al., 1991), grassland systems (Kelly et al., 1996; Parton et al., 1987, 1989, 1993, 1996; Seastedt et al., 1994), land use in Hawaii (Townsend et al., 1995), and CO_2 and climate change on tropical grasslands (Hall et al., 1995). Using a similar approach for military ecosystems, the ecological setting (e.g., climate, soil properties, plant communities and disturbance regime) can be characterized, and SOM dynamics can be modeled and evaluated using computer simulation. SOM dynamics simulation output, or the fluxes in SOM stocks as a result of anthropogenic management practices, can provide a metric for determining an ecosystem's response to various management practices. Finally, simulation can provide more refined hypotheses of soil response to munitions use that can be evaluated using field observations.

CENTURY Soil Organic Matter Dynamics Model

The CENTURY model developed by Parton et al. (1987) is a plant-soil ecosystem model that characterizes plant growth, nutrient cycling and soil organic matter dynamics for major ecosystems. The stated primary purposes of the model are to provide a tool for ecosystem analysis, to test the consistency of data and to evaluate the effect of changes in management and climate in a variety of ecosystems (Metherell et al., 1993). CENTURY predicts soil organic matter (SOM) change for different plant-soil systems through the simulation of natural and anthropogenic contributions into a comprehensive set of ecological based processes, the output of which is an array of descriptive ecosystem properties. CENTURY runs with a monthly time step and requires environmental and management input variables such as:

Environmental input variables-

- Monthly average maximum and minimum air temperature
- Monthly precipitation
- Lignin content of plant material
- Plant N, P, and S content
- Soil texture
- Atmospheric and soil N inputs
- Initial soil C, N, P, and S amounts

Management input variables-

- Grazing
- Forestry
- Fire
- Fertilization
- Crop cultivation

The model's output variables are:

- CO_2
- Crop and Grassland C

- Forest Carbon
- Nitrogen
- Phosphorus
- Soil Carbon (SOM)
- Sulfur
- Water and Temperature

CENTURY soil organic matter model is comprised of a combination of interactive submodels that simulate soil organic matter dynamics, plant production, nutrient cycling, and soil physical structure, water and temperature. A set of option files allows the user to parameterize CENTURY to desired site and management conditions. CENTURY submodels and parameterization files are summarized from Metherell et al. (1993) below.

Soil Organic Matter Submodel

The soil organic matter submodel (Figure 4-2) predicts SOM dynamics for a given ecological setting. In general, the plant production submodel inputs carbon to the SOM submodel in the form of above and belowground live biomass. Carbon losses for the model are accounted for through harvest, leaching and microbial respiration. Processes that degrade carbon and control its association to the soil are controlled by the soil water and temperature submodel, which is influenced by cultivation and soil texture.

The submodel is comprised of multiple compartments each with carbon fluxes regulated by environmental and management input variables described above. These compartments consist of the aboveground, surface, belowground and SOM compartments. The aboveground compartment consists of

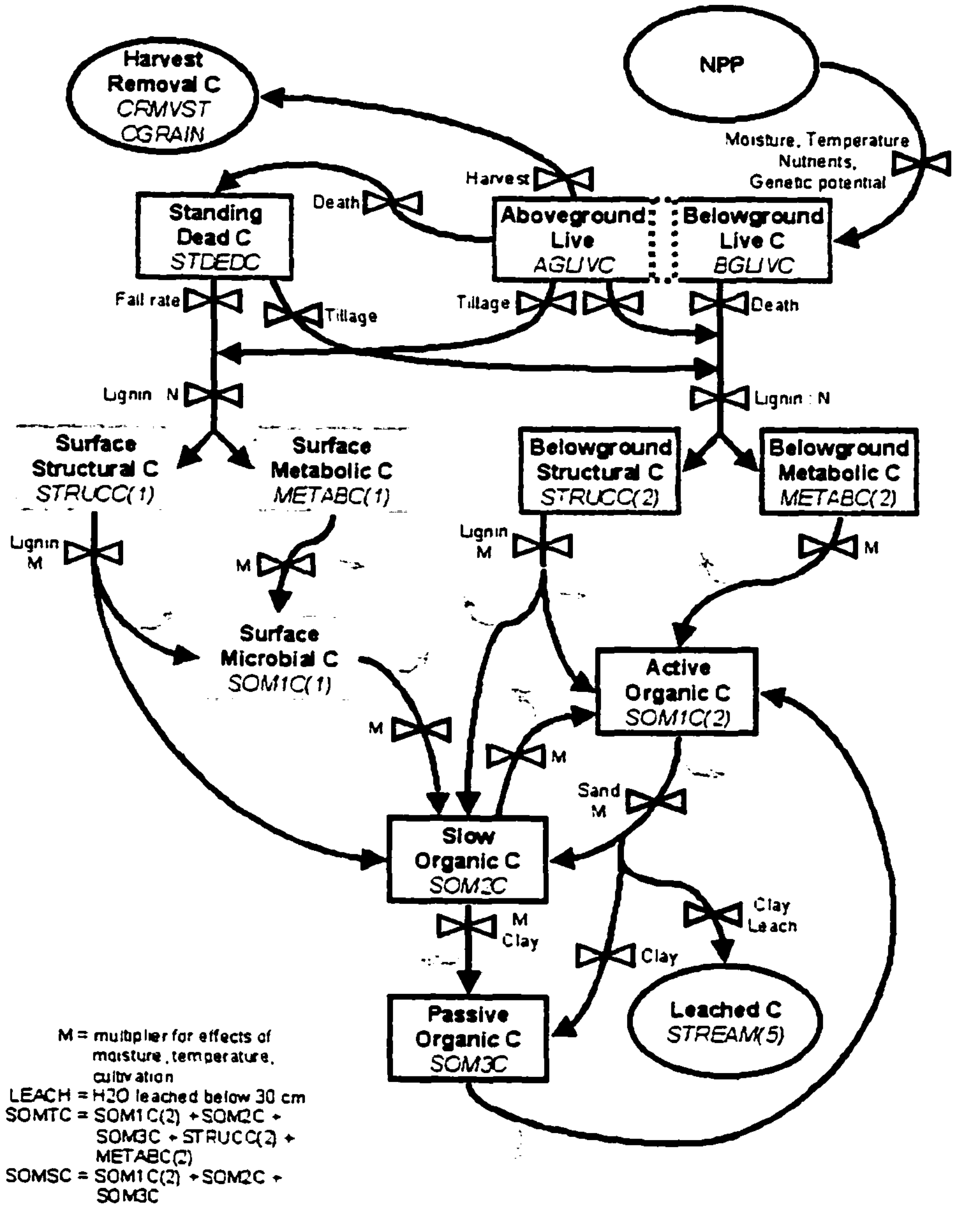


Figure 4-2. Diagram of the CENTURY soil organic matter submodel showing the major factors controlling the pools and flows of carbon. Reproduced from Metherell et al. (1993).

aboveground live and standing dead carbon pools. The aboveground live pool inputs are based on plant production submodels of the ecosystem of interest. Carbon can move out of the system through harvest, it can be converted to the standing dead pool or incorporated into the surface or belowground compartments through tillage. The surface compartment consists of structural, metabolic and microbial carbon pools. These pools receive organic matter inputs from the aboveground compartment. Partitioning to structural or to metabolic pools is based on lignin to nitrogen ratios. Higher ratios result in more partitioning to the structural pool, which has a slower decay rate than the metabolic pool. The microbial pool acts to further degrade organic matter from the structural and metabolic pools. Degraded organic matter flows from the surface compartment to the slow organic carbon pool of the SOM compartment.

The belowground compartment consists of live, structural and metabolic carbon pools. These pools receive organic matter inputs from the belowground compartment. Partitioning to structural or to metabolic pools is based on lignin to nitrogen ratios and higher ratios result in more partitioning to the structural compartment, which has a slower decay rate than the metabolic pool. Carbon outputs from the belowground compartment flow to the active and slow organic carbon pools of the SOM compartment.

The SOM compartment consists of the active, slow and passive organic carbon pools. The active organic carbon pool receives inputs from the belowground compartment and exchanges carbon with the slow organic carbon pool. It comprises approximately 2% of the total SOM compartment, is composed of soil microorganisms and their products, and has short turnover times of between one to three months. Carbon from the active organic carbon pool can be leached from the system, or transformed to the either the slow or passive organic carbon pools. The slow organic carbon pool receives carbon from the surface structural and microbial pools and the belowground structural pool, and exchanges carbon with the active organic carbon pool. It comprises 45 to 60% of the total SOM component, is composed of more decay resistant plant material and stabilized soil microbial products, and has turnover times from 10 to 50 years. If not exchanged with the active organic carbon pool, carbon from the slow organic carbon pool flows to the passive organic carbon pool. The passive organic carbon pool consists of highly stabilized organic matter. It comprises approximately 45 to 50% of the total SOM component and has turnover times of between 400 and 4000 years. The importance of the active, slow and passive organic carbon pools in determining the fate and transport of contaminants in the environment is summarized in Table 4-1.

Table 4-1

Description of the Active, Slow and Passive Soil Organic Matter Pools and Their Respective Contaminant Attenuation Qualities.

Soil Organic Matter Pool	% of Total[1]	Turnover Time[1]	Composition[1]	Attenuation Quality[2]
Active	2	1-3 months	Soil microorganisms and their products	Provides most of readily accessible food for soil microorganisms and most of the readily mineralizable nitrogen, most responsible for beneficial effect of soil structural stability
Slow	45-60	10-50 years.	Decay resistant plant material and stabilized soil microbial products	Important source of mineralizable nitrogen and other plant nutrients which affects biomass production and subsequent organic matter inputs
Passive	45-50	400-4000 years	Highly stabilized organic matter	Most responsible for Cation Exchange Capacity (CEC) and water holding capacity

[1] Metherell et al., 1993
[2] Brady and Weil, 1999

Plant Production Submodels and Management Practices

CENTURY utilizes two plant production submodels: the grassland/crop submodel and the forest submodel. Both can be used in concert with slight modifications for tree to grass light and nitrogen competition to simulate savanna systems. The grassland/crop submodel simulates production for herbaceous crops and plant communities. The forest submodel simulates production for deciduous and evergreen forests. Harvest, grazing, fire, and cultivation practices can be simulated in these submodels throughout a range of frequencies and intensities. Fertilizer additions and irrigation amounts and rates can be scheduled into the submodels as well as cultivation methods such as tillage.

Nitrogen, Phosphorus, and Sulfur Submodels

The nitrogen, phosphorous and sulfur submodels in CENTURY are similar to the carbon submodel. Mobilization of these elements is calculated as a product of carbon to element ratios and carbon flows. Immobilization is calculated based on carbon losses from the system in the form of CO_2 (e.g., plant and or microbial respiration) and when carbon flows from high ratio pools to low ratio pools. Additionally, the phosphorous and sulfur submodels are slightly different from the carbon submodel. Since significant phosphorous and sulfur inputs can be derived from soil parent material, these submodels also account for weathering rates and element to mineral occlusion and sorption processes.

Soil Physical Structure Submodel

The soil physical structure submodel describes soil texture, bulk density, water content, and bulk organic matter content throughout a soil profile. Also, this submodel simulates homogenization of the soil stratum resulting from cultivation.

Water Budget, Leaching, and Soil Temperature

The water budget submodel calculates water losses through evaporation transpiration, and interflow, runoff and leaching; determines potential evapotranspiration; calculates water content and saturated flow through the soil matrix; and accounts for frozen precipitation, snow melt and simple watershed stream flow. Soil water content is calculated as a function of measured or estimated site parameters including bulk density, soil texture and organic matter content and is updated at the end of every simulation time step. Leaching losses from carbon, nitrogen, phosphorous and sulfur pools is simulated across the active pool and mineral soil layers, and is a function of saturated water flow and soil texture. Maximum and minimum soil temperatures are calculated for the surface as a function of maximum and minimum air temperatures and canopy biomass. The model uses the average of these values to regulate decomposition and plant growth.

The CENTURY Modeling Environment

The CENTURY modeling environment is shown in Figure 4-3. The user can parameterize twelve "*.100" data files through the FILE100 program. For example, FILE100 is used to create and modify the "<site>.100" file. Parameters in this file include site-specific characteristics such as soil properties, climate and initial conditions for soil organic matter. The EVENT100 program is used to schedule events that will occur during simulations such as the first and last month of tree grown and disturbances such as fires, tree blow downs and tillage.

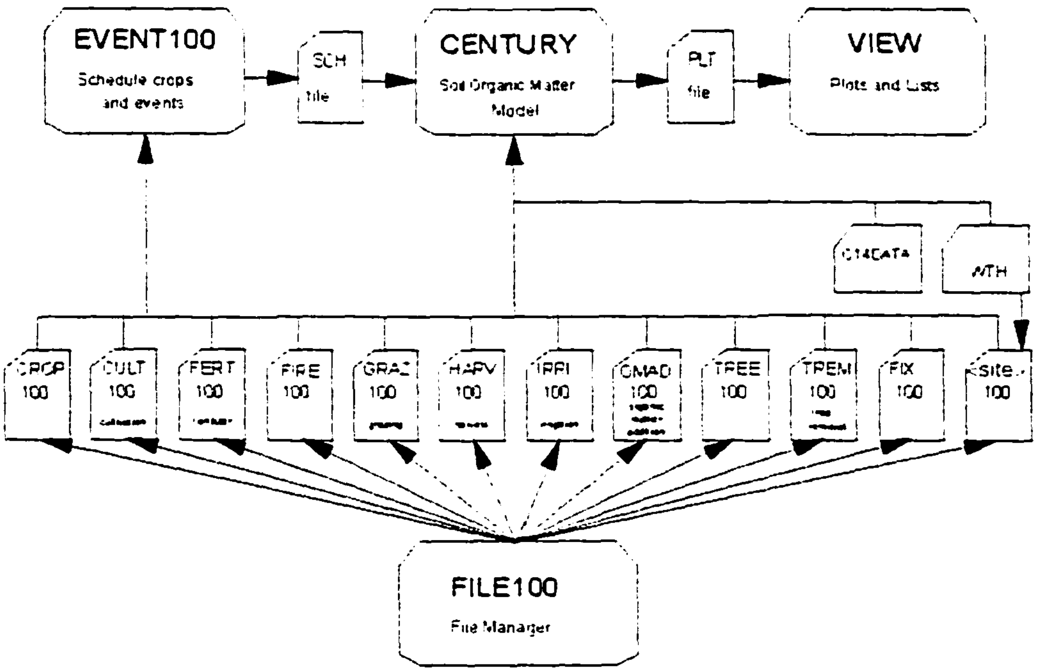


Figure 4-3. The CENTURY model environment showing the relationship between programs and the file structure (reproduced from Parton et al., 1992).

Research Objectives and Hypothesis

Given the potential attenuation effects SOM has on contaminant fate and transport in the soil, the objectives of this study were:

1. To explore the usefulness of computer simulation to assess the effects of munitions use on SOM dynamics.
2. To investigate the effect of different levels of munitions use on SOM stocks as measured by soil carbon.
3. To determine if the effect of munitions use on SOM dynamics depends on ecotype.

Research hypotheses for this study parallel the objectives listed above. They were:

1. CENTURY adequately predicts levels of primary production and soil carbon for modeled ecotypes.
2. The level of munitions use determines the rate of change in soil carbon stocks.
3. The rate of change in soil carbon stocks varies by ecotype.

The combination of study objectives/research hypotheses #2 and #3 provides the foundation for a contaminant attenuation metric that would be a function of munitions use level and ecotype.

Methods

Study Area Disturbance Characteristics

The simulation effort will focus on riverine ecotypes since many of Fort Greely's impact areas are situated along rivers and streams that traverse the reservation. Ecotypes that will be modeled are Jarvis Creek broadleaf, mixed leaf, needleleaf and scrub. A detailed study area description along with ecotype descriptions can be found in Chapter 3.

Natural disturbances such as erosion and fire drive succession in these riverine settings and are important elements of the simulation. Erosion caused by either water or by winds is prevalent in the riverine scrub ecotype. This is because it is situated in an active flood plain (Appendix B, Photo 1) and the limited vegetative cover associated with the scrub ecotype (Appendix B, Photo 2) is vulnerable to flood erosion (Appendix B, Photo 3) and provides relatively little protection from strong winds. Floodplain succession models indicate that this scrub ecotype is an early colonization stage which resides on intermediate elevation terraces (2.4-3 m above normal flow levels) that floods approximately every 10 years (Van Cleve et al., 1993; Viereck et al., 1993; Jorgenson et al., 2001). These floods often kill poorly established shrubs and remove any litter fall (Viereck et al., 1993). From observation in the study area, water erosion appears to remove surface organic materials down to gravel beds and little sedimentation occurs during a flood. The frequency of occurrence of wind erosion is not known but its effects are visible on the landscape (Appendix B, Photo 1) and resemble flood erosion.

Fire frequencies for the region are on the order of one in every one hundred years (Jorgenson et al., 2001) and affects all of the ecotypes. Successional stages following fire are moss-herb stage (1-5 years), tall shrub-sapling stage (5-30 years) dense tree stage (30-55 years), mixed forest stage (55-90) years), and spruce stage (90-200+ years) (Jorgenson et al., 2001).

While the modeling effort in this study does not attempt to replicate succession dynamics since each ecotype is modeled separately, these stages are associated with the simulated ecotypes described above.

Simulation Design, Parameterization and Calibration

The timeline for each simulation consists of an equilibrium period (i.e., AD 1 -1950) followed by an impact area utilization period of 50 years (i.e., 1950-2000) followed by a recovery period (i.e., 2000-2050). Data requirements for research hypothesis number one centered on assessing the effectiveness of parameterization and calibration of the CENTURY model. Primary production and soil carbon data for the ecotypes were compared to simulation output of these variables. Only relative comparisons between ecotype and munitions use were evaluated so accurate model responses were of more importance than precise soil carbon measures. Therefore, successful simulation calibration was achieved when primary production and soil carbon output was within 20% of measured values.

Data requirements for research hypotheses two and three required multiple CENTURY simulations for varying levels of munitions use in the various ecotypes. Rates of change in microbial, active, slow, and passive SOM pools (g carbon/m^2/yr) over the munitions use period and over a recovery period were used to evaluate relative differences in munitions use levels and ecotype effects. Direct statements cannot be made regarding simulated changes in SOM based on a statistical analysis other than to describe the relative importance of munitions use level and ecotype (Kelly et al., 1996). Additionally, and as described by Seastedt et al. (1994), statistical analysis on model output variables based on the known influence of management parameterization design would be inappropriate. However, since the primary interest was in the significance of a munitions use and the possible interaction effect between munitions use and ecotype, a standard two-way ANOVA was used as a tool to evaluate the relative importance of the variables of interest in the same manner as Seastedt et al. (1994). Therefore, study design entailed a two-factor, 3x4 factorial completely randomized design with ten replications per treatment (Table 4-2).

Table 4-2

Matrix Describes a Two-factor, 3x4 Factorial Design. Munitions use has 3 levels (Low, Moderate, and High levels) and ecotype has 4 levels (Scrub, Broadleaf, Mixed Leaf and Needleleaf). This design produced 120 observations.

Ecotype	Rep	Munitions Use		
Scrub	1,...,10	Low	Moderate	High
Broadleaf	1,...,10	Low	Moderate	High
Mixed Leaf	1,...,10	Low	Moderate	High
Needleleaf	1,...,10	Low	Moderate	High

CENTURY model parameterization consisted of creating 120 unique schedule files, and modifying existing site and tree files. Schedule file parameterization accounted for the natural disturbance régime and growth prior to munitions use (i.e., equilibrium period), the effects of munitions use (i.e., impact area utilization period) and the return to the natural disturbance régime and growth following release from munitions use (i.e., the recovery period). Equilibrium and recovery period event sequences were the same and consisted of repeating blocks of 99 years of growth followed by a year that included a fire that burned through the forest canopy (i.e., growth-fire-growth-fire). For broadleaf, mixed leaf and scrub ecotype models, month of first growth was set at April, month of senescence was set at September and month of last growth was set at October. For the needleleaf ecotype model, growth occurred throughout the year. In order to replicate water/wind erosion disturbance in the scrub ecotype models due to over-bank floods during heavy summer rains an erosion event was added every tenth year during the month of August. During this event 4 cm of surface material was removed and trees were killed using a tree blow down option.

The impact area utilization period represented a parameterization challenge in relating available management parameterization options to munitions effects. Munitions effects within an impact area are increased fire frequency, plant damage and cratering. These effects can be simulated in CENTURY by parameterizing them in terms of fire, forestry and cultivation management input variables. For crater disturbance the CENTURY parameterization event was a plowing event. A tree blow down event parameterized cutting and killing of vegetation. Fires were parameterized as shrub fires that burn low to the ground and leave mature trees unharmed.

Degree of disturbance was based on three levels of munitions use, which were:

1. Low level usage (L), which will entail a low range of cratering (i.e., tillage) vegetation cutting (i.e., residue input) and fire frequency.

2. Moderate level usage (M), which will entail a moderate range of cratering (i.e., tillage) vegetation cutting (i.e., residue input) and fire frequency.

3. High level usage (H), which will entail a high range of cratering (tillage) vegetation cutting (i.e., residue input) and fire frequency.

Additionally, a no usage simulation was executed to provide a baseline from which munitions use effects could be assessed.

Timing of treatments was based on a probability of occurrence. For example, bomb crater measurements indicate that some areas receive only one crater in a 10-year period while others are cratered every one to two years. Therefore, the probability of occurrence for low level usage was p=0.10 (i.e., once every 10 years) and the probability of occurrence for high level usage was p=0.50 (i.e., once every 2 years). A probability of occurrence of p=0.167 (i.e., once every 6 years), which is midway between low level and high level usage, was used for moderate level usage. Assuming that vegetation is cut and killed every time a crater is created results in complimentary probabilities of occurrence for residue inputs.

Fire event probabilities of occurrence are slightly lower since munitions cause fires less frequently than craters or vegetation kills. Fire frequencies for Fort Greely are slightly higher than the natural fire frequency for Alaska Forest land, which is one fire in every one hundred years (Jorgenson et al., 2001). Fort

Greely has had 15 major fires between 1954 and 1999 most of which occurred in impact areas and some impact areas have been repeatedly burned (CEMML, 1999). One of Fort Greely's high usage impact areas has had three fires in a 22-year period. Assuming this information approximates the increase in fire frequency due to munitions use, the low level fire treatment probability of occurrence was p=0.067 (i.e., once every 15 years); for high level usage, the probability of occurrence was p=0.20 (i.e., once every 5 years); and a probability of occurrence of p=0.10 (i.e., once every 10 years), which is midway between low level and high level usage, was used for moderate level usage. Table 4-3 shows how this probability of occurrence method was applied for 3 replications of low level usage.

Site parameterization used a Bonanza Creek Long Term Ecological Research (BNZ LTER) site parameterization file developed by the Natural Resource and Ecology Laboratory, Colorado State University for site characteristics. The BNZ LTER site is located 20 km south of Fairbanks, Alaska and approximately 160 km west of Fort Greely. The file was modified for each ecotype using soil survey data reported in Chapter 3, which was gathered from Fort Greely sampling plots in each of the ecotypes except the needleleaf ecotype. Additionally, climate and atmospheric nitrogen deposition data from the BIG Delta FAA/AMOS AP, AK (2001) and the NADP for North Star, AK (2001) respectively. Both are located within 30 km of Fort Greely. The equilibrium block described above allowed initial soil biogeochemistry, biomass and water parameters to equilibrate for model calibration.

Table 4-3

Management Parameterization Matrix for Low Intensity Management Over Three Replications.

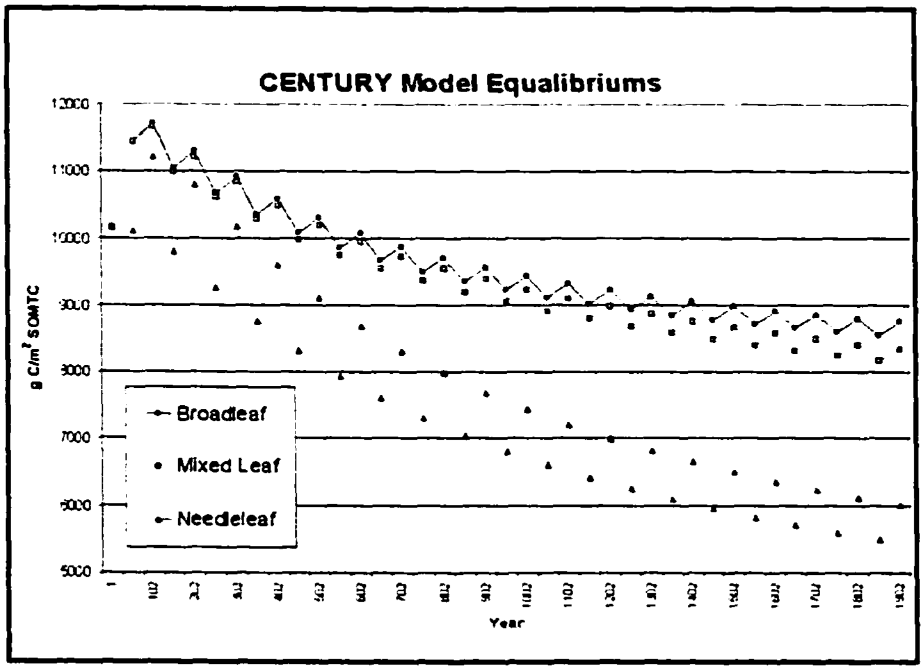
Scheduling Matrix for Low Intensity Munitions Use	Replication								
	1			2			3		
	Crater	Cut	Fire	Crater	Cut	Fire	Crater	Cut	Fire
Rate	1/10 yr	1/10 yr	1/15 yr	1/10 yr	1/10 yr	1/15 yr	1/10 yr	1/10 yr	1/15 yr
Year/p	0.1	0.1	0.067	0.1	0.1	0.067	0.1	0.1	0.067
1951	0	0	0	1	1	0	0	0	0
1952	0	0	0	0	0	0	0	0	1
1953	1	1	0	0	0	0	0	0	0
1954	1	1	0	0	0	0	0	0	0
1955	0	0	0	0	0	1	0	0	0
1956	0	0	0	0	0	1	0	0	0
1957	0	0	0	0	0	0	0	0	1
1958	0	0	0	0	0	8	1	1	0
1959	0	0	0	0	0	0	0	0	1
1960	0	0	1	0	0	1	0	0	0
1961	0	0	0	0	0	0	0	0	1
1962	0	0	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0
1965	1	1	0	0	0	0	1	1	0
1966	0	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0	0	0
1969	1	1	0	0	0	0	0	0	1
1970	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	1	0	0	0
1972	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	1	0	0	0
1975	0	0	0	0	0	0	0	0	1
1976	0	0	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0
1980	0	0	0	1	1	0	0	0	0
1981	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	1	0	0	0
1984	0	0	0	1	1	1	0	0	0
1985	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0
1988	0	0	1	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	1
1990	0	0	0	1	1	0	0	0	0
1991	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0
1996	1	1	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	1
1998	0	0	1	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0
2000	0	0	0	1	1	0	0	0	0
Total Events	5	5	3	5	5	15	2	2	8

Note: Highlighted numeral "1" indicates an occurrence that would be parameterized into a CENTURY schedule file. Numbers are generated by a Bernoulli method, which is characterized by a probability of success (*p* value), on a given trial. Bernoulli random variables have the value 0 or 1. For example, you can draw a uniform random variable in the range 0...1. If the variable is less than or equal to the probability of success, the Bernoulli random variable is assigned the value 1; otherwise, it is assigned the value 0.

The CENTURY tree.100 file was modified to reflect the study area climate and nutrient availability. This file contains various tree types that are used for forest simulations. Tree types that were modified were the Coweeta (CWT) deciduous system, which was used to represent the broadleaf ecotype; the Bonanza Creek (BNZ) coniferous system that was used to represent the needleleaf ecotype; and the Mixed (MIX) coniferous-deciduous system, which was used to represent the mixed leaf ecotype. The scrub ecotype was parameterized as a savanna system using the CWT and the Niwot (NWT) arctic tundra system. For the CWT and MIX systems, parameters controlling the optimum and maximum temperatures for production to simulate temperature effect on growth were adjusted to 15 and 32 °C, respectively. This adjustment reflects the BNZ system and better represents climate conditions for the study area. Nutrient adjustments were made during model calibration. Parameterization data for site files is at Appendix C. Tree and schedule file parameterization data are at Appendix D.

Model Equilibration

Once initial parameterization was completed, a simulation run was made to determine if the models were performing correctly and reaching equilibrium. All of the models responded appropriately to schedule file growth and disturbance parameterization, as well as site and tree file parameterization. An evaluation of the total soil organic carbon (SOMTC) output variable shows that the broadleaf, mixed leaf, and needleleaf models reached equilibrium after approximately 1,900 years of simulation time and the scrub model reached equilibrium after approximately 500 years of simulation time (Figure 4-4).



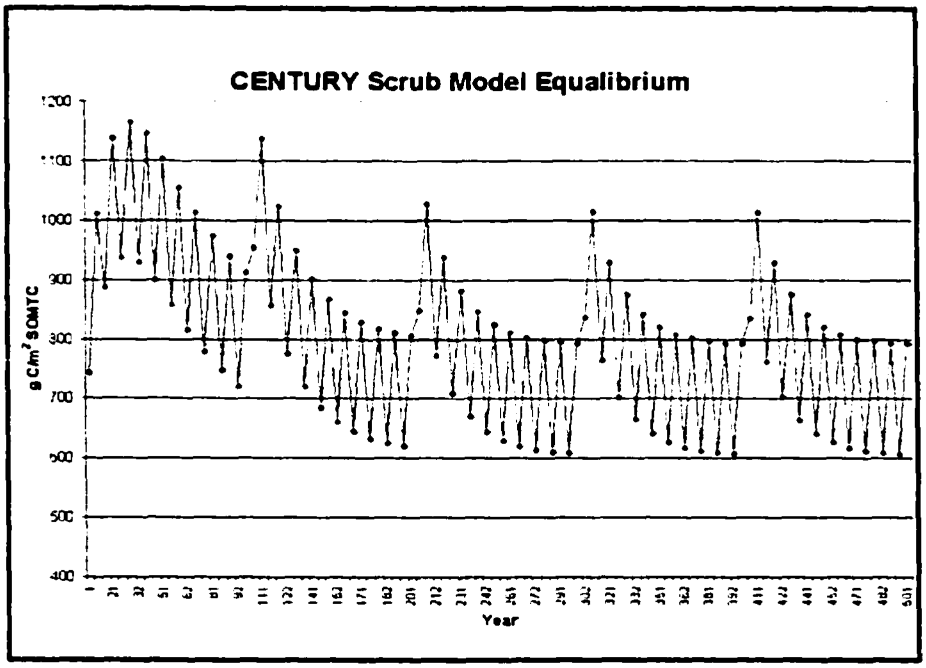


Figure 4-4. Equilibrium plots for SOMTC (Total Soil Carbon) of broadleaf, mixed leaf, needleleaf and scrub ecotypes.

Model Calibration

CENTURY output from the end of the equilibrium block was used to evaluate and calibrate model performance for each simulated ecotype. Model calibration involved evaluating CENTURY production and soil carbon output with study site data, and data reported by the BNZ LTER site (Table 4-4).

Table 4-4

Calibration Data Comparisons between CENTURY Output and Data Set Values. CENTURY performance indicates how closely output matched field data. Performance goals were ± 20 % of actual values.

CENTURY		Date Set Values			CENTURY
Output Variable	Output Value	BNZ (1)	CRREL (2)	CEMML (3)	Performance* ± %
Broadleaf Model					
SOMTC	8255.852			9765	-15%
$FCACC_{MOD}$	337.7032	415			-18%
RLVACC	172.9331	168			+3%
Mixed Leaf Model					
SOMTC	7977.102			9975	-20%
$FCACC_{MOD}$	295.8715	356			-19%
RLVACC	166.0645	320			-48%
Needleleaf Model					
SOMTC	5276.377	5358**		NA	-2%
$FCACC_{MOD}$	158.7272	133			+19%
RLVACC	57.9965	739			-92%
Scrub Model					
SOMTC	820.3817			696	+18%
AGCACC	15.5121		30.6		-18%
$FCACC_{MOD}$	67.8623		71.4		

* CENTURY performance goals for SOMTC and $FCACC_{MOD}$ or $FCACC_{MOD}$+AGCACC was ± 20%.

** Value is from the CENTURY BNZ LTER model.

SOMTC – Total soil organic C in the simulation soil layer C including belowground structural and metabolic (g/m2). AGCACC – Growing season accumulator for aboveground C production in grams per square meter per year (g/m2/y). $FCACC_{MOD}$ – Growing season accumulator for C production in forest system in grams per square meter per year (g/m2/y) and does not include belowground accumulator values for coarse and fine roots. RLVACC – Growing season accumulator for C production in forest leaf compartment (g/m2/y).

Data Set Description	Remarks
1. Bonanza Creek Long Term Ecological Research Site. Production, foliage biomass and nitrogen from LTER sites 1989 (Yane, 1989) http://www.lter.uaf.edu/Data_catalog_master.cfm	Data Set BNZD00108:98
2. US Army, Cold Regions Research and Engineering Laboratory (CRREL). Biomass Harvest, Washington Impact Area Fort Greely, Alaska Range Characterization (Bristol, 2001)	CRREL Draft Report
3. Center for Environmental Management of Military Lands (CEMML), CSU. Soil Characterization Fort Greely, Alaska (Houston, in prep)	Chapter 3 of this Dissertation

The primary CENTURY output variables used to evaluate model performance were SOMTC, and growing season accumulators for aboveground carbon production (AGCACC), and carbon production for the forest system (FCACC). FCACC output was modified ($FCACC_{MOD}$) to reflect aboveground production only (i.e., coarse and fine root accumulators are not included). Carbon production in forest leaf compartment (RLVACC) was used as an additional but secondary measure of production. The performance goal for successful model calibration was ±20% of field data values for SOMTC and $FCACC_{MOD}$ or $FCACC_{MOD}$+AGCACC in the case of the scrub model. Initially, values for all of these output variables for all models were approximately 50% below observed values and they decreased over time. However, an adjustment to the symbiotic N fixation maximum for forest net production input parameter in the tree.100 file corrected this problem. All tree systems were adjusted upward from zero to 0.0003 g N fixed/g C new growth to better replicate production resulting from both historic and contemporary alder N-fixation additions (Parton personal communication; Klingensmith and Van Cleve, 1993; Van Cleve et al., 1993; Viereck et al., 1993). Also, this parameter was used to adjust ecotype models to represent observed differences between ecotypes. For example, BNZ LTER data suggest that aboveground annual production values should be highest for broadleaf forests and lowest for needleleaf forests (Yarie, 1999). Therefore, final values for this tree.100 input parameter were 0.0004, 0.0003 and 0.0002 (g N fixed/g C new growth) for CWT, MIX and BNZ tree systems, respectively.

The broadleaf and mixed leaf models were evaluated with respect to SOMTC, $FCACC_{MOD}$ and RLVACC and were found to perform well when compared to reported soil carbon, production and foliage biomass (Table 4-4). SOMTC values were slightly low but within 20% of soil data, and $FCACC_{MOD}$ values were slightly high but within 20% of production data. The RLVACC value for broadleaf was very close to production data, however the RLVACC value for mixed leaf was about 39% of the production data. This was not deemed critical since the $FCACC_{MOD}$ output for the mixed leaf model seemed reasonable. Overall, these models appeared to adequately represent the ecotypes they intended to simulate.

Soil data for calibrating the needleleaf model was not available for comparison with model output. Therefore, needleleaf model SOMTC values were compared to mixed leaf model values and found to be slightly lower and not grossly different from mixed leaf values. Additionally, this model used previously parameterized BNZ site and tree files that were provided with the CENTURY software package (with the exception of the site-specific parameterization mentioned earlier - i.e., climate and atmospheric deposition). Therefore, the needleleaf model was compared to the BNZ LTER model. Model output for SOMTC closely matched the BNZ LTER model. $FCACC_{MOD}$ output slightly over estimates BNZ LTER production data. The model greatly underestimates BNZ LTER data for RLVACC and this may introduce some uncertainty about performance of this model. However, since aboveground production is comparable to BNZ LTER production data, and SOMTC output is similar to the

BNZ LTER model, this model was considered suitable for use in the relative rate of change comparisons of soil carbon pools described earlier.

Since, the scrub ecotype was modeled as a savanna system its calibration required the use of AGCACC output to account for grassland production. Data used to estimate production was derived from biomass harvests conducted within the scrub ecotype (Bristol, 2001). Biomass for scrub the ecotype is small compared to forest ecotypes. Since most of the biomass consists of grasses, leaves and fine branches, an assumption that all the biomass that was harvested represents annual growth (i.e., ignoring the comparatively small amount of scrub large wood biomass) enables a coarse comparison with model output. $FCACC_{MOD}$ output is slightly below CRREL harvest data and AGCACC output is approximately twice that of CRREL harvest. However, the sum of CENTURY $FCACC_{MOD}$ and AGCACC output for total aboveground output compares well (i.e., <20% difference) with total CRREL harvested biomass. Also, model output for SOMTC is within 20% of soil data. As with previous models, this model appeared to adequately represent the ecotype it was intended to simulate.

Finally, soil output variables such as net nitrogen and phosphorous mineralization annual accumulators (e.g., TNETMN(1) and TNETMN(2) respectively) and total mineral nitrogen TMINRL(1) for each modeled ecotype were evaluated and found to be reasonably similar to output generated using the CENTURY BNZ LTER model, and to soil data reported in chapter 3 of this dissertation (Metherell et al., 1993).

Results

Munitions Use Effects on SOMTC

Data generated by the 120 simulations yielded rates of response (i.e., loss) to munitions use and rates of recovery (i.e., accumulation) following munitions use for SOMTC, and the active, slow and passive SOM pools. Response rates were calculated for the 50-year period of munitions use between 1950 and 2000. Since rates of recovery generally did not show positive trends until approximately 20 years following the system's release from munitions use, these rates were calculated using output from the 20-year period between 2030-2050.

Graphical analysis of broadleaf and mixed leaf ecotype response to a single moderate munitions use level replication (Figure 4-5) shows demonstrative SOMTC responses to munitions disturbance events. Subsequent to each disturbance event period, the amount of SOMTC (g/m^2) increases due to organic matter inputs. Following the first 3 to 4 disturbance events overall SOMTC levels decline markedly. Averaging the response over 10 replications for each ecotype by munitions use level shows the same effect (Figure 4-5). Additionally, SOMTC loss rates during munitions use appear greater than accumulation rates during recovery.

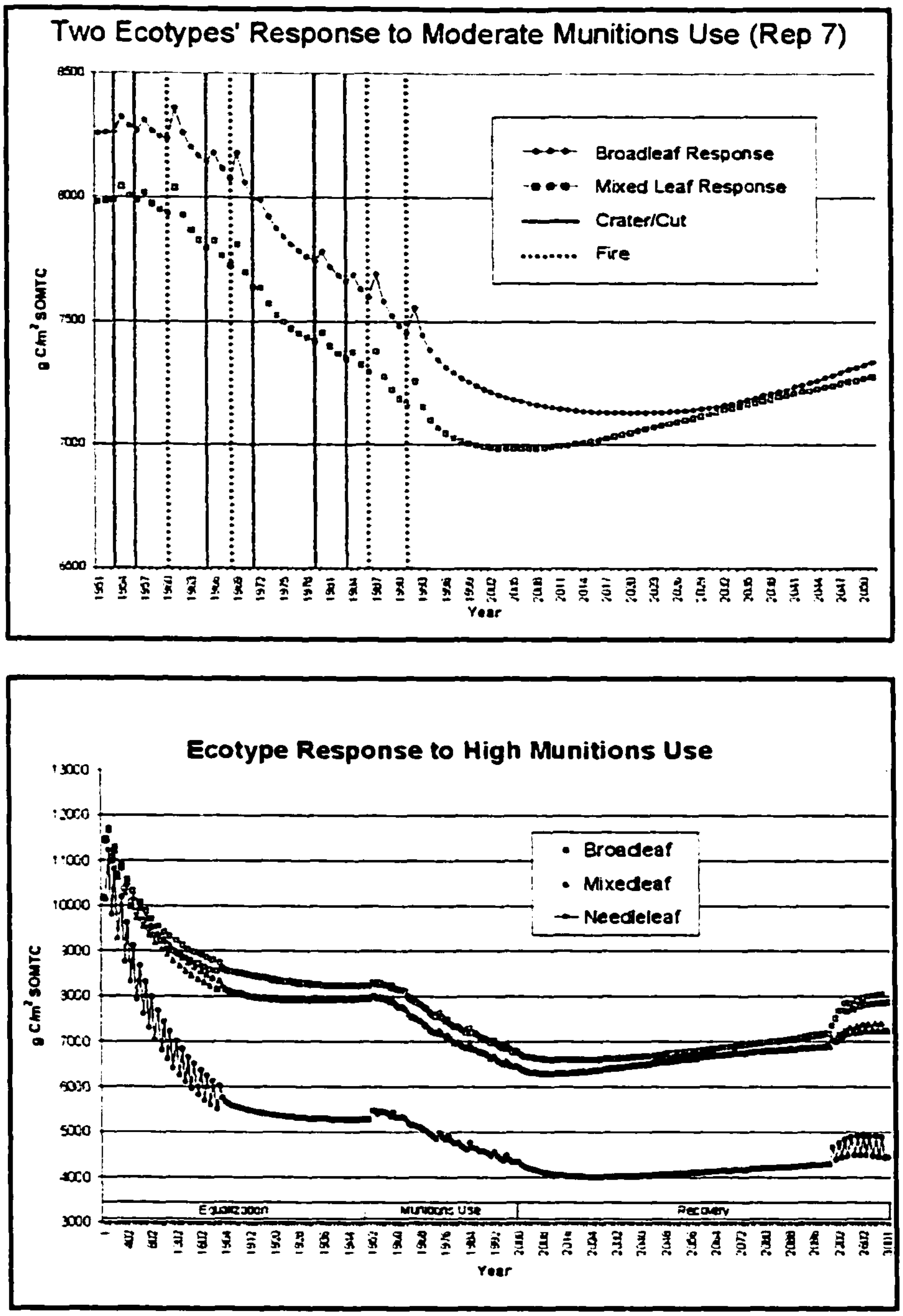


Figure 4-5. Ecotype responses to levels of munitions use. Top plot shows one replication of moderate level use for broadleaf and mixed leaf ecotypes. Note SOMTC response following a munitions use event and the overall trend in SOMTC loss. The bottom plot shows the average response (n=10 replications) for high intensity munitions use for three ecotypes (scrub ecotype is not plotted due to scale considerations).

Note change in time scale on bottom plot from 100-year increments during equalization (1-1950) to 1-year increments during munitions use and recovery (1951-2100) then back to 100-year increments from 2101 to 3001.

Individual ecotype response to munitions use levels is shown in Figures 4-6 a-d. Responses are generally similar for broadleaf, mixed leaf and needleleaf ecotypes in that higher the levels of munitions use result in higher SOMTC losses. However, the needleleaf response is slightly different because there is a small increase in SOMTC amounts during the first 10 years of munitions use. At first inspection, the scrub ecotype appears highly variable with regularly occurring peaks and troughs in SOMTC amounts. However, this is a result of the 10-year flood event that occurs throughout the simulation timeline. Closer inspection reveals that scrub response shows an overall decrease in SOMTC amounts during the munitions use period. Also, there is an initial increase in SOMTC amounts in the first one to two decades of munitions use and that subsequent to this early response, higher levels of munitions use result in higher SOMTC losses. Finally, the net decrease in SOMTC amounts for scrub is much smaller than for broadleaf, mixed leaf and needleleaf ecotypes.

Individual ecotype recovery from munitions use is similar for all ecotypes. SOMTC accumulation following release from munitions use indicates that higher levels of historical munition use result in lower amounts of accumulated SOMTC during the recovery period. Also, the rates of accumulation during the recovery period appear to be much less than the rates of loss during the munitions use period.

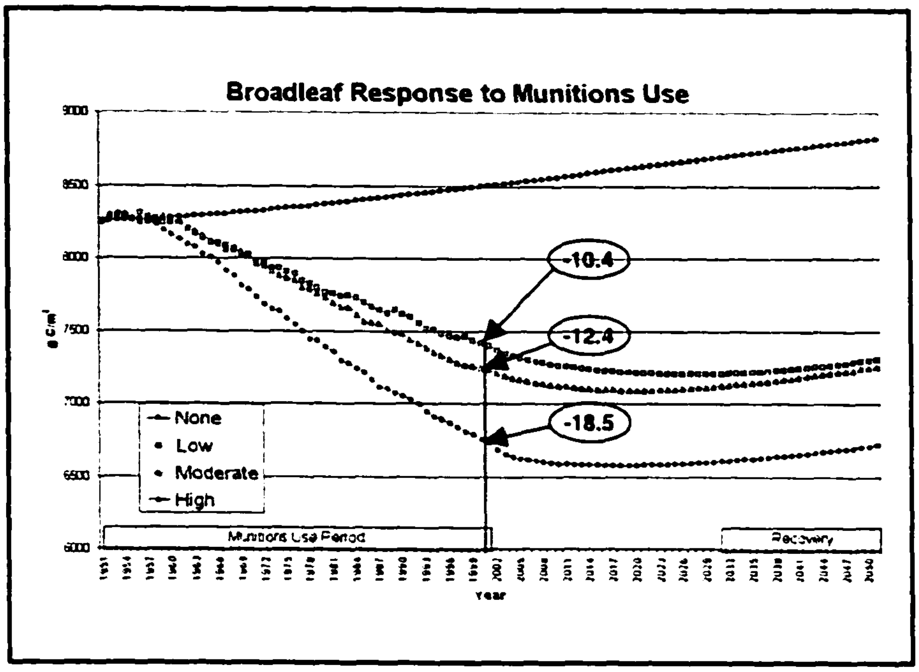


Figure 4-6a. Broadleaf ecotype SOMTC (Total Soil Organic Carbon) response to varying levels of munitions use. Percent loss during munitions use is indicated inside ovals.

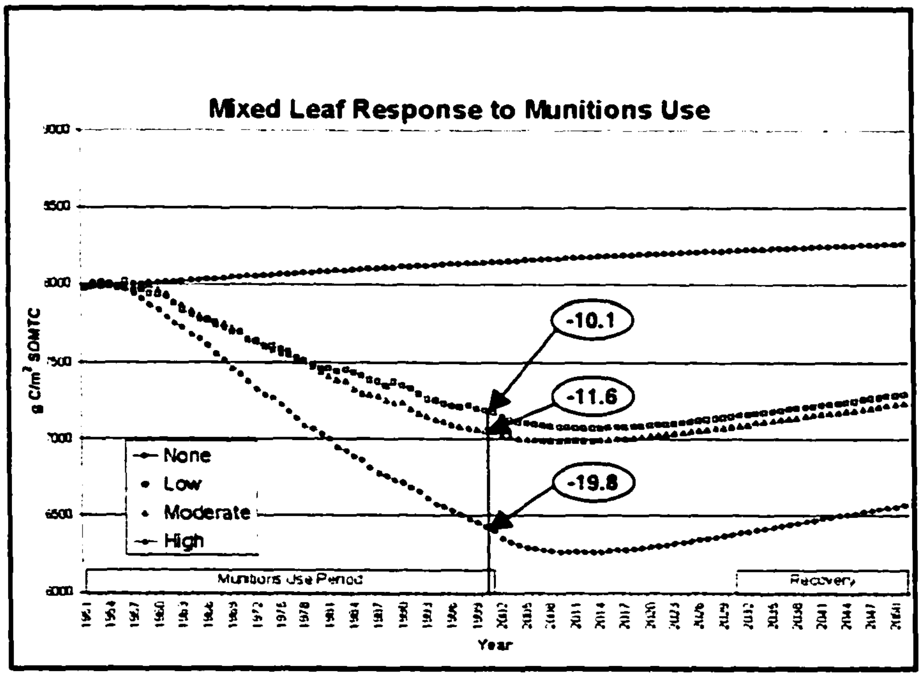


Figure 4-6b. Mixed Leaf ecotype SOMTC (Total Soil Organic Carbon) response to varying levels of munitions use. Percent loss during munitions use is indicated inside ovals.

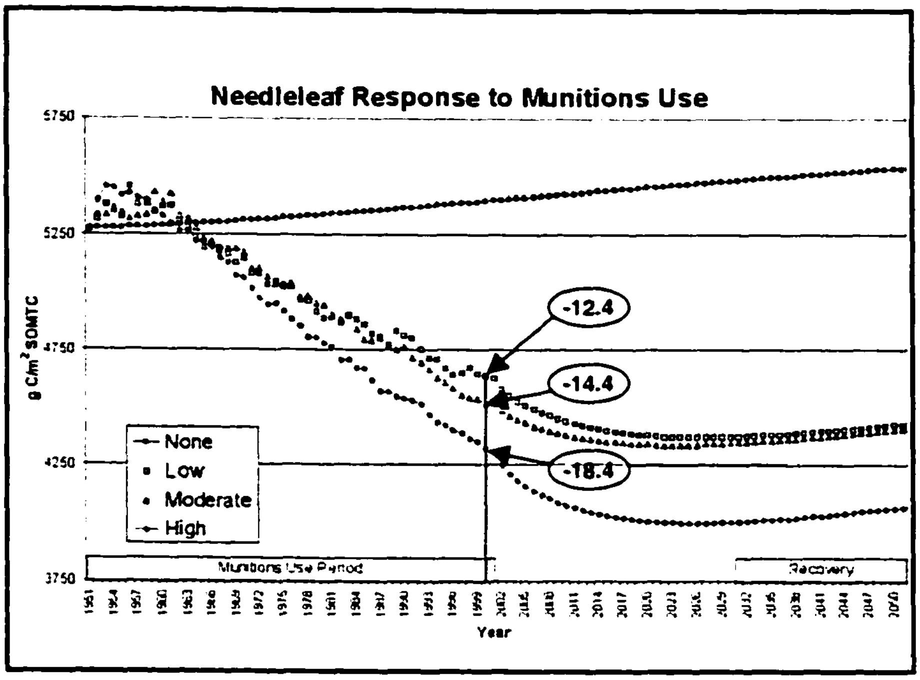


Figure 4-6c. Needleleaf ecotype SOMTC (Total Soil Organic Carbon) response to varying levels of munitions use. Percent loss during munitions use is indicated inside ovals.

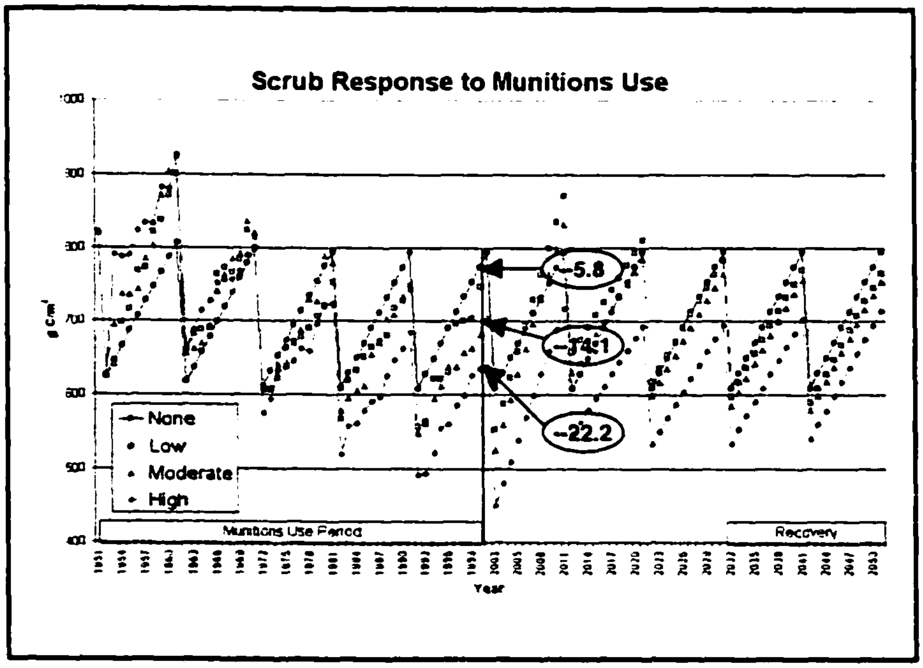


Figure 4-6d. Scrub ecotype SOMTC (Total Soil Organic Carbon) response to varying levels of munitions use. Percent loss during munitions use is indicated inside ovals.

ANOVA Analysis of SOMTC Rates

Two-way ANOVA analysis shows a significant ($F=10.66$, $p<0.0001$ with model $R^2=0.9348$) ecotype by munitions interaction for munitions use SOMTC response rates, and a significant ($F=2.92$, $p=0.0112$ with model $R^2=0.8858$) ecotype by munitions interaction for munitions use SOMTC recovery rates (Table 4-5). Interaction plots for each of these analyses is shown at Figure 4-7. Munitions use response rates for SOMTC losses are highest for the broadleaf and mixed leaf ecotypes and lowest for the scrub ecotype. Generally, SOMTC response rates are significantly different ($\alpha = 0.05$) within ecotypes. The exceptions are for all levels of munitions use in the scrub ecotype, and for low and moderate levels of munitions use in the needleleaf ecotype. Response rates are not significantly different between ecotypes. Exceptions are the scrub ecotype, which is significantly lower than all other types, and for high munitions use level for mixed leaf ecotype, which is significantly higher than the needleleaf ecotype.

Munitions use recovery rates for SOMTC accumulation were the highest for the mixed leaf ecotype, followed by the broadleaf, and needleleaf ecotypes with the scrub ecotype displaying the lowest recovery rate. Generally, recovery rates are not significantly different within ecotypes (Figure 4-7). The exceptions are the mixed leaf and scrub ecotypes in which high level munition use history significantly decreased recovery rates. Recovery rates are significantly different between ecotypes. The exceptions are the moderate level of munition use history for broadleaf and mixed leaf ecotypes, and for the moderate level of munition use

Table 4-5

Two-Way Analysis Of Variance Ecotype by Munitions Level Interactions for SOMTC Response to Munitions Use (top) and Recovery from Munitions Use (bottom).

Two-way ANOVA Table
Munitions Use SOMTC Response
The GLM Procedure

Dependent Variable: SOMTC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	15058.71034	1368.97367	140.88	<.0001
Error	108	1049.49307	9.71753		
Total	119	16108.20341			

R-Square	Coeff Var	Root MSE	SOMTC Mean
0.934847	-20.19620	3.117295	-15.43506

Source	DF	Type I/III SS	Mean Square	F Value	Pr > F
Ecotype	3	12240.43601	4080.14534	419.87	<.0001
Munitions	2	2196.85460	1098.42730	113.04	<.0001
Ecotype*Munitions	6	621.41973	103.56995	10.66	<.0001

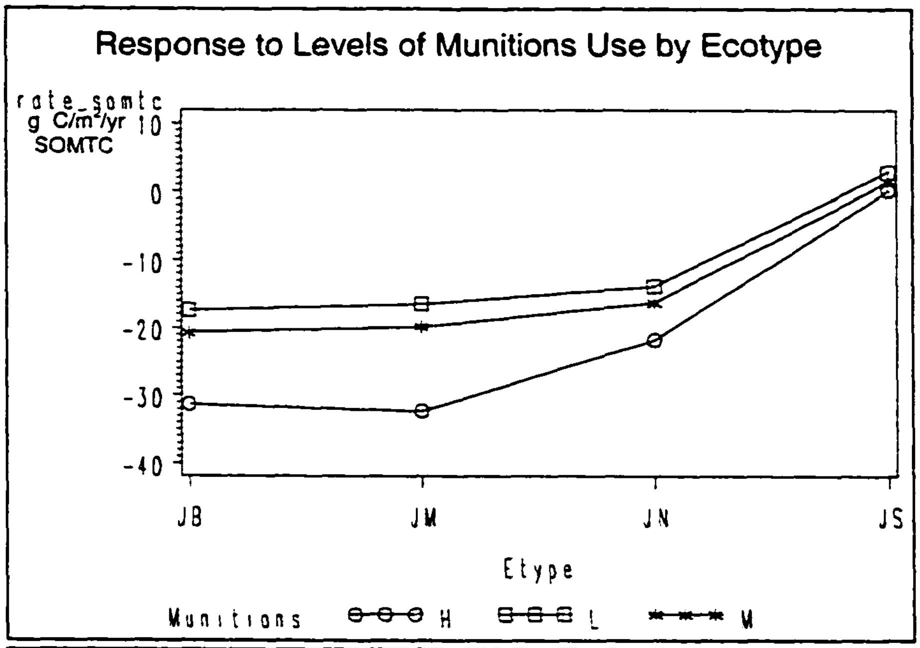
Two-way ANOVA Table
Munitions Use Recovery SOMTC Response
The GLM Procedure

Dependent Variable: SOMTC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	991.760606	90.160055	76.13	<.0001
Error	108	127.904847	1.184304		
Total	119	1119.665453			

R-Square	Coeff Var	Root MSE	SOMTC Mean
0.885765	28.27064	1.088257	3.849426

Source	DF	Type I/III SS	Mean Square	F Value	Pr > F
Ecotype	3	942.3685279	314.1228426	265.24	<.0001
Munitions	2	28.6416127	14.3208064	12.09	<.0001
Ecotype*Munitions	6	20.7504657	3.4584109	2.92	0.0112



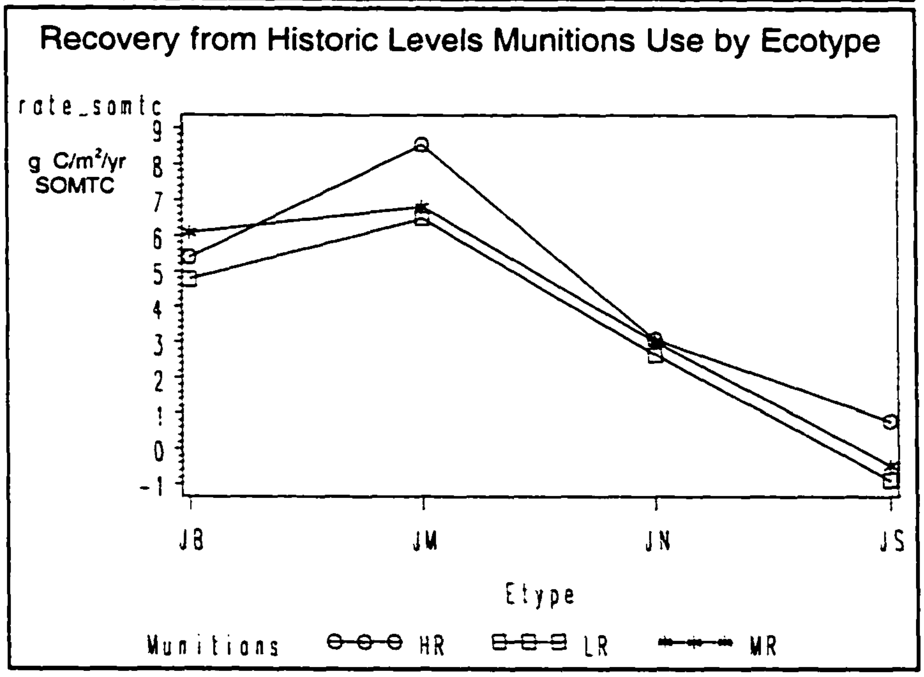


Figure 4-7. Top plot shows munitions use SOMTC (Total Soil Organic Carbon) response interactions between level of munitions use and ecotype. Bottom plot shows SOMTC recovery interactions between historic levels of munitions use and ecotype.

Munitions Use Level: H – High, M – Moderate and L – Low.
Historic Munitions Use Level: HR – High, MR – Moderate and LR – Low.
Ecotype: JB –Jarvis Creek Broadleaf, JM – Jarvis Creek Mixed Leaf, JN – Jarvis Creek Needleleaf and JS - Jarvis Creek Scrub.

history for the broadleaf as compared to the low level of munition use history for the mixed leaf ecotypes.

SOM Pool Response and Recovery

Graphical analysis of soil carbon pool response and recovery to munitions use (Figures 4-8 a-c) is consistent with the results described above. For all ecotypes, surface microbial, active, slow and passive carbon pools are negatively impacted at all levels of munitions use. Recovery rates of accumulation during the recovery period for surface microbial, active and slow pools following munitions use are positive with the exception of low and moderate munitions use history in the scrub ecotype. Recovery at these levels for scrub is negative. The passive pool for all ecotypes shows near zero to negative rates of accumulation. However, comments about all but the slow pool are be made with caution given that error associated with these observations indicates little if any differences from background rates of change.

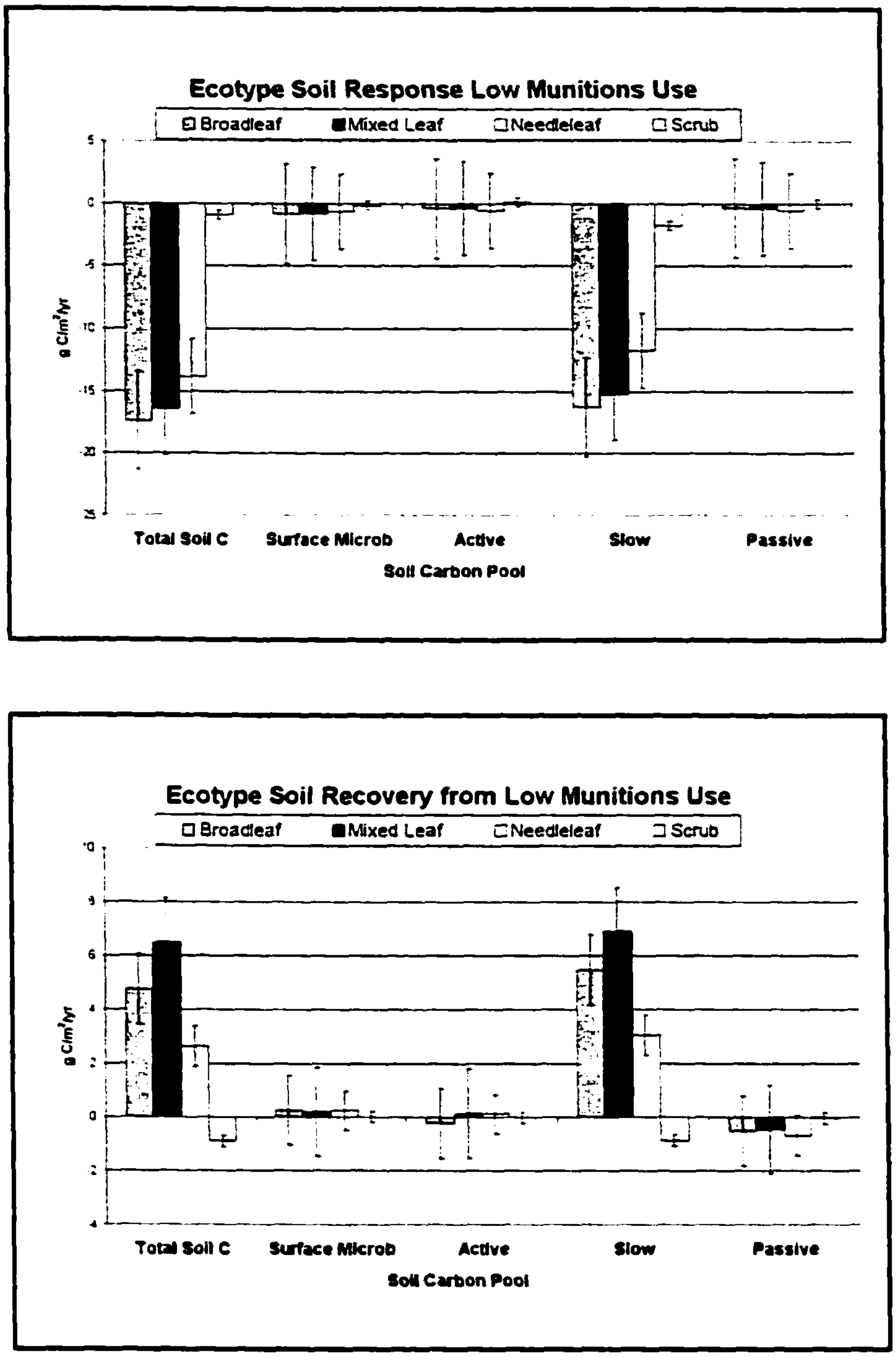
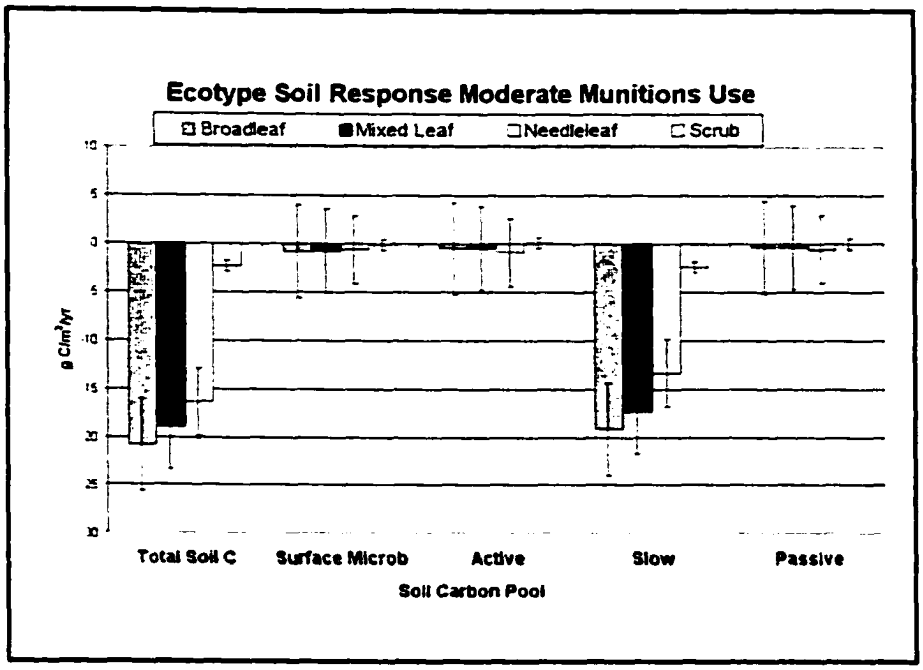


Figure 4-8a. Soil component response to low levels munitions use (top) and recovery from low levels munitions use (bottom). Error bars represent standard error of plotted values.



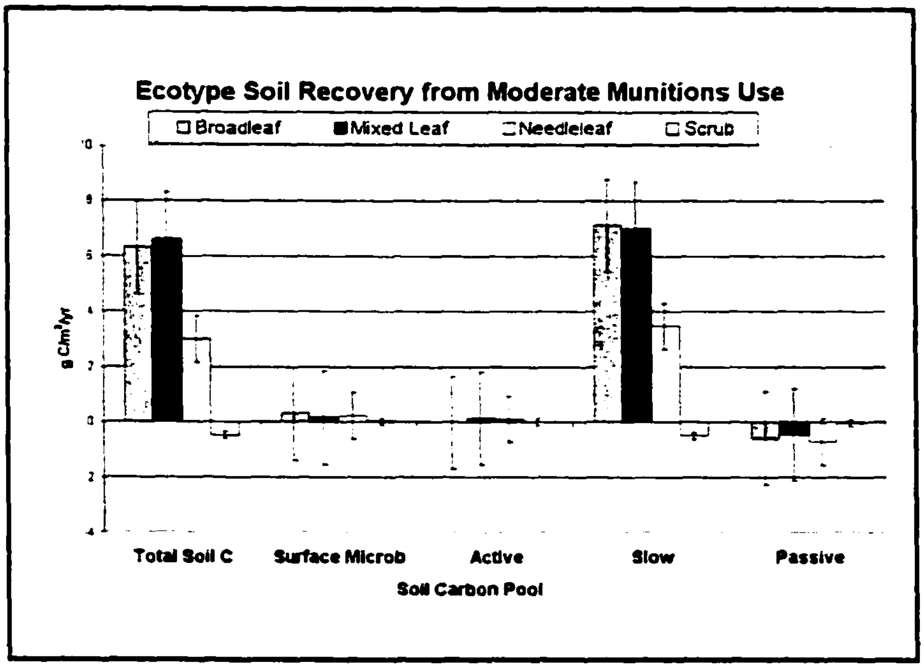


Figure 4-8b. Soil component response to moderate levels munitions use (top) and recovery from moderate levels munitions use (bottom). Error bars represent standard error of plotted values.

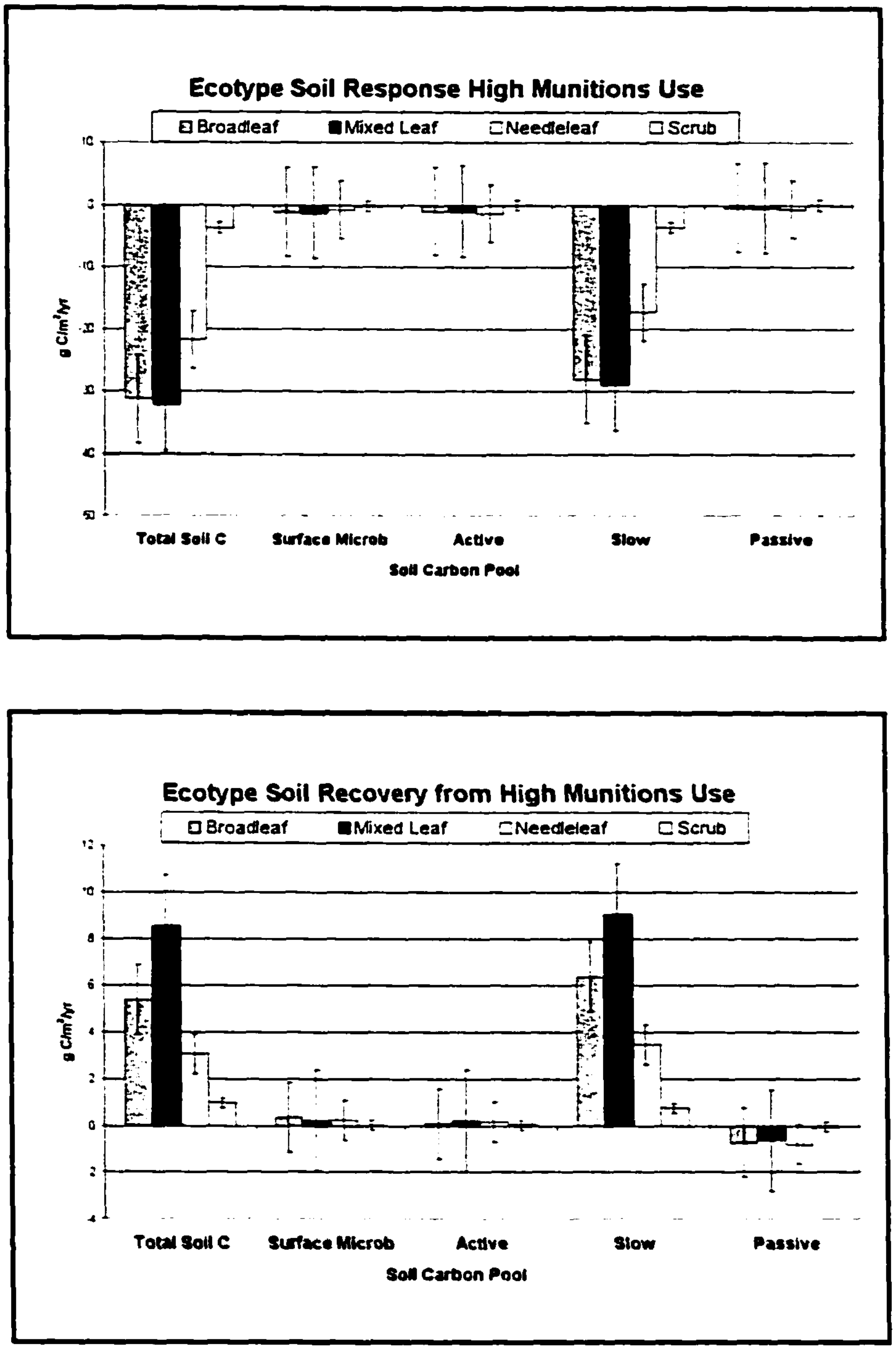


Figure 4-8c. Soil component response to high levels munitions use (top) and recovery from high levels munitions use (bottom). Error bars represent standard error of plotted values.

Discussion

Soils are highly variable and so are many of driving variables controlling SOM dynamics, therefore deductions about SOM response to disturbance can be challenging (Kladivko, 2001). There are innumerable interactions between ecological settings, management practices, ecological processes and ecosystem properties (Figure 4-1) that affect the ability of ecosystems to respond to disturbances (Van Cleve et al., 1993; Viereck et al., 1993; Jorgenson et al., 2001). However, the utility of CENTURY SOM dynamics simulation is the capability to examine disturbance and ecosystem response in a controlled environment, which permits the construction meaningful correlations between disturbance and response. The first step in this process is the creation of a reliable model that provides the foundation for successful experimentation, which was the first of three research objectives of this study. Based on equilibrium and calibration simulations, it was demonstrated that CENTURY adequately predicts levels of primary production and soil carbon for modeled ecotypes and could be relied upon to provide insight into disturbance-driven SOM dynamics. Correlations developed from simulation results described above help to address research objectives 2 and 3.

SOMTC Response to Munitions Use

The response of forested ecotypes (i.e., broadleaf, mixed leaf and needleleaf) to munitions use is similar both in terms of rates of loss at each level of munitions use, and in terms of the difference of response rates between munitions use levels. The similarity of rates of loss for each munitions use level may indicate that each of these forested ecotypes has been overwhelmed by munitions use and cannot achieve intermediate recoveries. Even the lowest level of munitions use negatively impacted SOM dynamics (Figures 4-6 a-d), which indicates that the interval between disturbance is shorter than the recovery time. Therefore, the frequency of disturbance may be affecting any ability for recovery (O'Neill, 1999). In this state, soil carbon losses exceed any accumulations and munitions use is essentially depleting SOM stocks.

It is apparent from Figures 4-6 and 4-7 that the forested ecotypes' response to munitions use is not linear. This is because the relative difference in soil carbon loss rates between munitions use levels is not equal. As the level of munitions use increases from low to moderate there is a relatively small increase in soil carbon losses. However, as the level increases from moderate to high there is a relatively large increase in soil carbon loss rates. Munitions use was parameterized in a linear fashion (i.e., low and high probabilities of occurrence with moderate probabilities taking the midpoint value between low and high probabilities). The combination of more frequent cratering and more frequent fires for high levels of munitions use may produce higher than expected disturbance intensity for the munitions use period that results in significantly higher soil carbon losses. Therefore, disturbance intensity may be the non-linear driver producing the observed differences in soil carbon response rates.

The scrub ecotype represents a different set of dynamics. The parameterized natural disturbance (i.e., an overbank flood or wind erosion event every 10th year) appears to be the predominant driver for SOM dynamics and munitions use has little if any effect. Unlike the forested ecotypes, the scrub ecotype appears to be resistant to sustained soil carbon losses at lower levels of munitions use. This may be due to the influence higher grassland energy fluxes, since the scrub model represents both grassland and tree dynamics (O'Neill, 1976).

SOM Pool Response to Munitions Use

The slow carbon pool largely determines the overall soil carbon response. This may be the result from crater parameterization, since in agricultural systems this loss is associated with tillage cultivation practices (Metherell, 1992; Hao et al., 2001). The slow carbon pool has the highest rate of loss for all of the forested ecotypes (Figure 4-8). Carbon pool loss rates tend to be highest in broadleaf and mixed leaf ecotypes than for needleleaf ecotype, which may reflect faster organic matter decomposition rates for these ecotypes (Ågren et al., 1991; Quideau et al., 2001) and due to higher nitrogen availability that was parameterized into the tree.100 file (Klingensmith and Van Cleve, 1993; Van Cleve et al., 1993; Viereck et al. 1993). The scrub ecotype exhibited the lowest declines in slow pool carbon at all munitions use levels. This would be consistent with increased biomass inputs from the killing and cutting of vegetation and the subsequent increased availability of nutrients in a system characterized by low productivity (Sanford et al., 1991).

Active and passive pool response analysis must be considered under the caveat mentioned in the previous section regarding their near zero differences between background rates. However, an assumption that these responses represent potential trends provides a basis for discussion. The active pool rates of loss were relatively high considering that it only represents approximately 2% of total SOM (Table 4-1) and is noteworthy considering that this pool represents the major microbial component of the soil influencing both organic material and contaminant degradation. Active and surface microbial pool losses may result from changes in environmental conditions caused by cratering such as increase aeration and changes in soil temperature (Aon et al., 2001; Kladivko, 2001). Cratering may also cause soil structural changes that affect water film and biofilm development critical to microbial contaminant degradation (Alvarez and Alvarez, 2000; Aon and Colaneri, 2001; Aon et al., 2001; Ehlers and Bouwer, 1999; Kitts et al., 2000; Kladivko, 2001).

Finally, passive pool losses (Figures 4-8 a-c) may be significant from contaminant transport perspective. Even though this pool represents almost half of total SOM, it is most responsible for a soil's cation exchange capacity (Table 4-1) and retardation of contaminant movement through the soil. Passive pool losses may be the result of increased microbial activity due to the increased availability of residue inputs caused by cutting and killing of vegetation. Once this microbial activity has peaked, it may promote the decomposition of the more resistant passive SOM pool (Brady and Weil, 1999).

SOMTC Recovery from Munitions Use

Once the system is released from munitions use SOMTC begins to recover. The level of munitions use does not appear to affect the rates of recovery within any of the ecotypes. However, the significant differences in rates of recovery between ecotypes indicate that they may be a better indicator of ecotype response than soil carbon loss rates. Observations indicating that needleleaf recovery rates were significantly lower than the other forested ecotypes is consistent with the findings of Ågren et al. (1991) and Quideau et al. (2001). They describe differences in SOM composition based on forest vegetation type and argue that because conifer forests retain more nutrients in standing biomass they are less productive than broadleaf forests. They also show that needleleaf SOM is more resistant to decomposition. This attribute produces high carbon to nutrient ratios in soils associated with needleleaf forests. As a result, nutrient deficient soil would be less capable of supporting biomass production and recovery would be limited by the rate of decomposition of needleleaf large wood carbon pools. Alternatively, in broadleaf and mixed leaf forests there is a more rapid nutrient cycling (Ågren et al., 1991; Quideau et al., 2001) between plant and soil (e.g., leaf fall), higher nitrogen availability (Klingensmith and Van Cleve, 1993; Van Cleve et al., 1993; Viereck et al., 1993), and a higher energy flux that may produce more biomass per unit time resulting in a more resilient system (O'Neill, 1976; Harwell et al., 1977; DeAngelis, 1980; DeAngelis et al., 1989; Loreau, 1994). Finally, the approximate 20-year time it takes these forested ecotypes to begin recovery following release from munitions use indicates that there may be a hysteresis effect due to coupled SOM carbon pool and nutrient losses (O'Neill, 1999).

SOMTC in the scrub ecotype shows no sign of recovery for low and moderate levels of munitions use history and the recovery rate for high munitions use history is significantly lower than the forested ecotypes. Loreau (1994) argued that while energy flow through a system is positively correlated with resiliency, it does so independently of nutrient cycling and that it is offset by concomitant increases in system resistance. Therefore, these low rates of recovery may be indicative of a low production, resistant system that requires a longer time to show recovery.

SOM Pool Recovery from Munitions Use

SOM pool recovery rates following munitions use is very low compared to rates at which SOM pools were depleted during munitions use (Figures 4-6, 7 and 8). As in SOM response to munitions use, the slow pool shows the highest rate of recovery and the most influence on recovery rates (Figures 4-8 a-c). Scrub and needleleaf ecotypes display the lowest rates with scrub rates negative for low and moderate level munitions use histories, indicating that decreased nutrient availability associated with slow pool losses may be negatively impacting these ecotypes. The active and passive pools show little to no recovery for all ecotypes under all munitions use histories although these rates may be indistinguishable from background levels.

Conclusion

CENTURY is a Useful Tool

The use of the CENTURY SOM dynamics model proved useful in determining:

1. Whether or not SOM dynamics could be effectively modeled for the study area.
2. What the potential effects of munitions use on SOM stocks might be.
3. What ecotype influences there might be for SOM dynamics in the face of munitions use.
4. The potential management implications of munitions use in impact areas.

CENTURY simulation adequately predicted levels of primary production and soil carbon for the modeled ecotypes of Fort Greely, Alaska. From this controlled simulation environment it was determined that the level of munitions use does determine the rate of change in soil carbon stocks with higher levels resulting in higher rates of loss particularly within SOM slow pools. Yet, based on these simulations there were no distinguishable differences in ecotype response to varying levels of munitions use except for the scrub ecotype. Therefore, the classification of soils by ecotype for use in predicting soil carbon losses based on munitions use levels may not be practical as a contaminant attenuation metric. However, CENTURY simulations indicate that soil carbon recovery rates following munitions use might be useful for this purpose. Finally, CENTURY helped identify potential management implications and areas in which future work could help in the understanding of munitions effects.

Management Implications

Since SOM provides a contaminant attenuation capacity through adsorption and microbial degradation processes, range managers should be aware of activities that disrupt natural SOM dynamics. The need for awareness is amplified by the fact that munitions use also results in UXO in the very locations in which SOM dynamics are being disrupted. This work utilizing CENTURY simulation shows that munitions use appears to be a disrupting influence and that contaminant attenuation capacity could be negatively affected. The next step would be to develop a decision making tool which would help range managers determine when, where, and at what level should munitions be used in a particular ecological setting. Geospatial information systems (GIS) provide a robust platform from which to develop such a tool. A GIS for impact area management would include data layers such as targetry, topographic information, and surface and groundwater characteristics. GIS could incorporate SOM dynamics data, which could relate a soil's fraction of organic carbon to its attenuation capacity. Such a system would enable range managers to better mitigate environmental risks associated with munitions use. For example, munitions that have higher failure rates might be used in ecotypes with a relatively large passive SOM pool and targetry locations could be adjusted to avoid excessive SOM pool losses in sensitive areas. At Fort Greely, it might be preferable to use munitions in the broadleaf or mixed leaf ecotypes since recovery rates appear higher than the scrub and needleleaf ecotypes, and because they have relatively large SOM pools. Also, range managers could schedule impact area UXO recovery operations based on soil attenuation capacity risk assessments.

Future Work

Using CENTURY simulations to assess the affects of munitions use at Fort Greely have highlighted two future research needs. The first need is to better understand scrub ecotype dynamics because many of Fort Greely's impact areas are located in this ecological setting. For example, what are the reasons for the scrub ecotype's apparent resistance to sustained soil carbon losses? Is it related to nutrient levels or the natural disturbance regime? Research should focus on spatial and temporal relationships between erosion, soil carbon levels, nutrient availability and production. Results would aid in future CENTURY parameterization and better understanding of the effects of munitions use and contaminant fate and transport in this ecotype.

Secondly, research is needed to determine cratering effects on SOM pools. In this study a crater was parameterized as a tillage event in agricultural soils. However, research regarding cratering effects on soil environmental conditions and structure would provide better insight into impact area SOM dynamics.

With better understanding of munitions disturbance and SOM dynamics through the use of simulations like CENTURY, scientist and range managers would be better able to address environmental concerns regarding range and impact area contamination. Techniques such as those demonstrated in this study could help conservation and sustainability management in military ecosystems become more effective and efficient.

CHAPTER 5

Integrating Impact Area Environmental and Ecological Data Using Geographic Information Systems

Introduction

Environmental problems such as impact area contamination are extremely challenging issues. At one level they can be addressed through an application of basic physical, chemical and biological principles that readily influence them such as adsorption or biodegradation. Yet, this approach is rarely effective since at another level these environmental processes are intimately tied to ecosystem dynamics that are characterized by complex, biotic and abiotic processes and interactions that operate across a spectrum of spatial and temporal scales (Gustafson, 1998; Burke et al., 1999). This complexity often contributes to highly charged social, cultural, and political disagreements because scientists and resource managers usually view problems at different levels (Gardner, 1998; Turner, 1989). An integrative approach that merges environmental and ecosystem science that can be communicated in a meaningful way is absolutely essential when dealing with such problems. A Geographic Information System (GIS) is regarded as a logical choice for developing ecological data requirements and analysis (Levin, 1992; Lugeri et al., 2000; Turner, 1989). It is also a great way to conclude this dissertation by integrating the environmental and ecological data generated in previous chapters into an applied analysis (Figure 5-1).

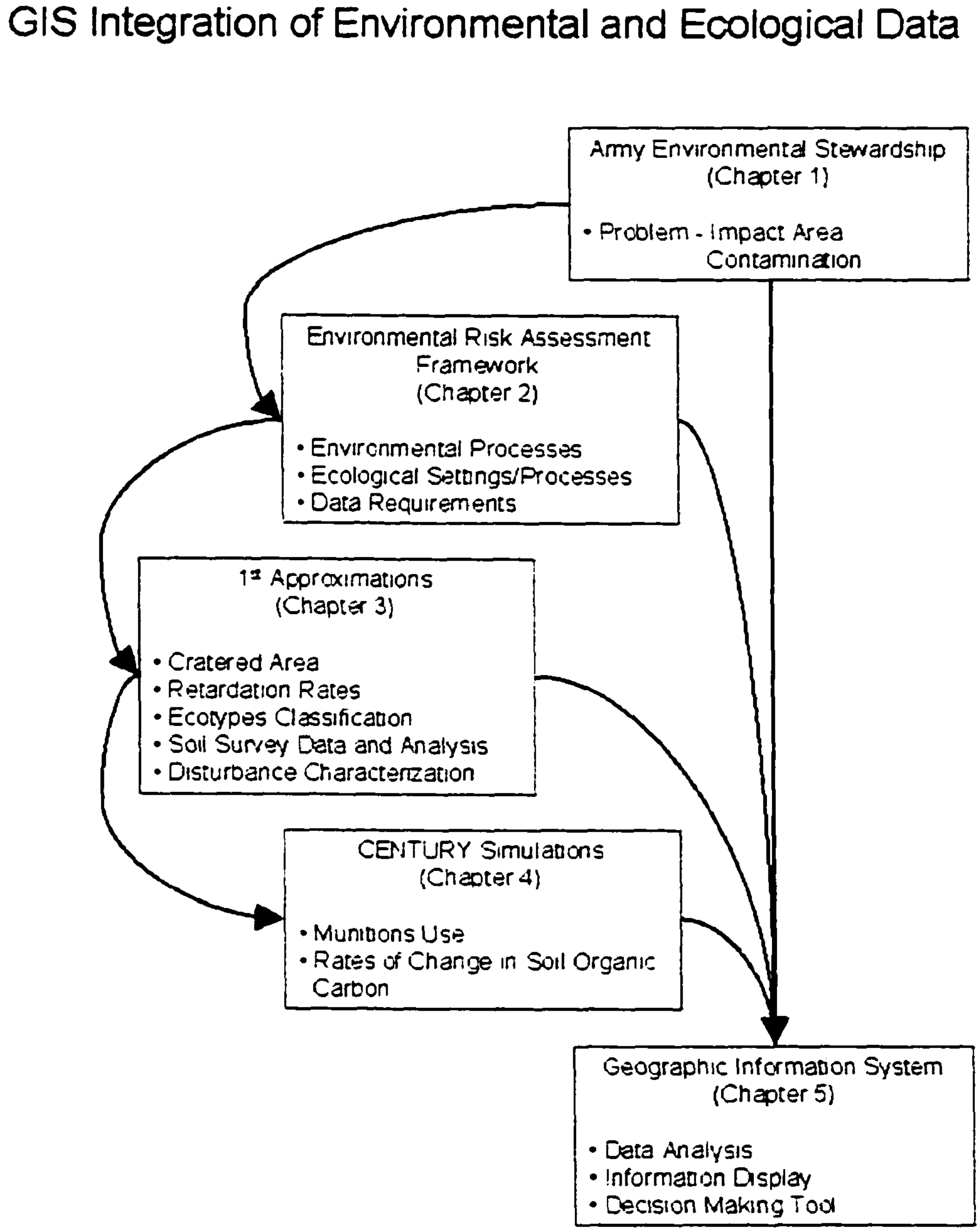


Figure 5-1. Flow diagram of the integration of environmental and ecological data into an applied analysis of impact area contamination at Fort Greely, Alaska. Arrows left of boxes indicate evolution of data development and arrows right of boxes indicate data integration into a geographic information system (GIS).

The goal in integrating GIS into this study is to describe and display ecotype attributes that can help determine soil's ability to attenuate munitions contamination. This is done through the integration of the environmental data described in chapter 2 with the environmental retardation process metric developed in chapter 3, and the ecological process of soil organic matter dynamics developed in chapter 4 into a applied GIS based management model.

This method is very similar to approaches taken by Mladenhoff and Host (1994) who developed an ecosystem management approach centered on ecological land unit mapping using physiography, landforms and soils of the lake states region for the US Forest Service. They identified ecological units using a hierarchical ranking system based on dominant controlling ecological parameters such as photosynthesis, carbon allocation and soil processes. They also identified that soil organic matter turnover and nutrient mineralization is the least developed area of research.

Maurer (2000) examined an ecosystem's ability to influence chemical contamination utilizing dissolved oxygen as an analytical parameter. He scored and reclassified these values using an Environmental Protection Agency natural attenuation assessment protocol. Using these reclassified grids he created a site map overlay to describe the natural attenuation potential of a site based on the dissolved oxygen analytical parameter.

In the case of munitions contamination, locations within impact areas are evaluated based on retardation capacities determined by soil organic carbon dynamics. These locations within the impact area are then assigned condition codes that describe their contaminant attenuation capacity. This is similar to approaches that use attribute ranking within databases (Ball, 2000; Bejleri et al., 2000; Maurer, 2000) to help determine vital tasks such as restoration priorities (Palík et al., 2000).

The utility of GIS is the ability to gather and organize various forms of spatial and temporal data. One of the most useful types of data available to ecosystem scientists is scale-sensitive, remotely sensed georeferenced spectral data (Turner, 1989). It is valuable because it can efficiently cover large and sometimes inaccessible areas (Steele, 2000). While there are many challenges in discerning ecological processes from remotely sensed data because of issues like temporal variability (Green, 1994), if it is correlated to appropriate field data it can be a very powerful tool. Peters and Hauff (2000) described remote sensing techniques used for detection and characterization of toxic substances. They demonstrated that by using Thematic Mapper (TM) data as a screening evaluation to focus efforts followed by the use of hyperspectral sensors and ground studies they were able to prioritize sites and focus field efforts. Similarly, the first step in this study was to process and analyze satellite derived multi-spectral data to evaluate ecotypes in the study area to determine soil-sampling locations. Data from this soil survey was then used to parameterize CENTURY soil organic matter dynamics simulations, which generated estimated soil organic carbon response rate data for each ecotype. Therefore, the multi-spectral data used in this represents the starting point for data collection that ultimately was organized and developed in a GIS.

Objectives

The objectives for this chapter are to:

1. Describe a remote sensing approach for site evaluation and field data collection.
2. Use GIS to model the soil carbon status of ecotypes in response to Trinitrotoluene (TNT) munitions use.
3. Use GIS to display the soil carbon status of ecotypes for use in range and impact area management for TNT munitions.

Methods

Computer-Analysis of Remote Sensed Data

The process of using computer-aided analysis of remotely sensed data involved four steps. The first step was identifying and obtaining the appropriate image. Next, was to classify spectral signatures using computer-aided techniques into the desired informational categories or ecotypes. Then, appropriate soil sampling and classification verification locations were determined for the georeferenced ecotypes. The final step was to assess the accuracy of the classification process using verification data.

Landsat 7 Enhanced Thematic Mapper (ETM+) images were reviewed using the United States Geological Survey Earth Explorer web site (http://edcsns17.cr.usgs.gov) using Latitude and Longitude coordinates (NW corner –147.04.00W, 64.20.00N and SE corner – 145.23.00W, 63.39.00N) to obtain a listing of metadata records for all available imagery of the area. Candidate images were reviewed based on the lowest available aggregate cloud cover and acquisition dates from June to early September to maximize temporal variability of vegetation growth for as many of the potentially present vegetation classes while at the same time avoiding snow cover at higher elevations. Additionally, the image had to be recently acquired (i.e., no more than 2 years old) in order to maintain a high degree of mapping confidence. A Landsat 7 ETM+ scene of the area taken on 10 September 1999 (path 67, row 15) with zero aggregate cloud cover was obtained through US Army Space Command Remote Sensing unit in Colorado Springs, Colorado and the Topographic Engineering Center, Fort Belvoir, Maryland.

The classification process began with the collection of reference data for Fort Greely, Alaska. This was obtained from the US Army Corps of Engineers Cold Regions Research and Engineering Laboratory, in Hanover, New Hampshire. They provided a report titled, "An Ecological Land Survey for Fort Greely, Alaska" authored by Jorgenson et al. (2001). Their field data was collected between 1996 and 1998 and consists of 253 surveyed reference points and 126 surveyed verification points that describe the major cover types found on the Fort Greely reservation.

Computer-aided processing of the image was accomplished using ERDAS Imagine (© 2001 ERDAS, Inc.) software. The scene was subsetted to capture the area of Jarvis Creek area interest as well as the Fort Greely reservation (the

Jarvis Creek control area description can be found in chapter 3). At this point, no enhancement was made to the image to preserve the spectral reflectance characteristics of the pixels. The scene had cloud cover and cloud shadow in the southeastern portion of the image centered over the Washington impact area (Appendix D, Photo 7).

A supervised classification of the scene was made using the reference and verification data generated by CRREL (Jorgenson et al., 2001). Reference point data was converted into an Arcview (© 2000, ESRI Inc.) cover, which was then brought displayed in Imagine. Attribute information was obtained for each reference point using the same cover in an Arcview 3.2 (© 2000, ESRI Inc.) environment. Using the Imagine region-growing tool for all seed pixels (Area constrained = 100 pixels and Euclidean Distance = 20), pixels were selected that corresponded to the appropriate cover type. These seed pixels were then used to grow training polygons of similar spectral reflectance. This procedure was repeated for all of the usable reference points. For significant cover types without reference points (e.g. bare exposed rock, glacier, snow, road, agriculture) training polygons were delineated based on a manual image interpretation of CIR composites of the September scene. Informational categories are listed in Table 5-1.

During this process, there was some overlap of training polygons of different reference classes. A best estimate of which polygon to use based upon a seed pixel's proximity to an edge signature. A polygon whose seed pixel was best encompassed by similar pixels (i.e., farthest from pixels of different color) was retained. Reference points associated with cloud and cloud shadows were not used. Upon completion of the training polygon selection process 68 polygons

Table 5-1

Informational Categories Used for a Supervised Classification of a Landsat 7 ETM+ Scene Taken on 10 September 1999 (path 67, row 15) Fort Greely, Alaska.

Level 1 Classification	Level 2 Classification
Water	• River • Pond and Lake
Vegetative Cover	• Broadleaf Forest • Needleleaf Forest • Mixed Forest • Scrub
Gravel/Pavement	• Roads • Bare Exposed Rock • Barrens
Agricultural Land	• Agricultural
Snow Cover	• Glacier • Snow

generated by seed pixels had been obtained along with 12 polygons generated by manual polygon selection for a total of 80 spectral classes. A maximum likelihood algorithm was used to classify the whole image based on the 80 training spectral classes. A signature seperability analysis was performed on the spectral classes using the transform divergence method for all 1-6 bands of information. This generated 2,926 pair-wise comparisons. Spectral classes that were similar based on signature seperability analysis were merged, and signatures that were impossible to distinguish from others were deleted. This brought the number of signatures for spectral classes down to 43. Like cover classes (e.g. Scrub 1 + Scrub 2 + ... Scrub *i*, etc) were then combined based on histogram evaluations using a recode process resulting in mapping set of 8 cover classes. Finally, these cover classes were recolored to better distinguish patterns. The classified image was processed with a 5X5-majority filter, which greatly enhanced its appearance. A map of the Jarvis Creek area of Fort Greely, Alaska was generated from this image (Figure 5-2).

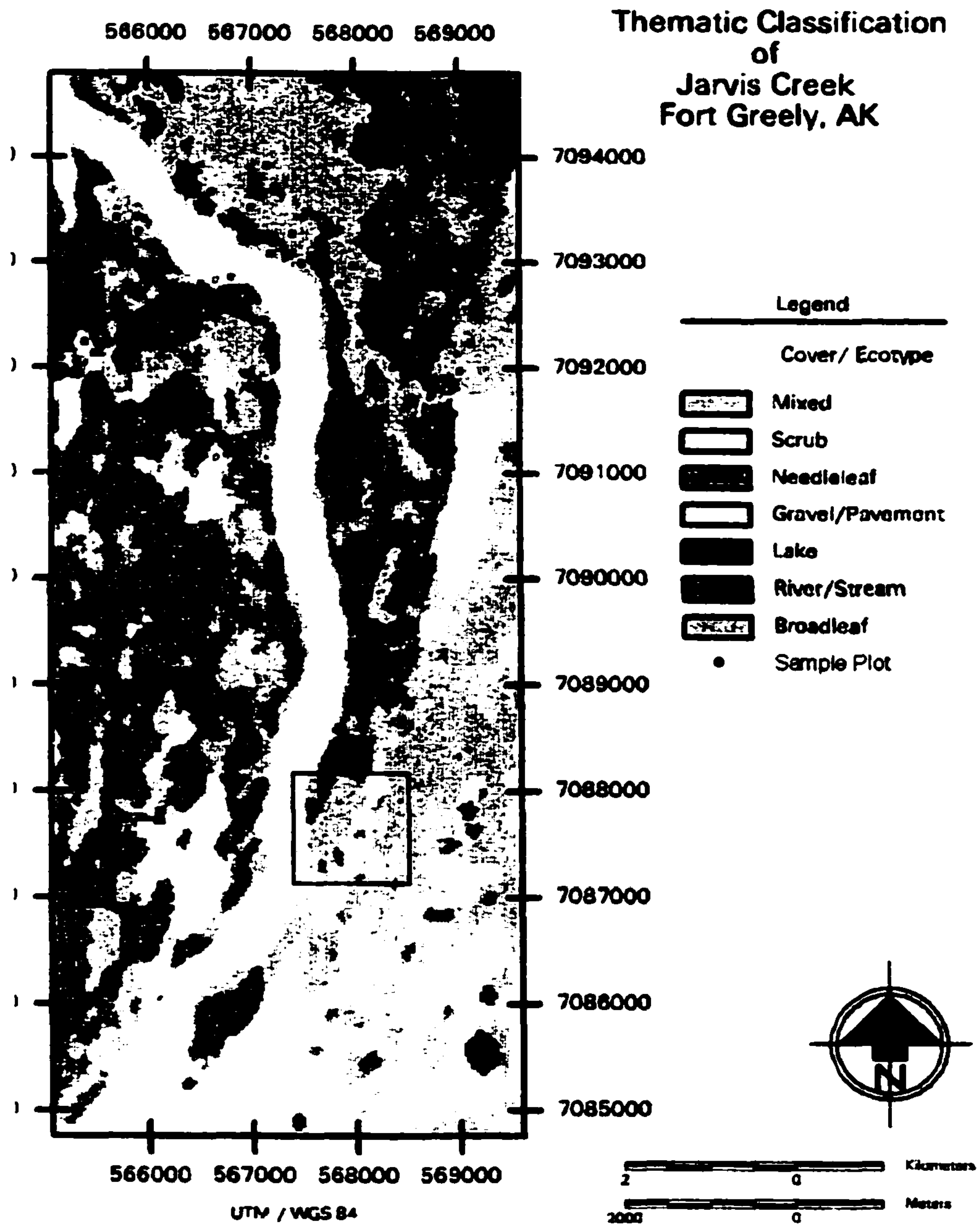


Figure 5-2. Thematic classification of Jarvis Creek, Fort Greely, Alaska. Box indicates area that was used for GIS modeling of soil organic carbon status.

From this map, over 100 discrete or non-overlapping and homogenous candidate sampling plots were identified using a random point generator within ERDAS Imagine (© 2001 ERDAS, Inc.). Actual field sampling locations, which doubled as verification points were randomly selected from this population. For small sampling areas such as the Jarvis Creek control area, with homogeneous cover-types, Jensen (1996) suggests that the total number of verification points can be estimated by the formula:

$$N = \frac{Z^2 (p)(q)}{E^2}$$ where,

Z is the standard normal deviate for the 95% two-sided confidence interval,
p is the expected percent accuracy,
q = 100-p and
E is the allowable error.

For this study, $Z = 1.96$, $p = 85\%$, $q = 15\%$, and $E = 10\%$ yielding an $N = 49$ points which were allocated across the four ecotypes of interest, which were scrub, broadleaf, mixed leaf and needleleaf.

Based on vegetative growth patterns, the classified image that appeared to satisfactorily classify cover types. The classified image appeared to emulate the transitions between river, barren, scrub, mixed leaf, broadleaf and needleleaf forested areas, and it seemed to accurately classified lakes and ponds and agricultural areas. Overall classification accuracy was 78.3% (Table 5-2). However, classification of three of the four riverine ecotypes was exceptionally accurate. Mapping of scrub, broadleaf and mixed leaf ecotypes resulted in 100%, 90% and 89% User's Accuracy respectively and the Kappa statistics

Table 5-2

Error Matrix, Mapping Accuracy and Kappa Statistics for Ecotype Classification of the Jarvis Creek Area at Fort Greely, Alaska. Overall Accuracy is a measure of total correctly classified pixels versus the total number of pixels. Producer's Accuracy indicates the probability that a reference pixel is correctly classified and User's Accuracy indicates the probability that the reference pixel actually represents the cover type found on the ground. Kappa statistic is a measure of overall accuracy that accounts for row and column error.

CLASSIFICATION ACCURACY ASSESSMENT REPORT

ERROR MATRIX

	Reference Data					
Classified Data	Mixed Forest	Scrub	Needleleaf Forest	Gravel Pavement	Broadleaf Forest	Row Total
Mixed Forest	8	0	1	0	0	9
Scrub	0	14	0	0	0	14
Needleleaf Forest	3	4	7	0	2	16
Gravel/Pavement	0	0	1	9	1	11
Broadleaf Forest	1	0	0	0	9	10
Column Total	12	18	9	9	12	

Overall Classification Accuracy = 78.33%

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers (Column) Accuracy	Users (Row) Accuracy
Mixed Forest	12	9	8	66.67%	88.89%
Scrub	18	14	14	77.78%	100.00%
Needleleaf Forest	9	16	7	77.78%	43.75%
Gravel/Pavement	9	11	9	100.00%	81.82%
Broadleaf Forest	12	10	9	75.00%	90.00%
Totals or *Average*	60	60	47	*79.45%*	*80.89%*

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.7289

Conditional Kappa for each Category.

Class Name	Kappa
Mixed Forest	0.8611
Scrub	1
Needleleaf Forest	0.3382
Gravel/Pavement	0.7861
Broadleaf Forest	0.875

describing classified verses reference data were equally as good. Needleleaf ecotype was not accurately classified due to confusion with the other three ecotypes. This was probably due to verification interpretation of the dominant canopy present during sampling. Of note was the classification's ability to map scrub ecotype, which is the predominant ecotype of the Washington impact area and of other impact areas on Fort Greely. It had a user's accuracy of 100%.

Soil Carbon Threshold Levels Analysis

Soil carbon level thresholds needed to be established prior to the GIS modeling effort in order to define a soil's ability to attenuate TNT contamination. Since soil organic carbon is influential in contaminant movement through the soil, a combination of environmental and ecological process parameters were use to determine appropriate threshold levels at which ecotype soil carbon status would change condition from “Green” to “Amber” to “Red” (i.e. good to fair to poor contaminant attenuation capacity respectively). First, an evaluation of TNT rate of movement through the soil using retardation factor calculations described in Chapter 3 provided an indication of the required appropriate minimum level of total soil carbon. For this determination several assumptions were made beyond those already made regarding retardation factor formula development and CENTURY model validity. The first assumption was that since the broadleaf soil carbon losses due to munitions use was the greatest of all the ecotypes it would serve as a base-line response for all ecotypes. The second assumption was that TNT contamination should not move more than 10m in a 75-day period due to

TNT-soil adsorption in order to allow for contaminant transformation. Based on TNT movement contour lines (Figure 5-3) this yielded a required soil carbon value of approximately 6,800 g C/m^2. This represents a 20% reduction for the broadleaf ecotype (Figure 4-6) and was used as the initial "Red" threshold response for all ecotypes. The initial "Amber" threshold response value was set at 10% or mid-way between no response and the "Red" threshold response.

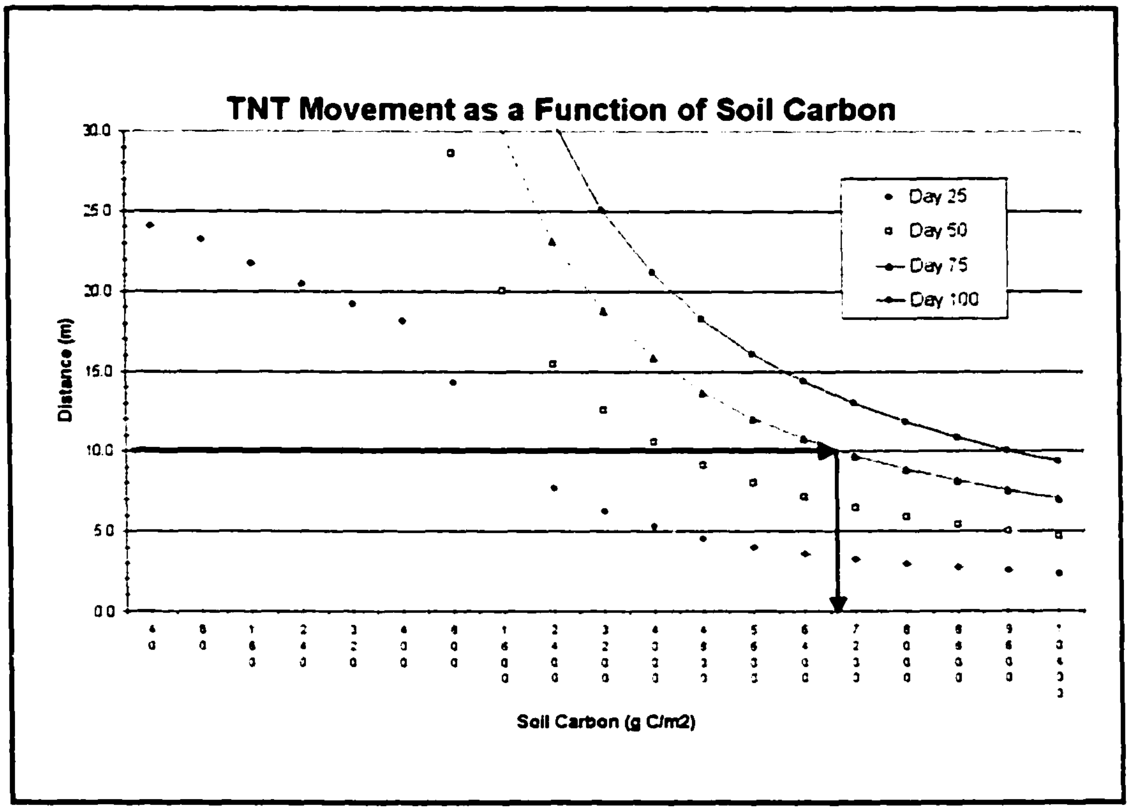


Figure 5-3. TNT movement as a function of soil carbon. Contour lines represent the distance traveled by TNT contaminant for a soil carbon value at Day 25, 50, 75 and 100. Arrows show how the "Red" threshold soil carbon value for TNT movement was derived. Maximum TNT movement distance was 10 meters in 75 days. This represents a soil carbon requirement of approximately 6,800 g C/m^2.

These response thresholds were then adjusted for each ecotype using a weighting system based on recovery rates generated by CENTURY simulation described in Chapter 4. Simulation indicated that the mixed leaf ecotype showed greater recovery rates than the other ecotypes (Figure 4-7). Therefore, no change was made to its threshold response (Table 5-3). The broadleaf ecotype was approximately 1 g C/m^2/yr below that of the mixed leaf ecotype. Since it does not recover as quickly as the mixed leaf ecotype its threshold responses were reduced by a resiliency factor of 0.9. The needleleaf ecotype was slower to recover than the mixed leaf ecotype by approximately 3 g C/m^2/yr. Therefore, its threshold response was reduced by a resiliency factor of 0.7. Adjusting the scrub ecotype thresholds using the same logic would have reduced them beyond what was deemed reasonable given that the scrub ecotype demonstrated little or no losses during munitions use, but since it did have the lowest recovery its threshold response was reduced by a resiliency factor of 0.6. These threshold percentages were applied to soil carbon initial values to determine soil carbon threshold values (Table 5-3).

GIS Soil Attenuation Capacity Model

Development of a GIS retardation factor model (Figure 5-4) began by combining the classification data described with its associated soil property attributes (i.e., the soil property data described in Chapter 3) and soil organic matter dynamics attributes (i.e., the rates of change in soil organic carbon described in Chapter 4). ERDAS Imagine (© 2001 ERDAS, Inc.) was used as the GIS modeling environment. The classified thematic data was processed using 10, 20, 30, 40 and 50-year soil organic carbon munitions use loss rate functions for each ecotype. This produced soil organic carbon values for each

Table 5-3

Initial Soil Organic Carbon Levels, Response Rates (derived from CENTURY simulations in Chapter 4) and Thresholds for Each Ecotype in the GIS Model for Munitions Use at Fort Greely, Alaska. Resiliency factors represent recovery differences between ecotypes.

	Scrub	Broadleaf	Mixed Leaf	Needleleaf
Initial Soil Organic Carbon Levels (g C/m^2)	820	8255	7977	5276
Munitions Use Level	CENTURY derived soil organic carbon loss rate (g C/m2/yr)			
Low	-0.949	-17.396	-16.386	-13.839
Moderate	-2.309	-20.826	-18.959	-16.352
High	-3.648	-31.312	-32.293	-21.776
Munitions Use Level	CENTURY derived soil organic carbon rates of recovery (g C/m2/yr)			
Low	-0.889	4.762	6.484	2.648
Moderate	-0.476	6.310	6.617	3.004
High	0.971	5.389	8.545	3.076
Threshold Calculations				
Resiliency Factor applied to 10% and 20% losses	0.6	0.9	1	0.7
Amber Percent Loss	6	9	10	7
Red Percent Loss	12	18	20	14
Amber Threshold	770.8	7512.1	7179.3	4906.7
Red Threshold	721.6	6769.1	6381.6	4537.4

GIS Model of Soil Attenuation Capacity

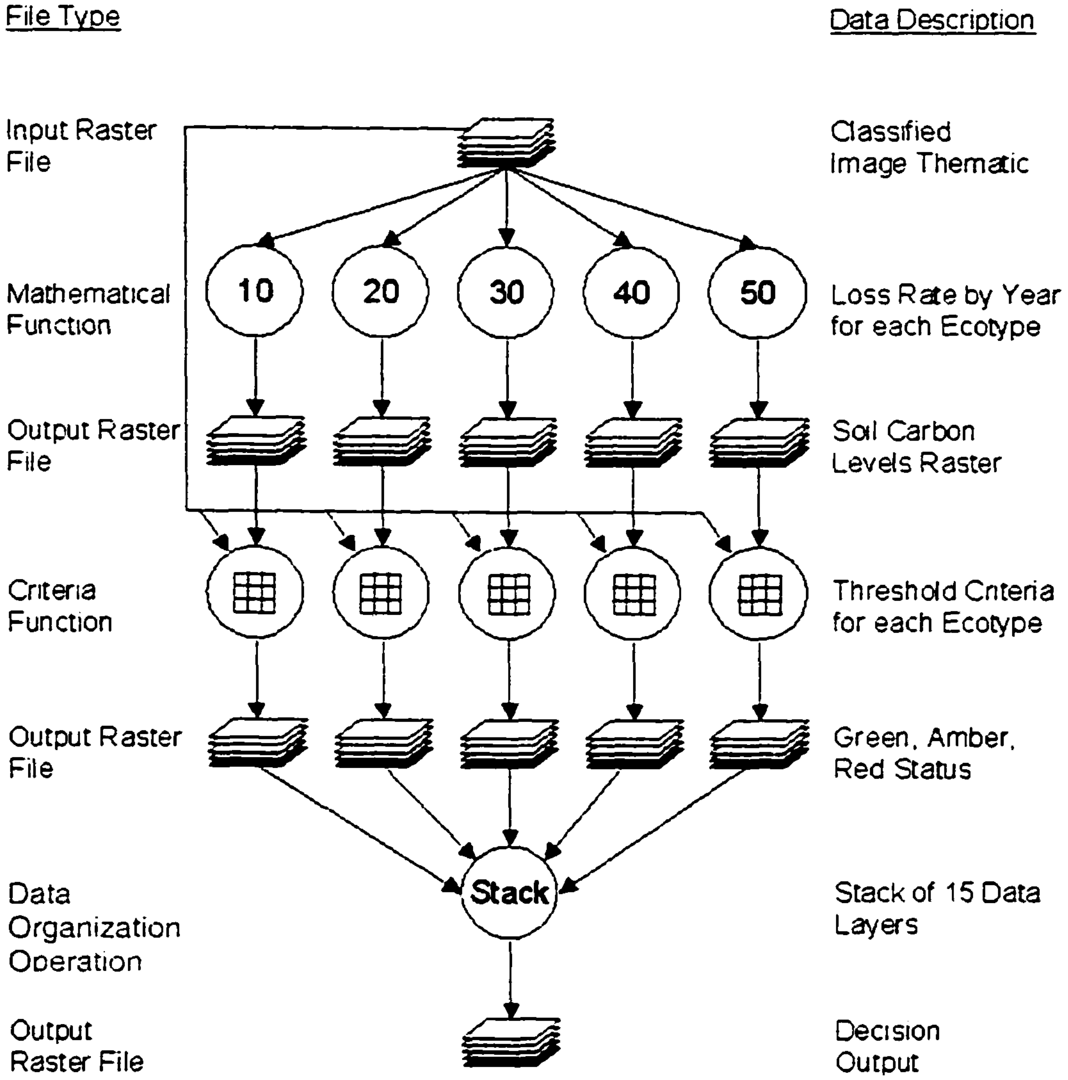


Figure 5-4. Geographic information system (GIS) model flow diagram describing model operations, and input and output files. The classified thematic data was processed using 10, 20, 30, 40 and 50-year soil organic carbon munitions use loss rate functions for each ecotype. This produced soil organic carbon values for each ecotype for the end of each of the periods. Classified thematic data was compared to soil organic carbon values for each ecotype for the end of each of the period of munitions use using thresholds as a criteria function. Output from this operation went to a soil organic carbon status file for each period and was recoded to "Green," "Amber" or "Red" status. Finally, the layers were compiled into one output file with 15 layers of information representing three soil carbon statuses for each 10-year period.

ecotype for the end of each of the periods. This data was then compared to the threshold values described above. Classified thematic data was compared to soil organic carbon values for each ecotype for the end of each of the period of munitions use using thresholds as a criteria function and output to a soil organic carbon status file for each period. If the soil organic carbon value for an ecotype was less than a threshold value, it was coded the appropriate condition level. For example, if the soil organic carbon values for the scrub ecotype was less than 770.8, but greater than 721.6 g C/m^2 (Table 5-3) it was coded as an "Amber" soil carbon status. Status files were then compiled into thematic layers or images that can be displayed for use as a decision making tool.

Soil Carbon Status GIS Display

In addition to the original classification, 15 thematic images of the effects of low, moderate and high levels of munitions use in scrub, broadleaf, mixed leaf, and needleleaf ecotypes for each time period were displayed in the ERDAS Imagine (© 2001 ERDAS, Inc.) viewer. Ordering the images by time period for each munitions level enables the user to compare soil organic carbon responses for each ecotype. There are several ways to display the results on a computer monitor. These include using multiple viewing windows, using the ERDAS Imagine (© 2001 ERDAS, Inc.) "swipe" function that allows the top layer to be lifted or dropped over the next layer as if it were an overlay, or the opacity of the top layer can be decreased so that the lower layer is visible. However, for results and discussion purposes for this study the images were converted to image files that could be displayed in a document or in standard presentation software. Additionally, for demonstration purposes, a small portion (approximately 1x1 km area) of the output image was displayed.

Results and Discussion

Computer Analysis of Remote Sensed Data

The use of remotely sensed data in the form of Landsat 7 ETM+ coupled with computer aided analysis for classification into a geographic information system appears to be a viable method of determining ecotype in a riverine setting. When soil characteristics such as organic carbon levels are correlated with ecotype, it should be a practical method of inferring soil contaminant attenuation capacity for situations in which large inaccessible areas must be evaluated. However, this classification's usefulness may only extend to riverine settings since all of the verification points fell within riverine ecotypes. Also, the classification process grouped two or three forms of ecotypes (e.g., level 3 classification of three types of scrub vegetation), which could possibly have been labeled in further detail, had additional information been available. Even so, this method may still be appropriate for impact area soil evaluations in other settings as long as larger scale ecosystem components such as physiography are held constant.

Soil Carbon Status GIS Display

Output for each level of munitions use are shown in Figures 5-5 a-c. Figure 5-2 shows the modeled area. For low level munitions use the needleleaf is the ecotype first to change from "Green" to "Amber" soil carbon status doing so by the 30-year mark. Soil carbon status remains the same for all ecotypes until the 50-year mark when all of the ecotypes have dropped to "Amber" status. As in the low level munitions use, the first change in status for moderate levels of munitions use occurs by the 30-year mark. However, in this scenario the needleleaf ecotype is joined by the scrub as the first ecotypes to change to "Amber" status. By the 40-year mark broadleaf ecotype changes to "Amber", yet mixed leave remains in a "Green" status. At the 50-year mark the needleleaf and scrub ecotypes change to "Red" status, and the broadleaf is joined by the mixed leaf ecotype at an "Amber" status. High munitions use levels show faster soil carbon status changes. Again the needleleaf and scrub are first to drop to "Amber" status, but in this scenario they do so earlier by the 20-year mark. Needleleaf and scrub ecotypes are joined in an "Amber" status by broadleaf and mixed leaf ecotypes by the 30-year mark. Needleleaf and scrub are first to drop to "Red" status by the 40-year mark and are joined in an "Red" status by broadleaf and mixed leaf ecotypes by the 50-year mark.

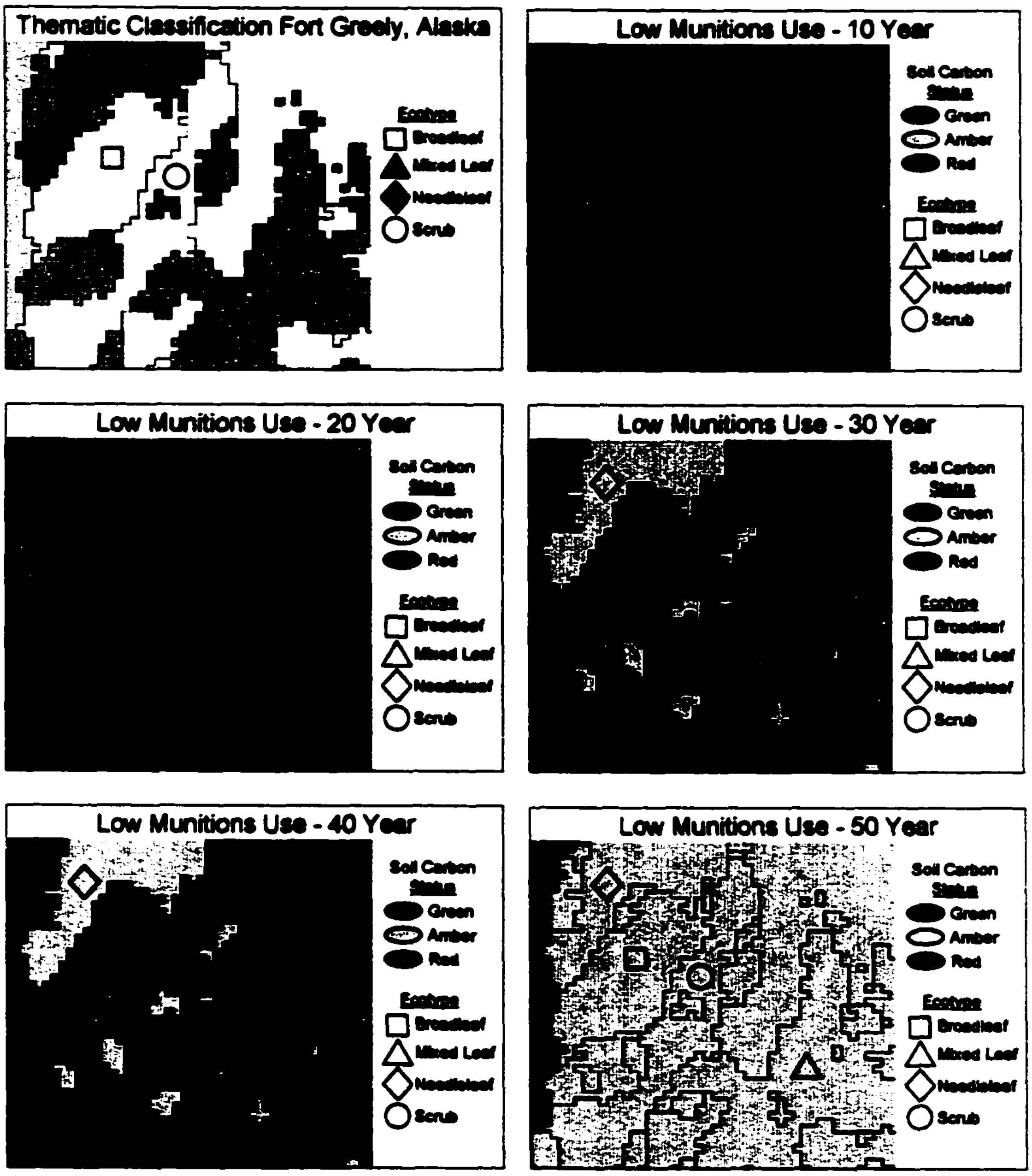


Figure 5-5a. Soil organic carbon status displayed in ten-year increments for simulated low level munitions use for a portion of Fort Greely, Alaska. Thematic classification in upper left panel is provided for reference.

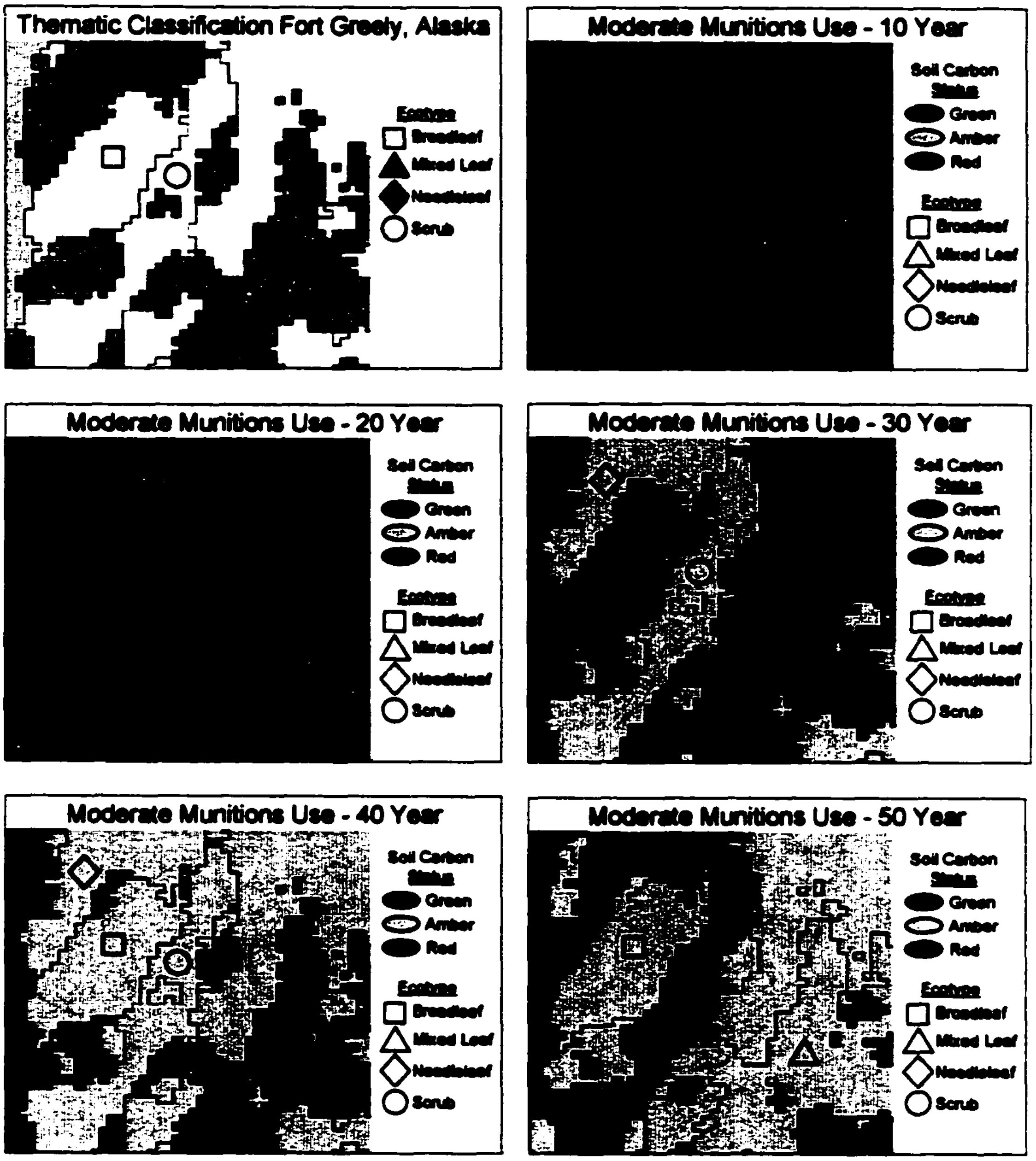


Figure 5-5b. Soil organic carbon status displayed in ten-year increments for simulated moderate level munitions use for a portion of Fort Greely, Alaska. Thematic classification in upper left panel is provided for reference.

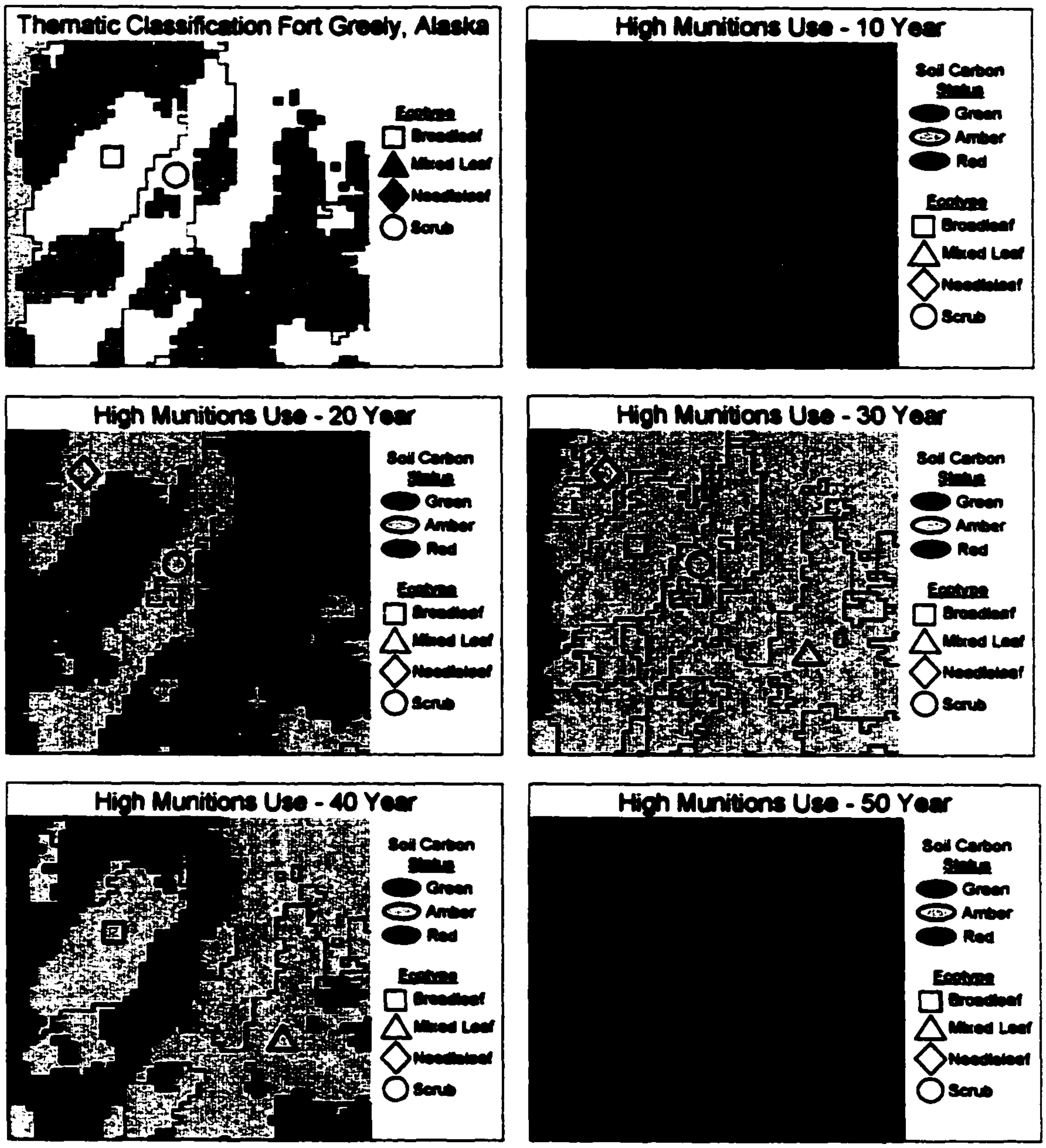


Figure 5-5c. Soil organic carbon status displayed in ten-year increments for simulated high level munitions use for a portion of Fort Greely, Alaska. Thematic classification in upper left panel is provided for reference.

Evaluating the response at the low-level munitions use 30-year display it is apparent that the needleleaf ecotype is the first to drop in soil carbon status. It is closely followed by scrub then broadleaf as shown in the moderate munitions use level 30-year and 40-year displays respectively. Mixed leaf is the slowest to drop as evidenced by the moderate munitions use level 40-year display. These first-to-change rankings: 1st - needleleaf, 2nd - scrub, 3rd - broadleaf and 4th - mixed leaf hold at every level of munitions use though, based on resiliency factors (Table 5-3), one would expect the scrub ecotype to change first followed by needleleaf, broadleaf and mixed leaf. However, this reversal can be accounted for because the scrub had the lowest soil organic carbon loss rates based on CENTURY simulation results. It simply lost soil carbon at a slower rate than the needleleaf ecotype.

Range and Impact Area Management

Range and impact area managers could use this type of GIS model and display to make adaptive management decisions. For example, they may want to determine what level of munitions use would be appropriate for each ecotype base on soil carbon status. Varying the levels of munitions use would result in varying rates of soil carbon and attenuation capacity loss and intermittent munitions use would be reflected in slower overall rates of loss. Another adaptive management action might be to use munitions with high failure rates only in soils that have a large attenuation capacity thereby mitigating some degree of contaminate input.

It is important to note that the threshold for each ecotype was different in the formulation of the GIS model presented here and was based on a maximum allowable percent change for one ecotype applied across all the ecotypes. There were no common soil carbon levels at which all ecotypes changed at the same time, but if the model were formulated in this manner range and impact area managers could elect to allow munitions use within the ecotypes that had the highest levels of soil carbon. Munitions use could continue as long as levels remained above this common threshold. Also, thresholds and therefore the model are based on TNT rates of movement through the soil. Other types of explosive contaminants will have different rates of movement resulting in different thresholds and different model results.

Finally, for demonstration purposes, this presentation treats all the area represented by the ecotypes as being under the influence of munitions use when in reality this would not be the case. There will be targetry placed within these ecotypes and munitions use effects will only be associated with those areas abutting or in close proximity to targetry. Adding a vector layer of data to the GIS model that described the locations and area extent of targetry would be a straightforward next step. Munitions effects would then be constrained to the target locations. In addition to the same management options described above, range and impact area managers could manipulate this targetry layer to determine the optimum levels of munitions use throughout the impact area.

Conclusion

Impact area contamination is a complex problem. An understanding and application of environmental and ecological science provides a vehicle for adequately addressing the problem. This dissertation has demonstrated a methodology that integrates these disciplines into a problem solving approach that provides foundation for effective management, future research and better resource management.

An environmental risk assessment framework can identify a location's relevant fate and transport environmental processes, their relationships to the location's ecological settings and the dominant ecological process and related metrics that ultimately determine the location's ability to respond to environmental threats.

For impact areas at Fort Greely, relevant contaminant fate and transport environmental processes were adsorption and biodegradation, which were largely governed by SOM dynamics. SOM dynamics provided the integrative link between environmental process and ecological setting resolving the complex problem of impact area contamination into an understandable and manageable problem.

Computer technology made this approach possible. Analysis of remotely sensed multispectral data helped to identify affected ecotypes and soil sampling locations forming the foundation of this analysis. Statistical and mathematical analysis provided insight into relevant soil-contaminant-disturbance relationships. CENTURY SOM dynamics simulation identified key disturbance-response relationships between ecotypes and soil organic carbon rates of change. Finally, GIS brought all of the data and relationships together into an integrated analysis that produced an environmentally and ecologically based measure of the system's ability to attenuate contamination.

Future effort should concentrate on coupling contaminant fate and transport simulation with CENTURY simulation to provide a robust management and risk assessment tool. It is only through such an integrated approach that those concerned with environmental problems such as impact area contamination will achieve appreciative results.

REFERENCES

Ågren, G.I., McMurtrie, R.E., W.J. Parton, Pastor, J., and Shugart, H. H. (1991). State-of-the-art of models of production-decomposition linkages in conifer and grassland ecosystems. *Ecological Applications, 1*(2), 118-138.

Alvarez, C.R., and Alvarez, R. (2000). Short-term effects of tillage systems on active soil microbial biomass. *Biology of Fertile Soils. 31*, 157-161.

Aon, M.A., and Colaneri, A. C. (2001). II. Temporal and spatial evolution of enzymatic activities and physico-chemical properties in an agricultural soil, *Applied Soil Ecology, 18* (3), 255-270.

Aon, M.A., Sarena, D. E., Burgos, J. L., and Cortassa, S. (2001). (Micro)biological, chemical and physical properties of soils subjected to conventional or no-till management: an assessment of their quality status. *Soil And Tillage Research, 60*, (3-4), 173-186.

Army Regulation 210-21 (AR 210-21). (1997). *Army Ranges and Training Land Program*. Headquarters, Department of the Army. Washington, D.C.

Bailey, R. G. (1998). *Ecoregions – The Ecosystem Geography of the Oceans and Continents*. New York: Springer-Verlag.

Ball, B.J. (2000). *Creation of Coverage Representing Ecological Sensitivity Categories on NAS Point Mugu, California*. ESRI Users Conference. Retrieved 15 April 2001 from http://www.esri.com/library/userconf/proc00/professional/papers/PAP862/p862.htm

Bejleri, I., Papajorgji, J., Zwick, P., and Boan, J. (2000). *A GIS-Enabled Application to Assist Environmental Assessment of Wetlands*. ESRI Users Conference. Retrieved 15 April 2001 from http://www.esri.com/library/userconf/proc00/professional/papers/PAP553/p553.htm

Big Delta FAA/AMOS AP, AK. (2001). *Climate Data for Big Delta*. Retrieved November 11, 2002, from http://www.wrcc.dri.edu

Brady, N. C., and Weil, R. R. (1999). *The Nature and Properties of Soils*. (12th Ed.). Upper Saddle River, NJ: Prentice Hall.

Brannon, J.M. and Myers T.E. (1997). *Review of Fate and Transport Processes of Explosives.* (Technical Report IRRP-97-21). US Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Brannon, J. M., Deliman, P. N., Gerald, J. A., Ruiz, C. E., Price, C. B., Hayes, C., Yost, S. and Qasim, M. (1999). *Conceptual Model and Process Descriptor Formulations for Fate and Transport of UXO* (Technical Report IRRP-99-1). U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Bristol Environmental and Engineering Services. (2001). *Biomass Harvest, Washington Impact Area Fort Greely, Alaska Range Characterization.* U.S. Army, Cold Regions Research and Engineering Laboratory (CRREL), Fort Wainwright, AK.

Burke, I. C., Lauenroth, W. K., Riggle, R., Brannen, P., Madigan, B., and Beard, S. (1999). Spatial variability of soil properties in the shortgrass steppe: The relative importance of topography, grazing, microsite, and plant species in controlling spatial patterns. *Ecosystems, 2,* 422-438.

Center for the Ecological Management of Military Lands (CEMML). (1999). *Alaska Army Lands Withdrawal Renewal – Final Legislative Environmental Impact Statement* (Volume II). U.S. Army Alaska, Department of the Army. CEMML, Colorado State University, Fort Collins.

Comfort, S.D., Shea, P. J., Hundal, L. S., Li, Z., Woodbury, B. L., Martin, J. L., and Powers, W. L. (1995). TNT transport and fate in contaminated soil. *Journal of Environmental Quality, 24* (6), 1174-1182.

DeAngelis, D.L. (1980). Energy flow, nutrient cycling, and ecosystem resilience. *Ecology, 6* (4), 764-771.

DeAngelis, D.L., Bartell, S. M., and Brenkert, A. L. (1989). Effects of nutrient cycling and food-chain length on resilience. *The American Naturalist,* 134, 778-805.

Demarais, S., Tazik, D. J., Guertin, P. J., and Jorgensen, E. E. (1999). Disturbance associated with military exercises. In L. R. Walker (Ed.). *Ecosystems of Disturbed Ground.* Amsterdam: Elsevier.

Department of Defense Directive (1999). *Environmental and Explosives Safety Management of Department of Defense Active and Inactive Ranges Within the United States (DODD 4715.11).* Headquarters, Department of the Army. Washington, D.C.

Deputy Under Secretary of Defense (Environmental Security) Memorandum (DUSDES). (1994). *Implementation of Ecosystem Management in the DOD,* Washington D.C. Department of Defense.

Diersing, W.E., Courson, J. A., Warren, S. D., Tazik, D. J., and Novak, E. W. (1990). *A Climatic Basis for planning Military Training Operations and Land Maintenance Activities.* U.S. Army Corps of Engineers, Construction Engineering Laboratory (USACERL), Champaign, IL.

Doe, W.W. III, Shaw, R.B., Bailey, R.G., Jones, D. S., and Macia, T.E. (1999). Locations and Environments of U.S. Army Training and Testing Lands: An Ecoregional Framework for Assessment, Center for the Ecological Management of Military Lands (CEMML), Colorado State University, *Federal Facilities Environmental Journal, Autumn.*

Ehlers, L.J. and Bouwer, E. J. (1999). RP4 plasmid transfer among species of Pseudomonas in a biofilm reator, *Water Science and Technology, 39,* (7), 163-171.

Environmental Protection Agency. (2000a). *Administrative Order for: Massachusetts Military Reservation Training Range and Impact Area Response Actions.* United States Environmental Protection Agency Region 1. (EPA Docket No.:SDWA-1-2000-14).

Environmental Protection Agency. (2000b). *Used or Fired Munitions and Unexploded Ordnance at Closed, Transferred, and Transferring Military Ranges – Interim Report and Analysis of EPA Survey Results* Washington, DC. Office of Solid Waste and Emergency Response. (EPA 505-R-00-01).

Environmental Protection Agency. (2002). EPA Region III Risk Based Concentration (RBC) Table. Retrieved on 20 March 2002 from (http://www.epa.gov/reg3/reg3hwmd/risk/index.htm) EPA Region III, Philadelphia, PA.

Espenshade, E., B., and Hudson, J. C. (Eds.). (1995). *Goode's World Atlas.* 19th Edition. Rand McNally and Company, U.S.A.

Federation of American Scientists (FAS). 2001. Munitions Descriptions Retrieved on 24 November 2001 from: http://www.fas.org

Field Manual No. 1 (FM 1). (2001). *The Army.* Department of the Army Headquarters, Washington, D.C.

Freeze, R.A. and Cherry J.A. (1979). *Goundwater.* Englewood Cliffs, NJ: Prentice-Hall.

Gardner, R. H. (1998). Pattern, Process and The Analysis of Spatial Scales. In D. L. Peterson and V. T. Parker (Eds.), *Ecological Scale: Theory and Applications* (pp. 17-34). New York: Columbia University Press.

Green, K. (1994). The Potential and Limitations of Remote Sensing and GIS in Providing Ecological Information. In V. Alaric Sample (Ed.), *Remote Sensing and GIS in Ecosystem Management* (pp. 327-336). Washington, DC: Island Press.

Gustafson, E.J. (1998). Quantifying Landscape Spatial Pattern: What is the state of the art? *Ecosystems, 1*,143-156.

Hall, D.O., Ojima, D. S., Parton, W. J., and Scurlock, M. O. (1995). Response of temperate and tropical grasslands to CO_2 and climate change. *Journal of Biogeography. 22*, 537-547.

Hampton, H.D. (1971). *How the U.S. Cavalry Saved Our National Parks.* Bloomington, Indiana: Indiana University Press.

Hao, X., Chang, C., and Lindwall, C. W. (2001). Tillage and crop sequence effects on organic carbon and total nitrogen content in an irrigated Alberta soil. *Soil And Tillage Research, 62,* 167, 169.

Harwell, M.A., Cropper, W. P. Jr., and Ragsdale, H. L. (1977). Nutrient stability and stability: a reevaluation. *Ecology, 58*, 660-666.

Hundal, L.S., Shea, P. J., Comfort, S. D., Powers, W. L., Singj, J. (1997). Long-term TNT sorption and bound residue formation in soil. *Journal of Environmental Quality, 26* (3), 896-904.

Jane's .(2000). *Jane's Ammunition Handbook 2000-2001.* (9th Ed.). T.J. Gander and C.Q. Cutshaw (Eds). Surrey, UK: Jane's Information Group.

Jenkins, T. F., Walsh, M. E., Thorpe, P. G., Miyares, P. H., Ranney, T. A. Grant, C. L., et al. (1998). *Site Characterization for Explosives Contamination at a Military Firing Range Impact Area.* Hanover, NH: U.S. Army Corps of Engineers, Cold Regions Research Laboratory (Special Report 98-9).

Jensen, J.R. (1996). *Introductory Digital Image Processing: A remote sensing perspective, 2nd edition.* K.C. Clark (Ed.). Upper Saddle River, NJ: Prentice-Hall.

Jorgenson, M.T., Roth, J. E., Smith, M. D., Schlentner, S., Lentz, W., Pullman, E. R., and Racine, C.H. (2001). *An ecological land survey for Fort Greely, Alaska*. Hanover, NH: U.S. Army Corps of Engineers, Engineer Research and Development Center, and Cold Regions Engineering Laboratory Technical Report (TR-01-4).

Kelly, R.H., Burke, I. C., and Lauenroth, W. K. (1996). Soil organic matter and nutrient availability responses to reduced plant inputs in shortgrass steppe. *Ecology, 77* (8), 2516-2527.

King, W.C. (2000). *Understanding International Environmental Security: A strategic perspective*. Atlanta, GA: Army Environmental Policy Institute.

Kitts, C.L., Green, C. E., Otley, R A., Alvarez, M. A., and Unkefer, P. J. (2000). In Type I nitroreductases in soil enterobacteria reduce TNT (2,4,6-trinitrotolulene) and RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine), *Canadian Journal of Microbiology, 46*, (3), 278-282.

Kladivko, E.J. (2001). Tillage systems and soil ecology. *Soil and Tillage Research, 61* (1-2), 61-76.

Klingensmith, K.M., and Van Cleve, K. (1993). Denitrification and nitrogen fixation in floodplain successional soils along the Tanana River, interior Alaska. *Canadian Journal for Forest Research, 23*, 956-963.

Klute, A. (1986). *Methods of Soil Analysis: Part 1. Physical and Mineralogical Methods*. Madison, WI: Soil Science of America.

LaGrega, M. D., Buckingham, P. L., Evans, J. C., and The Environmental Resources Management Group. (1994). *Hazardous Waste Management*. In B. J. Clark and J. M. Morriss (Eds.), McGraw-Hill Series in Water Resources and Environmental Engineering. New York, NY: McGraw-Hill.

Larson, S. L., Strong, A. B., Yost, S. L., Escalon, B. L., and Parker, D. (1998a). *Analysis of Explosives in Plant Tissues: Modifications to Method 8330 for Soil*. Vicksburg, MS: Installation Restoration Research Program, U.S. Army Corps of Engineers, Waterways Experiment Station. (Technical Report IRRP-98-5).

Larson, S. L., Weiss, C. A., Jr., Martino, M. R., and Adams, J. W. (1998b). *Role of Expandable Clays in the Environmental Fate of Trinitroluene Contamination* Vicksburg, MS: U.S. Army Corps of Engineers, Waterways Experiment Station. (Technical Report IRRP-98-6).

Levin, S. A. (1992). The problem of pattern and scale in ecology. *Ecology, 73,* 1943-1967.

Loreau M. (1994). Material cycling and the stability of ecosystems. *The American Naturalist, 143,* 508-513.

Lugeri, N., Amadei, M., Bagnaia, R., Dragan, M., Fernetti, M., Laureti, L., Lugeri, F. R., et al. (2000). *Environmental quality and territorial vulnerability assessment through the GIS of Landscape Units of Italy: the experience of the Map of Nature project.* ESRI Users Conference. Retrieved 15 April 2001 from http://www.esri.com/library/userconf/ proc00/ professional/papers/PAP522/p522.htm

Lynch, J.C., Myers K.F., Brannon J.M. and Delfino J.J. (2001). Effects of pH and temperature on the aqueous solubility and dissolution rate of 2,4,6-Trinitrotoluene (TNT), Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), and Octahydro-1,3,5,7-tetanitro-1,2,5,7-tetrazocine (HMX). *Journal of Chemical Engineering Data.* 46, 1549-1555.

Maurer, B.R. (2000). *Using GIS to Assess the Occurrence of Natural Attenuation in Groundwater at an NPL Site.* Cummings/Riter Consultants, Inc. ESRI Users Conference. Retrieved 15 April 2001 from (http://www.esri.com/library/userconf/proc00/professional/papers/PAP553/p553.htm)

McLendon, T., Childress, W.M., Price, D., and Anderson, A.B. (1998). *A Successional Dynamics Simulation Model as a Factor for Determining Military Training Land Carrying Capacity.* Champaign, IL: U.S. Army Corps of Engineers Construction and Engineering Laboratories Technical Report.

Metherell, A.K. (1992). Simulation of soil organic matter dynamics and nutrient cycling in agroecosystems. (Doctoral dissertation). Colorado State University, Fort Collins.

Metherell, A.K., Harding, L. A., Cole, C. V., and Parton, W. J. (1993). *CENTURY Soil organic matter model environment* (Technical documentation Agroecosystem version 4.0). Fort Collins, CO: Great Plains System Research Unit (Technical Report No. 4. USDA-ARS).

Milchunas, D. E., Shultz, K. A., and Shaw, R. B. (2000). Plant community structure in relation to long-term disturbance by mechanized military maneuvers in a semiarid region. *Environmental Management, 25,* 525-539.

Mladenoff, D.J., and Host, G. E. (1994). Ecological Perspective: Current and Potential Applications of Remote Sensing and GIS to Ecosystem Analysis. *Remote Sensing and GIS in Ecosystem Management.* V. Alaric Sample (Ed.), Washington, D.C.: Island Press.

Myers, T. E., Brannon, J. M., Pennington, J. C., Davis, W. M., Myers, K. F., Townsend, D. M., Ochman, M. K., and Hayes C. A. (1998). *Laboratory Studies of Soil Sorption/Transformation of TNT, RDX, and HMX.* Vicksburg, MS: Installation Restoration Research Program, U.S. Army Corps of Engineers, Waterways Experiment Station (Technical Report IRRP-98-8).

National Atmospheric Depostion Program (NAPD) /NTN (2001). North Star, AK Site ID: AK01, Date Range: 1992-2001. Report Date: June 7, 2001.

National Institute for Occupational Safety and Health (NIOSH). (1994). *Pocket Guide to Chemical Hazards.* U.S. Department of Health and Human Services.

National Research Council (NRC). (2000). *Ecological Indicators for the Nation.* National Academy of Sciences. Washington, DC: National Academy Press.

Needelman, B.A., Wander, Bollero, M. M., Boast, C. W., Sims, G. K., and Bullock, D. G., (1999). Interaction of tillage and soil texture: biologically active soil organic matter in Illinois. *Soil Science Society of America Journal, 63,* 1326-1334.

O'Neill, R.V. (1976). Ecosystem persistance and heterotrophic regulation. *Ecology, 57,* 1244-1253.

O'Neill, R.V. (1999). Recovery in complex ecosystems. *Journal of Aquatic Ecosystem Stress and Recovery, 6,* 181-187.

Ott, R.L. (1993). *An Introduction to Statistical Methods and Data Analysis.* (4th Ed.) Belmont, CA: Wadsworth Publishing Company.

Palik, Brian J., Goebel, P. C., Kirkman, L. K., and West, L. (2000). Using landscape hierarchies to guide restoration of disturbed ecosystems. *Ecological Applications, 10* (1), 189-202.

Parton, W.J., Cole, C. V., Stewart, J. W. B., Ojima, D. S. and Schimel, D. S. (1989). Simulating regional patterns of soil C, N, and P dynamics in the U.S. central grasslands region. In M. Clarholm and L. Bergström (Eds.), *Ecology of Arable Lands* (pp. 99-108). Amsterdam: Kluwer Academic Publishers.

Parton, W.J., Coughenour, M. B., Scurlock, J. M. O., Ojima, D. S., Gilmanov, T. G., Scholes, R. J., Schimel, D. S., et al. (1996). Global grassland ecosystem modeling: Development and test of ecosystem models for grassland systems. In A.I. Breymeyer, D.O. Hall, J.M. Melillo, and G.I. Ågren, (Eds.). *Global Change: Effects on Coniferous Forests and Grasslands, Scope Vol. 56*. (pp. 229-266). Chichester, West Sussex, England: John Wiley and Sons.

Parton, W.J., McKeown, B., Kirchner, V., and Ojima, D. S. (1992). *CENTURY Users Manual*. Natural Resource and Ecology Laboratory Publication, Colorado State University, Fort Collins.

Parton, W.J., Schimel, D. S., Cole, D. V., and Ojima, D. S. (1987). Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science Society of America Journal, 51*, 1173-1179.

Parton, W.J., Scurlock, J. M. O. Ojima, D. S., Gilmanov, T. G., Scholes, R. J., Schimel, D. S., Kirchner, T., et al. (1993). Observations and modeling of biomass and soil organic matter dynamics for the grassland biome worldwide. *Global Biogeochemical Cycles, 7*, 785-809.

Pennington, J.C. (1988). *Soil sorption and plant uptake of 2,4,6-trinitrotoluene.* Vicksburg, MS: Environmental Laboratory, Waterways Experiment Station.

Pennington, J. C., Zakikhani, M., Harrelson, D. W., and Allen, D. S. (1999a). *Monitored Natural Attenuation of Explosives in Groundwater. Environmental Security Technology Certification Program – Cost and Performance*. Vicksburg, MS: Environmental Laboratory, Waterways Experiment Station. (Technical Report EL-99).

Pennington, J. C., Thorn, K. A., Inouye, L. S., McFarland, V. A., Jarvis, A. S., Lutz, C. H., Hayes, C.A., et al. (1999b). *Explosive Conjugation Products in Remediation Matricies: Final Report*. Vicksburg, MS: Strategic Environmental Research and Development Program, U.S. Army Corps of Engineers, Engineering Research and Development Center. (Technical Report SERDP-99-4).

Pennington, J. C., Miyares, P. H., Ringelberg, D. B., Zakikhani, M., Reynolds, C. M., Felt, D., Coffin, R. B., Gunnison, D., Cifuentes, L., Fredrickson, H. L., and Jenkins, T. F. (1999c). *Natural Attenuation of Explosives in Soil and Water Systems at Department of Defense Sites: Final Report*. Vicksburg, MS: Strategic Environmental Research and Development Program, U.S. Army Corps of Engineers, Waterways Experiment Station. (Technical Report SERDP-99-1).

Peters, D.C., and Hauff, P. L. (2000). Multispectral Remote Sensing to Characterize Mine Waste (Cripple Creek and Goldfield, U.S.A.). *Remote Sensing for Site Characterization.* Friedrich Kuehn, Bernard Hoering, Truse V.V. King and Douglas C. Peters (Eds.). Berlin, Heidelberg, New York: Springer-Verlag.

Price, C. B., Brannon, J. M., and Yost, S. L. (1998). *Transformation of RDX, and HMX Under Controlled Eh/pH Conditions.* Vicksburg, MS: Installation Restoration Research Program, U.S. Army Corps of Engineers, Waterways Experiment Station. (Technical Report-IRRP 98-2).

Quideau, S.A., Chadwick, O. A., Benesi, A., Graham, R. C., and Anderson, M. A. (2001). A direct link between forest vegetation type and soil organic matter composition, *Geodermam, 104* (1-2), 41-60.

Roberts, P.V., Reinhard M. and Valocchi A.J. (1982). Movement of organic contaminants in groundwater: implications for water supply. *Journal of the American Water Works* Association *(74)*, 408-413.

Rubenson, D., Aroesty, J., and Thompsen, C. (1992). *Two Shades of Green – Environmental Protection and Combat Training*, Arroyo Center, RAND.

Rubenson, D., Aroesty, J., Wicinas, P.W., Farnsworth, G., and Ramsey, K. (1994). *Marching to Different Drummers – Evolution of the Army's Environmental Program*, Arroyo Center, RAND.

Reuss, M. (1983). *Shaping Environmental Awareness – The United States Army Corps of Engineers Environmental Advisory Board 1970-1980.* Historical Division, Office of Administrative Services, Office of the Chief of Engineers. Department of the Army, Washington, D.C.

Sanford, R.L., Parton, W. J., Ojima, D. S. and Lodge, D. J. (1991). Hurricane effects on soil organic matter dynamics and forest production in the Luguillo Experimental Forest, Puerto Rico: Results of simulation modeling. *Biotropica, 23* (4a), 364-372.

Seastedt, T.R., Coxwell, C. C., Ojima, D. S., and Parton, W. J. (1994). Controls of plant and soil carbon in a semihumid temperate grassland. *Ecological Applications, 4* (2), 344-353.

Shaw, R. B., and Diersing, V. E. (1990). Tracked vehicle impacts on vegetation at the Pinon Canyon Maneuver Site, Colorado. *Journal of Environmental Quality, 19,* 234-243.

Shaw, R.B., Doe, W.W. III, Palka, E.J., and Macia, T.E. (2000). *Where does the U.S. Army Train to Fight?: Sustaining Army Lands for Readiness in the 21st Century*, Center for the Ecological Management of Military Lands (CEMML), Colorado State University, Military Review.

Singh, J., Comfort, S. D., Hundal, L. S., and Shea, P. J. (1998). Long-term RDX sorption and fate in soil. *Journal of Environmental Quality, 27* (3), 572-577.

Spark, D.L. (Ed). (1996). *Methods of Soil Analysis: Part3, Chemical Methods.* Madison, WI: Soil Science Society of America.

Steele, B.N. (2000). Combining Multiple Classifiers: An application using spatial and remotely sensed information for land cover type mapping. *Remote Sensing of the Environment, 74,* 545-556.

Strategic Environmental Research and Development Program (SERDP) Report. (1995). *Ecological Modeling for Military Land Use Decision Support: Interim Progress Report for Case Studies.* SERDP Program Office Arlington, VA.

Strategic Environmental Research and Development Program (SERDP). (1998a). Ecosystem Management Project (SEPM), FY 99 Statement of Need (SON). *Determination of Indicators of Ecosystem Health.* SERDP Program Office Arlington, VA.

Strategic Environmental Research and Development Program (SERDP). (1998b). Ecosystem Management Project (SEPM), FY 00 Statement of Need (SON). *Ecological Disturbance in the Context of Military Landscapes.* SERDP Program Office Arlington, VA.

Strategic Environmental Research and Development Program (SERDP) (2000). Ecosystem Management Project (SEPM), Work Plan. *SEMP Ecosystem Characterization and Monitoring Initiative*, SERDP Program Office Arlington, VA.

Sullivan, G.R., and Stone, M.P.W. (1992). *U.S. Army Environmental Strategy Into the 21st Century,* Headquarters, Department of the Army.

Townsend, A.R., Vitousek, P. M., and Trumbore, S. E. (1995). Soil organic matter dynamics along gradients in temperature and land use on the island of Hawaii. *Ecology, 76* (3), 721-733.

Training Circular 25-1 (TC 25-1). (1991). *Training Land.* Headquarters, Department of the Army. Washington, D.C.

Training Circular 25-8 (TC 25-8). (1992). *Training Ranges.* Headquarters, Department of the Army. Washington, D.C.

Training Circular 5-400 (TC 5-400). (1994). *Unit Leader's Handbook for Environmental Stewardship*, Headquarters, Department of the Army. Washington, D.C.

Turner, M. G. (1989). Landscape ecology: the effect of pattern on process. *Annual Review of Ecology and Systematics, 20,* 171-197.

U.S. Army Environmental Center (USAEC). (2000). *Army Range Inventory Management Plan, 2002.* U.S. Army Environmental Center, Aberdeen Proving Ground, MD.

U.S. Army Public Affairs Office (USAPAO). (1999). *Fiscal Year 2000 Army Budget.* Headquarters, Department of the Army.

U.S. Army Defense Ammunition Center, Technical Center for Explosives Safety (USATCES). (2000). *Report of Findings for: Study of Ammunitions Dud and Low Order Detonation Rates.* US Army Environmental Center. Aberdeen Proving Ground, MD.

United States Forest Service. (1994). *Ecological Subregions of the United States: Section Descriptions.* United States Department of Agriculture, Ecosystem Management, Washington, D.C.

Van Cleve, K., Dyrness, C. T., Marion, G. M., and Erickson, R. (1993). Control of soil development on the Tanana River floodplain, interior Alaska. *Canadian Journal for Forest Research, 23,* 941-955.

VanDervort. J. D. B. (1999). *UXO(C) Issues and the Impact on Active Ranges Briefing to the Training and Doctrine Command SAFE Conference.* Headquarters Department of the Army, Office of the Deputy Chief of Staff for Operations and Plans, Washington, D.C.

Verschueren, K. (1996). *Handbook of Environmental Data on Organic Chemicals*, (3rd Ed.), New York, NY: Wiley.

Viereck, L.A., Dyrness, C. T., and Foote, M. J. (1993). An overview of the vegetation and soils of the floodplain ecosystems of the Tanana River, interior Alaska. *Canadian Journal for Forest Research 23*, 889-898.

Walsh, M.E., Collins C.M., Racine C.H., Jenkins T.F., Gelvin A.B., and Ranney T.A. (2001). *Sampling for explosives residues at Fort Greely, Alaska – Reconnaissance visit July 2000.* Technical Report (TR-01-15). U.S. Army Corps of Engineers, Engineer Research and Development Center, and Cold Regions Engineering Laboratory, Hanover, NH.

Weissmahr, K. W., Haderlein, S. B., and Schwarzenbach, R. P. (1998). Complex formation of soil minerals with nitroaromatic explosives and other π-acceptors. *Soil Science Society of America, J* (62), 369-378.

Yarie, J. (1989). *Production, foliage biomass and nitrogen from LTER sites 1989.* Bonanza Creek Long Term Ecological Research Site. Retrieved 20 April 2002 from http://www.lter.uaf.edu/Data_catalog_master.cfm

Yarie, J. (1991). *Soil Chemical Analysis, LTER sites, 1989 and 1991.* Bonanza Creek Long Term Ecological Research Site. Retrieved 20 April 2002 from http://www.lter.uaf.edu/Data_catalog_master.cfm

Yinon, J. (1999). *Forensic and Environmental Detection of Explosives.* West Sussex, England: John Wiley and Sons.

APPENDICES

APPENDIX A

Fort Greely, Alaska Soil Data

Appendix A

Soil Data from survey plots at Fort Greely, Alaska. Soil analysis was performed by the Colorado State University Soils Laboratory. Ecotype abbreviations are: WS – Washington Control Area Scrub, WIS – Washington Impact Area Scrub, JS – Jarvis Creek Control Area Scrub, JML – Jarvis Creek Control Area Mixed Leaf, JBL – Jarvis Creek Control Area Broadleaf, CRT – Crater.

Ecotype	CEC	PrcC	PrcN	NH4	NO3	N	P	K
Units	meq/100g	%	mg/kg	mg/kg	ppm	ppm	ppm	ppm
Abbrev.	Cation Exchange Capacity	Percent Carbon	Percent Nitrogen	Nitrogen as ammonia	Nitrogen as nitrate	Total Nitrogen	Phos-phorous	Potassium
WS	19.5	2.891	0.169	4.4	15.2	19.6	4.17	75.74
WS	9.4	1.904	0.133	4.1	9.0	13.1	3.28	63.22
WS	10.6	1.935	0.131	2.3	32.7	35.0	4.57	68.16
WS	10.9	1.959	0.125	1.5	38.0	39.5	3.96	65.89
WS	5.8	1.018	0.064	2.1	36.9	39.0	3.23	55.18
WS	10.4	2.161	0.151	5.5	5.7	11.2	4.69	54.05
WS	9.5	1.581	0.125	3.5	6.8	10.3	3.93	69.5
WS	6.8	1.217	0.100	1.9	26.5	28.4	3.99	57.19
WS	2.2	0.411	0.018	1.2	5.3	6.5	3.02	33.55
WS	9.9	2.775	0.207	7.6	3.9	11.5	5.47	69.98
WS	5.8	1.217	0.086	1.5	35.3	36.8	3.40	69.1
WS	9.2	1.799	0.123	6.7	3.9	10.6	4.04	67.6
WIS	9.8	1.951	0.158	1.3	25.1	26.4	4.76	73.94
WIS	21.1	5.047	0.362	1.5	47.9	49.4	7.82	117.9
WIS	15.4	2.897	0.229	2.7	110	112.7	5.97	90.5
WIS	5.5	1.425	0.110	2.2	61.4	63.6	0.19	66.4
WIS	8.2	1.329	0.099	2.5	47.6	50.1	1.91	87.4
WIS	8.2	0.823	0.061	1.5	43.0	44.5	1.39	87.77
WIS	17.6	2.411	0.174	4.4	3.2	7.6	6.30	97.55
WIS	8.6	1.339	0.082	6.8	1.7	8.5	5.45	51.22
WIS	8.8	0.950	0.053	6.2	2.9	9.1	1.15	59.5
WIS	8.6	0.914	0.065	2.3	60.1	62.4	0.70	55.7
WIS	15.3	2.606	0.196	6.0	33.2	39.2	4.01	94.58
WIS	16.7	3.277	0.220	4.4	67.9	72.3	5.21	111.6
JS	6.0	1.167	0.102	5.6	2.0	7.6	3.35	42.41
JS	6.7	1.523	0.097	4.3	6.0	10.3	3.20	36.81
JS	7.9	1.582	0.122	6.2	24.2	30.4	3.87	49.41
JS	8.9	1.131	0.085	3.8	9.2	13.0	5.07	39.66
JS	9.7	2.354	0.122	5.3	2.2	7.5	5.28	38.12
JS	64.8	10.94	1.007	13.2	2.5	15.7	2.83	107.6
JS	31.1	5.121	0.258	3.4	2.7	6.1	3.18	67.84
JS	22.0	10.40	0.719	3.6	7.7	11.3	3.16	105.1
JS	39.6	7.616	0.364	11.8	1.4	13.2	4.82	185.8
JS	25.3	8.056	0.424	18.2	1.8	20.0	9.23	178.7
JS	26.9	8.968	0.535	1.8	9.6	11.4	3.39	72.9
JS	76.0	13.49	0.861	2.4	23.3	25.7	7.72	121.1
JML	26.1	3.237	0.177	4.3	2.2	6.5	4.45	91.06

Ecotype	CEC	PrcC	PrcN	NH4	NO3	N	P	K
Units	meq/100g	%	mg/kg	mg/kg	ppm	ppm	ppm	ppm
Abbrev.	Cation Exchange Capacity	Percent Carbon	Percent Nitrogen	Nitrogen as ammonia	Nitrogen as nitrate	Total Nitrogen	Phos- phorous	Potassium
JML	53.3	11.08	0.587	11.6	2.3	13.9	6.14	167.5
JML	41.7	6.588	0.330	10.5	2.6	13.1	4.98	103.6
JML	70.1	14.47	0.581	25.8	2.0	27.8	15.5	489.1
JML	23.0	3.848	0.195	2.4	1.3	3.7	3.12	81.25
JML	16.5	3.177	0.159	2.6	1.7	4.3	3.06	68.57
JML	27.5	6.966	0.352	21.2	4.5	25.7	9.24	282.1
JML	38.3	9.583	0.403	7.2	1.4	8.6	24.5	215.1
JML	28.9	6.172	0.261	12.5	1.3	13.8	3.13	129.6
JML	26.1	4.575	0.221	6.6	10.1	16.7	3.16	89.1
JML	43.9	6.692	0.272	8.6	3.7	12.3	3.37	127.9
JML	12.2	3.461	0.179	4.2	18.5	22.7	3.24	150.2
JBL	22.1	5.033	0.363	15.8	2.2	18.0	3.46	147.8
JBL	27.1	4.445	0.289	2.1	10.8	12.9	4.81	104.5
JBL	34.8	5.761	0.349	4.6	16.4	21.0	4.74	155.1
JBL	56.3	10.01	0.536	39.4	3.8	43.2	13.7	176.4
JBL	40.5	8.593	0.427	2.2	1.9	4.1	10.2	128.1
JBL	44.6	8.812	0.414	15.1	6.6	21.7	5.35	144.8
JBL	34.6	6.484	0.315	19.7	1.5	21.2	25.8	124.7
JBL	31.3	5.923	0.295	2.9	3.1	6.0	4.66	75.22
JBL	26.5	4.316	0.272	2.1	24.4	26.5	4.28	71.48
JBL	5.6	4.36	0.263	12.4	10.5	22.9	3.84	121.1
JBL	30.7	8.512	0.407	9.4	1.8	11.2	7.82	157.2
JBL	26.2	5.829	0.351	3.6	1.7	5.3	4.31	147.7
CRT	5.7	1.122	0.078	1.7	36.9	38.6	12.8	117.4
CRT	6.3	0.983	0.063	6.0	8.4	14.4	0.38	83.25
CRT	4.9	1.173	0.037	1.6	24.8	26.4	1.55	94.34
CRT	5.5	0.945	0.062	5.3	14.3	19.6	4.73	45.51
CRT	4.3	0.613	0.037	3.4	2.4	5.8	16.6	44.18
CRT	5.4	0.730	0.060	5.4	2.5	7.9	0.38	38.75
CRT	4.4	0.459	0.026	4.2	2.2	6.4	2.11	37.62
CRT	5.2	0.746	0.041	3.2	2.0	5.2	3.87	33.62
CRT	4.1	0.437	0.027	2.2	1.9	4.1	3.26	48.51
CRT	5.1	0.590	0.034	5.3	6.9	12.2	2.99	48.28
CRT	4.1	0.439	0.018	4.2	13.6	17.8	2.30	46.31
CRT	4.9	0.586	0.044	2.4	2.4	4.8	3.01	43.77
CRT	8.6	0.767	0.051	3.3	2.4	5.7	3.02	48.44
CRT	7.4	0.633	0.048	2.0	2.5	4.5	4.77	45.92
CRT	9.3	0.762	0.046	4.1	22.3	26.4	1.78	39.71
CRT	9.1	0.846	0.055	1.6	37.2	38.8	3.55	87.52
CRT	14.2	1.204	0.081	1.5	28.0	29.5	3.77	92.72
CRT	15.3	1.282	0.097	1.2	31.0	32.2	1.88	93.8
CRT	4.1	0.400	0.036	2.0	48.5	50.5	2.62	70.96
CRT	16.3	1.592	0.112	1.3	31.2	32.5	2.81	69.25
CRT	14.1	1.121	0.078	1.8	51.9	53.7	3.22	84.04

Ecotype	CEC	PrcC	PrcN	NH4	NO3	N	P	K
Units	meq/100g	%	mg/kg	mg/kg	ppm	ppm	ppm	ppm
Abbrev.	Cation Exchange Capacity	Percent Carbon	Percent Nitrogen	Nitrogen as ammonia	Nitrogen as nitrate	Total Nitrogen	Phos-phorous	Potassium
CRT	7.3	0.883	0.056	4.2	2.6	6.8	1.55	47
CRT	9.5	1.241	0.088	5.1	1.6	6.7	2.08	57.64
CRT	9.2	0.758	0.063	6.5	6.4	12.9	0.67	46.88
CRT	11.4	1.139	0.074	7.3	3.3	10.6	1.17	64.75
CRT	11.1	1.055	0.061	1.8	45.7	47.5	0.85	73.73
CRT	10.5	0.968	0.063	1.9	34.6	36.5	1.98	60.04
CRT	13.5	1.464	0.091	6.6	3.6	10.2	2.69	63.72
CRT	12.2	1.307	0.075	6.6	32.5	39.1	4.68	77.39
CRT	10.9	0.806	0.049	5.8	28.8	34.6	4.21	121.8
CRT	10.1	0.908	0.045	1.5	20.3	21.8	1.39	42.15
CRT	11.1	0.828	0.049	5.9	3.3	9.2	5.12	92.56
CRT	10.4	0.831	0.050	2.2	14.6	16.8	4.91	40.38
CRT	5.6	0.526	0.029	2.4	16.8	19.2	6.33	53.53
CRT	12.2	0.884	0.049	5.0	2.7	7.7	6.83	48.77
CRT	11.4	0.761	0.056	1.9	1.6	3.5	6.40	40.59
CRT	3.4	0.349	0.017	1.2	0.8	2.0	4.76	15.43
CRT	10.5	0.899	0.020	1.3	0.8	2.1	4.98	16.88
CRT	3.5	0.325	0.017	2.8	0.9	3.7	6.68	19.47
CRT	4.9	0.537	0.044	4.6	2.5	7.1	7.39	28.06
CRT	8.5	0.711	0.045	1.6	34.2	35.8	4.76	30.13
CRT	6.2	0.603	0.041	1.7	0.7	2.4	5.62	24.33
CRT	6.4	0.687	0.058	5.5	3.8	9.3	6.97	26.71
CRT	10.3	0.873	0.080	2.4	23.3	25.7	7.89	37.79
CRT	7.4	0.682	0.047	2.0	18.8	20.8	8.46	29.72
CRT	4.0	0.580	0.028	1.1	1.3	2.4	7.07	39.37
CRT	3.2	0.425	0.019	1.3	1.6	2.9	7.80	26.29
CRT	3.1	0.373	0.007	0.8	1.1	1.9	7.53	30.86
CRT	4.2	0.429	0.033	0.1	2.0	2.1	6.13	8.146
CRT	4.5	0.496	0.023	0.4	1.0	1.4	6.80	7.282
CRT	3.9	0.348	0.026	0.7	1.1	1.8	5.00	9.751
CRT	4.1	0.451	0.022	2.0	1.9	3.9	7.13	12.59
CRT	5.9	0.641	0.044	1.2	1.8	3.0	6.93	18.76
CRT	5.4	0.594	0.043	1.1	1.2	2.3	9.53	13.33
CRT	22.5	2.005	0.144	2.6	2.0	4.6	9.07	40.86
CRT	15.4	1.483	0.104	2.3	2.5	4.8	7.57	49.45
CRT	12.5	1.176	0.089	2.9	2.2	5.1	7.04	37.94
CRT	26.4	2.319	0.155	1.4	31.1	32.5	8.87	47.46
CRT	27.5	2.829	0.208	8.2	4.2	12.4	10.1	51.88
CRT	26.3	2.763	0.209	4.8	3.0	7.8	11.4	54.76
CRT	12.4	1.068	0.072	5.4	3.0	8.4	10.8	101.8
CRT	11.5	0.961	0.070	1.1	35.3	36.4	11.3	53.21
CRT	14.0	1.207	0.086	4.5	2.6	7.1	10.6	48.34
CRT	6.4	0.640	0.047	1.1	27.3	28.4	8.48	30.97
CRT	4.2	0.576	0.034	1.5	28.7	30.2	10.2	37.06

Ecotype	CEC	PrcC	PrcN	NH4	NO3	N	P	K
Units	meq/100g	%	mg/kg	mg/kg	ppm	ppm	ppm	ppm
Abbrev.	Cation Exchange Capacity	Percent Carbon	Percent Nitrogen	Nitrogen as ammonia	Nitrogen as nitrate	Total Nitrogen	Phos-phorous	Potassium
CRT	7.2	0.623	0.044	1.0	30.4	31.4	8.94	31.19
CRT	5.3	0.581	0.043	1.5	22.3	23.8	9.13	27.77
CRT	5.4	0.827	0.059	2.3	3.9	6.2	10.8	31.86
CRT	7.3	0.568	0.044	1.1	36.2	37.3	9.39	36.84
CRT	7.7	0.611	0.048	1.3	22.2	23.5	9.39	33.41
CRT	9.4	0.868	0.058	1.3	27.1	28.4	11.7	35.84
CRT	6.8	0.811	0.060	3.6	20.3	23.9	10.4	33.63
CRT	7.2	0.683	0.076	1.7	32.0	33.7	9.59	34.85
CRT	8.5	0.723	0.060	1.0	39.1	40.1	10.5	29.76
CRT	10.2	0.899	0.048	0.7	46.6	47.3	8.61	32.96

Ecotype	PrcOM	pH	BpH	CumO	Sand	Silt	Clay	Ca
Units	%	pH	BpH	cm	%	%	%	ppm
Abbrev.	Percent Organic Matter	pH	Buffer pH	Organic Matter Depth	Percent Sand	Percent Silt	Percent Clay	Calcium
WS	4.98408	7.4	7.5	2	46	50	4	3501
WS	3.2825	7.5	7.5	2	45	51	4	4101
WS	3.33594	7.1	7.5	2	51	45	4	3345
WS	3.37732	7.2	7.5	1	48	48	4	3765
WS	1.75503	7.5	7.5	2	60	37	3	5079
WS	3.72556	7.4	7.5	2	50	47	3	2306
WS	2.72564	7.5	7.5	1	44	52	4	4228
WS	2.09811	7.6	7.5	0	56	40	4	4806
WS	0.70856	7.7	7.5	29	80	17	3	5622
WS	4.7841	7.5	7.5	1	57	39	4	3265
WS	2.09811	7.5	7.5	2	54	41	5	4121
WS	3.10148	7.6	7.5	3	46	50	4	4095
WIS	3.36352	7.2	7.5	1	60	36	4	3625
WIS	8.70103	6.6	7.5	3	50	46	4	4321
WIS	4.99443	6.9	7.5	2	66	32	2	2051
WIS	2.4567	7.4	7.5	0	74	22	4	2132
WIS	2.2912	7.4	7.5	1	48	46	6	3589
WIS	1.41885	7.4	7.4	1	62	34	4	3116
WIS	4.15656	7.2	7.2	2	58	38	4	2894
WIS	2.30844	7.7	7.4	3	66	30	4	1937
WIS	1.6378	7.6	7.5	0	62	34	4	3037
WIS	1.57574	7.3	7.3	1	68	28	4	2062
WIS	4.49274	7.4	7.5	2	66	30	4	2165
WIS	5.64955	7.1	7.4	1	60	38	2	2382
JS	2.01191	7.3	7.5	3	68	28	4	2086
JS	2.62565	7.1	7.5	2	74	23	3	1985
JS	2.72737	7.3	7.5	1	65	31	4	2224
JS	1.94984	7	7.4	2	80	15	5	1552

Ecotype	PrcOM	pH	BpH	CumO	Sand	Silt	Clay	Ca
Units	%	pH	BpH	cm	%	%	%	ppm
Abbrev.	Percent Organic Matter	pH	Buffer pH	Organic Matter Depth	Percent Sand	Percent Silt	Percent Clay	Calcium
JS	4.0583	6.9	7.4	2	84	12	4	1278
JS	18.8606	5.3	7	44	44	38	18	5969
JS	8.8286	4.7	6.8	12	40	49	11	1243
JS	17.9296	5.2	7.1	23	42	34	24	4323
JS	13.13	5.3	6.8	30	36	56	8	2202
JS	13.8885	5.1	7	14	34	42	24	2878
JS	15.4608	6.6	7.4	26	46	40	14	7976
JS	23.2568	6.7	7.4	13	48	36	16	11830
JML	5.58059	5.4	7.3	30	54	42	4	2812
JML	19.1019	4.5	7.3	25	54	32	14	3064
JML	11.3577	6.5	7.4	40	44	48	8	6368
JML	24.9463	5.4	7.2	14	52	38	10	6845
JML	6.63395	5.7	7.4	30	36	52	12	2561
JML	5.47715	6.4	7.4	12	42	50	8	2635
JML	12.0094	7.1	7.4	8	58	36	6	4835
JML	16.5211	4.7	7	5	30	60	10	2425
JML	10.6405	5.4	7.3	28	38	51	11	2852
JML	7.8873	5.7	7.3	35	53	39	8	2832
JML	11.537	5.8	7.3	19	44	44	12	4462
JML	5.96676	5.2	7.3	14	42	50	8	2615
JBL	8.67689	6.7	7.4	18	16	74	10	3628
JBL	7.66318	7.5	7.5	15	52	44	4	6130
JBL	9.93196	5.9	7.3	8	36	52	12	4906
JBL	17.2572	5.8	7.3	20	44	48	8	6575
JBL	14.8143	4.9	6.7	20	46	44	10	2348
JBL	15.1919	5.3	7.1	17	52	40	8	4289
JBL	11.1784	4.6	7	19	36	54	10	1789
JBL	10.2113	6	7.3	17	58	30	12	4407
JBL	7.44078	6.9	7.4	19	45	51	4	5347
JBL	7.51147	6.5	7.5	21	36	54	10	4517
JBL	14.6747	5.4	7.2	26	26	48	26	4261
JBL	10.0492	6.3	7.4	30	16	66	18	3599
CRT	1.93433	7.9	7.3	0	70	24	6	4441
CRT	1.69469	8	7.2		72	24	4	3751
CRT	2.02225	7.8	7.5		72	24	4	4606
CRT	1.62918	7.8	7.5		78	22	0	2199
CRT	1.05681	7.9	7.5		78	18	4	1882
CRT	1.25852	8.1	7.5		66	28	6	1616
CRT	0.79132	8.2	7.5		72	22	6	1544
CRT	1.2861	8.1	7.5		74	22	4	1488
CRT	0.75339	7.6	7.5		76	20	4	2264
CRT	1.01716	7.4	7.5		68	26	6	2241
CRT	0.75684	7.5	7.5		72	24	4	1950
CRT	1.01026	7.5	7.5		70	24	6	1517
CRT	1.32231	7.6	7.5		72	24	4	2196
CRT	1.09129	7.6	7.4		72	22	6	2191

Ecotype	PrcOM	pH	BpH	CumO	Sand	Silt	Clay	Ca
Units	%	pH	BpH	cm	%	%	%	ppm
Abbrev.	Percent Organic Matter	pH	Buffer pH	Organic Matter Depth	Percent Sand	Percent Silt	Percent Clay	Calcium
CRT	1.31369	7.4	7.3		72	24	4	1705
CRT	1.4585	7.4	7.5	1	64	30	6	4363
CRT	2.0757	7.6	7.2		64	22	14	4887
CRT	2.21017	7.5	7.5		62	32	6	4611
CRT	0.6896	7.4	7.4		64	30	6	2593
CRT	2.74461	7.4	7.5		66	30	4	2769
CRT	1.9326	7.1	7.5		66	30	4	2875
CRT	1.52229	7.1	7.5		76	18	6	1854
CRT	2.13948	7.3	7.5		70	24	6	4904
CRT	1.30679	7.2	7.5		72	22	6	1534
CRT	1.96364	7.3	7.5		64	30	6	2231
CRT	1.81882	7.2	7.5		68	28	4	2809
CRT	1.66883	7.1	7.5		68	26	6	2316
CRT	2.52394	7.4	7.5		64	30	6	2074
CRT	2.25327	7.1	7.5		62	32	6	1959
CRT	1.38954	7.1	7.5		64	30	6	4214
CRT	1.56539	7.6	7.5	0	66	30	4	7851
CRT	1.42747	7.7	7.5		64	30	6	5587
CRT	1.43264	7.5	7.5		64	30	6	2122
CRT	0.90682	7.4	7.5		62	32	6	3399
CRT	1.52402	7.6	7.5		64	30	6	2802
CRT	1.31196	7.5	7.5		70	26	4	3827
CRT	0.60168	7.4	7.5		80	16	4	2297
CRT	1.54988	7.5	7.5		82	14	4	1382
CRT	0.5603	7.5	7.5		80	16	4	2504
CRT	0.92579	7.5	7.5		72	22	6	2670
CRT	1.22576	7.4	7.5		74	22	4	2235
CRT	1.03957	7.5	7.5		74	22	4	2226
CRT	1.18439	7.5	7.5		72	24	4	2087
CRT	1.50505	7.4	7.5		76	20	4	2118
CRT	1.17577	7.4	7.5		76	20	4	2239
CRT	0.99992	7.6	7.5	1	70	22	8	3988
CRT	0.7327	7.8	7.5		76	16	8	3615
CRT	0.64305	7.7	7.5		76	16	8	4026
CRT	0.7396	7.6	7.5		90	4	6	1341
CRT	0.8551	7.7	7.5		88	8	4	1216
CRT	0.59995	7.7	7.5		92	4	4	1288
CRT	0.77752	7.5	7.5		82	14	4	846.4
CRT	1.10508	7.5	7.5		80	16	4	138
CRT	1.02406	7.5	7.5		80	16	4	814.8
CRT	3.45662	7.4	7.5		62	34	4	1387
CRT	2.55669	7.4	7.5		64	30	6	1191
CRT	2.02742	7.4	7.5		56	36	8	1216
CRT	3.99796	7.2	7.5		54	38	8	1718
CRT	4.8772	7.5	7.5		58	34	8	1786
CRT	4.76341	7.5	7.5		54	38	8	1660

Ecotype	PrcOM	pH	BpH	CumO	Sand	Silt	Clay	Ca
Units	%	pH	BpH	cm	%	%	%	ppm
Abbrev.	Percent Organic Matter	pH	Buffer pH	Organic Matter Depth	Percent Sand	Percent Silt	Percent Clay	Calcium
CRT	1.84123	8	7.5	1	56	36	8	4157
CRT	1.65676	7.7	7.5		62	30	8	3671
CRT	2.08087	7.7	7.5		62	30	8	4499
CRT	1.10336	7.8	7.5		66	24	10	2778
CRT	0.99302	7.8	7.5		70	22	8	2641
CRT	1.07405	7.8	7.5		58	34	8	3088
CRT	1.00164	7.6	7.5		54	38	8	2014
CRT	1.42575	7.8	7.5		60	32	8	1972
CRT	0.97923	7.5	7.5		64	28	8	2138
CRT	1.05336	7.6	7.5		58	34	8	1963
CRT	1.49643	7.6	7.5		62	30	8	1951
CRT	1.39816	7.8	7.5		60	28	12	1970
CRT	1.17749	7.7	7.5		64	28	8	1948
CRT	1.24645	7.5	7.5		62	30	8	1874
CRT	1.54988	7.4	7.5		64	28	8	1918

Ecotype	Mg	Zn	Fe	Mn	Cu	Cr	Pb
Units	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Abbrev.	Magnesium	Zinc	Iron	Manganese	Copper	Chromium	Lead
WS	324.2	6.972	455.7	116.4	5.687	0.162	1.76
WS	263.8	9.108	457.6	114.4	7.077	0.1665	2.08
WS	311.6	8.244	416.4	108.9	7.27	0.1674	2.62
WS	291.3	8.108	444.2	109.1	6.457	0.1662	2.25
WS	213.2	8.216	453.4	108.3	8.015	0.1683	4.06
WS	231.3	7.318	369.4	96.1	6.494	0.1644	3.45
WS	310.7	9.002	454.4	126.8	6.329	0.1641	2.01
WS	201.1	8.342	418.7	114.5	9.208	0.1662	4.71
WS	156.9	6.304	372.7	98.29	6.765	0.1698	4.90
WS	306.4	8.802	401.8	121.7	7.558	0.1662	3.78
WS	283.7	8.371	453.8	122.9	7.74	0.1683	2.57
WS	276.1	7.835	440.3	120	7.087	0.1722	2.74
WIS	366.3	8.839	340.6	127.4	5.694	0.1779	3.27
WIS	435.6	15.15	367.9	112.3	4.991	0.1692	2.51
WIS	209.7	8.974	201.5	41.34	2.657	0.0865	0.89
WIS	125.2	8.033	210.7	52.56	4.222	0.0618	1.17
WIS	203.7	4.256	358.7	77.68	3.921	0.1165	1.01
WIS	140.1	7.683	246.2	56.71	4.163	0.069	0.79
WIS	234.3	5.527	280.7	66.44	3.593	0.0832	0.12
WIS	138.7	6.444	319.9	61.84	7.494	0.1289	2.45
WIS	131.1	11.26	306.5	64.9	3.453	0.0778	0.81
WIS	115.5	7.256	230.1	49.72	3.339	0.0315	0.67
WIS	186.6	6.423	222.3	54.04	4.929	0.079	0.65
WIS	224.1	7.598	210.2	52.5	4.327	0.0555	1.05
JS	330.4	5.63	358.8	144.1	5.273	0.1812	5.55
JS	332.5	5.446	365.4	131.7	5.246	0.1677	5.27

Ecotype	Mg	Zn	Fe	Mn	Cu	Cr	Pb
Units	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Abbrev.	Magnesium	Zinc	Iron	Manganese	Copper	Chromium	Lead
JS	349.5	6.279	349.6	150.7	4.846	0.174	5.76
JS	290.3	3.766	311.5	104.8	2.867	0.1999	3.14
JS	196	4.107	261.8	105.4	5.04	0.2074	4.24
JS	801.5	14.83	457.3	148.2	3.546	0.1674	1.07
JS	254	1.823	429.9	22.2	1.811	0.2095	0.99
JS	560.4	29.42	451.7	109.7	2.246	0.1659	1.08
JS	416	1.943	459	50.31	1.509	0.2026	1.07
JS	391	19.07	395	69.05	1.967	0.3662	1.07
JS	772.6	5.285	373.5	72.14	3.928	0.1803	1.69
JS	1052	16.8	343.2	235.3	1.647	0.1707	1.20
JML	551.3	7.208	544.8	121.5	1.816	0.165	1.08
JML	407.4	29.3	412.5	238	10.02	0.1863	1.10
JML	711.5	15.32	466.4	143.7	1.89	0.1626	1.49
JML	1113	17.39	465.6	180.2	1.96	0.165	1.48
JML	407.9	8.785	441.3	122.2	5.74	0.1662	1.80
JML	428.8	7.786	447.8	121.1	5.758	0.1629	1.79
JML	645.1	19.59	410.4	140.1	2.834	0.1602	2.51
JML	493.5	4.423	450.5	266.2	2.6	0.1788	0.99
JML	656.1	6.217	508.9	123.6	4.989	0.1662	1.61
WS	324.2	6.972	455.7	116.4	5.687	0.162	1.76
JML	566.4	4.327	479.2	113.4	2.107	0.1695	1.41
JML	898.1	6.47	462	120.4	3.756	0.1644	1.49
JML	514.5	4.721	462.6	98.45	1.798	0.1638	1.34
JBL	569.6	15.42	434.5	138.7	2.994	0.1602	1.47
JBL	533	18.3	403.9	116.4	3.032	0.1671	2.17
JBL	689	12.4	428.7	132.5	2.101	0.1617	1.32
JBL	830.1	24.4	449.8	144.2	3.175	0.1653	1.30
JBL	377.5	6.04	432.3	109.6	2.359	0.1698	1.16
JBL	778.8	16.13	444.1	119.6	2.344	0.1665	1.20
JBL	371	3.2	447.6	174.3	2.032	0.18	1.29
JBL	696.4	11.74	483.4	108.5	2.782	0.1635	1.44
JBL	586.8	9.241	424.8	142.4	1.96	0.1698	1.41
JBL	592.1	8.674	436.6	134.4	2.06	0.1641	1.46
JBL	648.6	12.14	404.7	157	2.149	0.1626	1.61
JBL	574.7	24.72	407.7	140.8	3.253	0.171	2.30
CRT	217	7.623	379.4	67.39	8.692	0.1394	1.15
CRT	140.1	7.45	226.4	53.08	3.496	0.0576	0.75
CRT	181.3	7.396	317.4	67.12	5.328	0.1358	0.99
CRT	107	8.566	238.1	54.28	2.72	0.0513	0.47
CRT	94.75	6.261	243.3	50.1	9.649	0.0976	2.25
CRT	123.5	6.594	286.3	53.35	4.139	0.0898	0.78
CRT	101.7	22.76	263.2	47.93	3.22	0.0739	0.62
CRT	82.84	4.927	241	43.98	4.741	0.1169	1.39
CRT	131.7	14.12	338	55.4	4.068	2.25	0.70
CRT	159.4	5.001	404.7	67.37	4.751	0.199	0.98
CRT	142.7	3.118	336.7	60.09	3.965	0.1665	0.60

Ecotype	Mg	Zn	Fe	Mn	Cu	Cr	Pb
Units	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Abbrev.	Magnesium	Zinc	Iron	Manganese	Copper	Chromium	Lead
CRT	115.6	6.764	294	50.84	4.404	0.1485	0.86
CRT	169.4	4.784	421.1	70.93	4.878	0.1569	0.95
CRT	166.4	6.47	417.1	71.9	6.121	0.1948	1.46
CRT	101	13.88	235.5	47.96	3.339	0.0868	0.71
CRT	182.7	5.196	263	59.44	2.752	0.1069	1.37
CRT	248.6	4.329	343.3	75.16	3.159	0.1469	0.84
CRT	237.2	9.472	360.1	70.44	3.43	0.1909	0.82
CRT	206.2	5.411	328.7	65.38	3.68	0.1478	0.90
CRT	200.7	7.078	360.7	65.72	4.123	0.1503	0.86
CRT	228.1	5.513	351	74.1	3.575	0.1313	0.57
CRT	117	3.84	243.3	52.05	3.006	0.0985	0.81
CRT	207.6	10	399.5	75.2	3.426	0.3391	0.76
CRT	107.7	2.708	219.4	49.36	2.531	0.1075	0.73
CRT	149.4	3.844	274.8	58.75	3.327	0.1036	0.55
CRT	158.5	4.031	259.9	55.38	2.788	0.1024	0.26
CRT	171.7	12.33	311	62.19	3.731	0.1214	1.19
CRT	179.8	9.629	337.1	66.52	4.653	0.1265	1.19
CRT	147	4.081	238.7	56.1	3.315	0.1133	0.85
CRT	313.1	11.52	485.7	115.2	6.745	0.22	1.45
WS	324.2	6.972	455.7	116.4	5.687	0.162	1.76
CRT	242.2	8.365	364.8	120	4.157	0.3451	3.85
CRT	218	6.226	448.7	110.7	4.014	1.502	6.95
CRT	106.9	3.781	278.5	40.26	1.886	0.764	4.58
CRT	247.9	11.16	716.6	104.8	4.519	1.818	9.79
CRT	111.4	7.479	341.4	74.63	3.507	0.9484	6.32
CRT	130.7	8.301	424.3	95.51	3.837	1.12	8.21
CRT	94.33	8.856	395.7	64.76	3.793	1.001	6.32
CRT	69.54	7.911	294.8	46.31	4.063	0.685	7.26
CRT	120	12.66	497.8	78.83	3.942	1.949	9.95
CRT	157.5	8.63	527.2	94.49	4.577	1.357	7.58
CRT	95.56	8.836	319.8	65.06	5.08	0.9879	9.16
CRT	99.84	7.87	370.7	71.36	4.355	1.172	8.21
CRT	114.7	6.329	361.3	64.99	3.982	0.8694	7.11
CRT	152.2	10.99	445.1	75.48	6.675	0.9747	6.95
CRT	149.5	9.514	475	78.65	7.609	1.212	8.84
CRT	184.5	2.625	394.6	128.7	3.342	1.055	5.44
CRT	160.3	2.447	366.4	105.3	3.254	0.9477	6.56
CRT	145.2	3.158	330.4	104.9	3.28	0.9878	6.56
CRT	76.48	2.526	256.9	54.41	3.228	0.614	4.33
CRT	69.12	2.724	245.3	54.26	3.12	0.614	6.42
CRT	81.37	2.447	267.6	55.14	2.781	0.6407	4.19
CRT	84.94	3.099	277.1	51.87	3.405	0.4672	5.58
CRT	153.9	3.947	452.5	86.18	3.485	0.6407	5.86
CRT	93.95	3.276	306.2	53.76	3.729	0.4138	7.54
CRT	176	9.888	452.7	89.3	3.243	0.7074	6.14
CRT	157.4	16.03	387	79.06	2.921	0.7101	4.20

Ecotype	Mg	Zn	Fe	Mn	Cu	Cr	Pb
Units	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Abbrev.	Magnesium	Zinc	Iron	Manganese	Copper	Chromium	Lead
CRT	152.4	8.444	361.5	72.04	3.327	0.6981	4.05
CRT	200.6	18.13	355.8	85.56	3.007	0.7222	4.50
CRT	213	9.246	366.6	86.39	2.504	0.8666	5.10
CRT	192.4	13.73	362.1	85.39	2.599	0.6981	6.15
CRT	202.5	12.75	502	105.4	3.9	1.107	6.75
CRT	194.1	9.21	521.1	108.1	7.288	1.18	7.65
CRT	262.4	36.24	669.9	262.4	4.756	1.372	8.10
CRT	220.2	9.155	720.8	220.2	7.112	1.107	7.95
CRT	154.6	8.59	509.4	154.6	5.091	0.8907	8.70
CRT	165.6	14.59	536.7	165.6	4.579	1.011	7.65
CRT	156.6	11.43	515	156.6	13.78	0.8425	8.10
CRT	157.5	12.11	458.4	157.5	4.306	0.8064	7.80
CRT	198.3	16.23	662.4	198.3	5.442	0.9629	7.95
CRT	179.1	12.55	548.2	179.1	7.134	0.8907	8.10
CRT	178.6	17.18	540.4	178.6	6.763	0.9027	9.60
CRT	166.5	14.19	539.9	166.5	6.935	0.8907	9.00
CRT	179.9	12.89	562.5	179.9	6.114	0.8546	8.25
CRT	178.1	14.44	519.4	178.1	6.962	0.8546	9.30
CRT	217.1	26.04	711.7	217.1	10.89	1.047	7.80

Ecotype	Plot	UTM Grid (WGS84)	LAT/LON (NAD27 - AK)
WS	100	6 V 551730 7072000	N63.77214 W145.94858
WS	101	6 V 551580 7072000	N63.77216 W145.95162
WS	102	6 V 551730 7072150	N63.77348 W145.94853
WS	103	6 V 551581 7072150	N63.77351 W145.95156
WS	104	6 V 551430 7072150	N63.77353 W145.95461
WS	105	6 V 551731 7072300	N63.77483 W145.94847
WS	106	6 V 551580 7072300	N63.77485 W145.95152
WS	107	6 V 551431 7072300	N63.77488 W145.95455
WS	108	6 V 551280 7072300	N63.77490 W145.95761
WS	109	6 V 551730 7072450	N63.77618 W145.94843
WS	110	6 V 551580 7072449	N63.77619 W145.95147
WS	111	6 V 551430 7072450	N63.77622 W145.95452
WIS	E05	6 V 550387 7076651	N63.81407 W145.97430
WIS	G01	6 V 551387 7076143	N63.80937 W145.95415
WIS	I01	6 V 551385 7075646	N63.80491 W145.95436
WIS	I04	6 V 550639 7075643	N63.80498 W145.96952
WIS	I06	6 V 550135 7075646	N63.80509 W145.97974
WIS	J06	6 V 550135 7075398	N63.80286 W145.97981
WIS	K03	6 V 550999 7075001	N63.80051 W145.96473
WIS	K04	6 V 550753 7074998	N63.80052 W145.96971
WIS	K05	6 V 550502 7074998	N63.80055 W145.97480
WIS	L04	6 V 550635 7074889	N63.79822 W145.96984
WIS	Q01	6 V 551157 7075604	N63.80457 W145.95900
WIS	Q02	6 V 551061 7075545	N63.80405 W145.96097
JS	300	6 V 565077 7083989	N63.87881 W145.67523

Ecotype	Plot	UTM Grid (WGS84)	LAT/LON (NAD27 - AK)
JS	301	6 V 565067 7084140	N63.88016 W145.67538
JS	302	6 V 565055 7084289	N63.88151 W145.67554
JS	1243	6 V 566364 7092566	N63.95552 W145.64533
JS	1274	6 V 566216 7092554	N63.95544 W145.64836
JS	1439	6 V 565899 7090859	N63.93896 W145.65325
JS	1722	6 V 563101 7080999	N63.85102 W145.71437
JS	1913	6 V 566099 7091010	N63.94027 W145.64911
JS	1298A	6 V 565586 7090817	N63.93864 W145.65965
JS	1741A	6 V 563485 7080972	N63.85070 W145.70658
JS	1752A	6 V 564078 7080489	N63.84626 W145.69472
JS	1762A	6 V 564039 7080349	N63.84501 W145.69557
JML	124	6 V 566680 7092177	N63.95197 W145.63905
JML	711	6 V 564374 7075943	N63.80542 W145.69060
JML	794	6 V 566834 7093133	N63.95918 W145.63319
JML	1000	6 V 566600 7093791	N63.96513 W145.63768
JML	1020	6 V 568475 7091841	N63.94727 W145.60028
JML	1287	6 V 566072 7093541	N63.96298 W145.64856
JML	1321	6 V 564601 7081174	N63.85231 W145.68380
JML	1328	6 V 565231 7092617	N63.95619 W145.66843
JML	1331	6 V 566463 7091061	N63.94066 W145.64166
JML	1362	6 V 567950 7090462	N63.93500 W145.61160
JML	1412	6 V 565483 7093016	N63.95972 W145.66312
JML	1842	6 V 566443 7093391	N63.96157 W145.64106
JBL	158	6 V 565184 7093283	N63.96084 W145.66680
JBL	501	6 V 566737 7092800	N63.95755 W145.63762
JBL	502	6 V 567506 7092093	N63.95105 W145.62224
JBL	1001	6 V 567439 7092837	N63.95641 W145.62098
JBL	1019	6 V 563901 7083829	N63.87626 W145.69693
JBL	1124	6 V 566273 7093981	N63.96689 W145.64427
JBL	1153	6 V 564829 7092113	N63.95041 W145.67454
JBL	1191	6 V 565680 7093980	N63.96700 W145.65638
JBL	1316	6 V 566926 7092861	N63.95672 W145.63143
JBL	1981	6 V 567293 7092662	N63.95487 W145.62403
JBL	1326A	6 V 567801 7091815	N63.94850 W145.61635
JBL	478A	6 V 568013 7091613	N63.94531 W145.60980
CRT	CR15	6 V 550771 7074989	N63.80043 W145.96936
CRT	CR16	6 V 550731 7075020	N63.80071 W145.97016
CRT	CR17	6 V 550198 7075689	N63.80546 W145.97845
CRT	CR7	6 V 550401 7076680	N63.81432 W145.97401
CRT	CR9	6 V 550602 7075600	N63.80461 W145.97027

APPENDIX B

Photographs

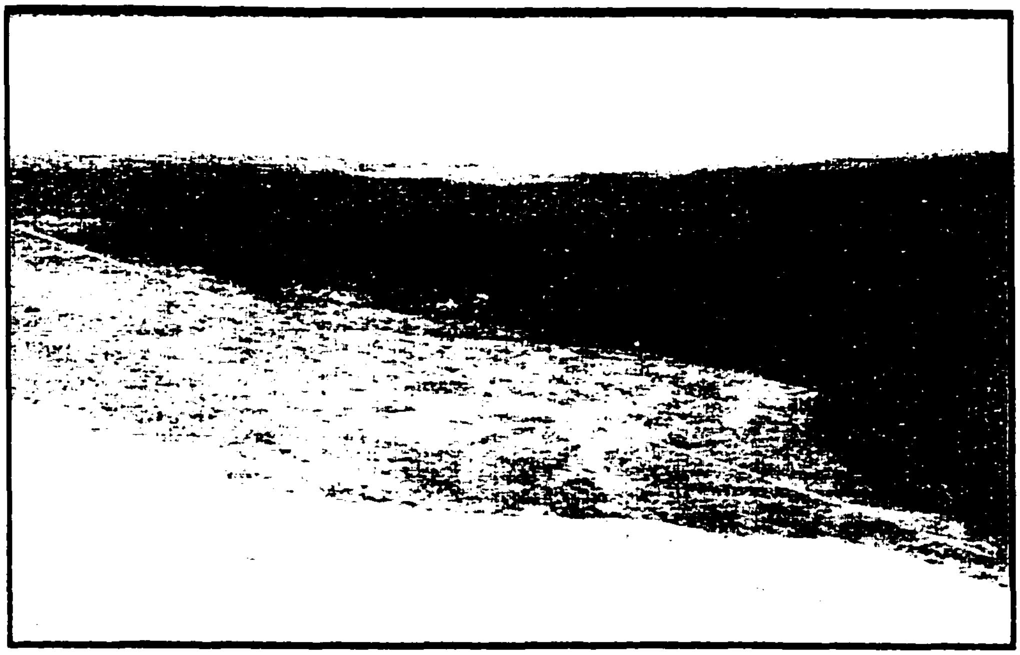


Photo 1. Aerial view of the Washington Range and Impact Area (looking north), Fort Greely, Alaska. The area in the active flood plain is dominated by the scrub ecotype.

Photo 2. Scrub ecotype in the Washington Impact Area, Fort Greely, Alaska.

Photo 3. Aerial view of scrub ecotype showing high water flow and evidence of water erosion.

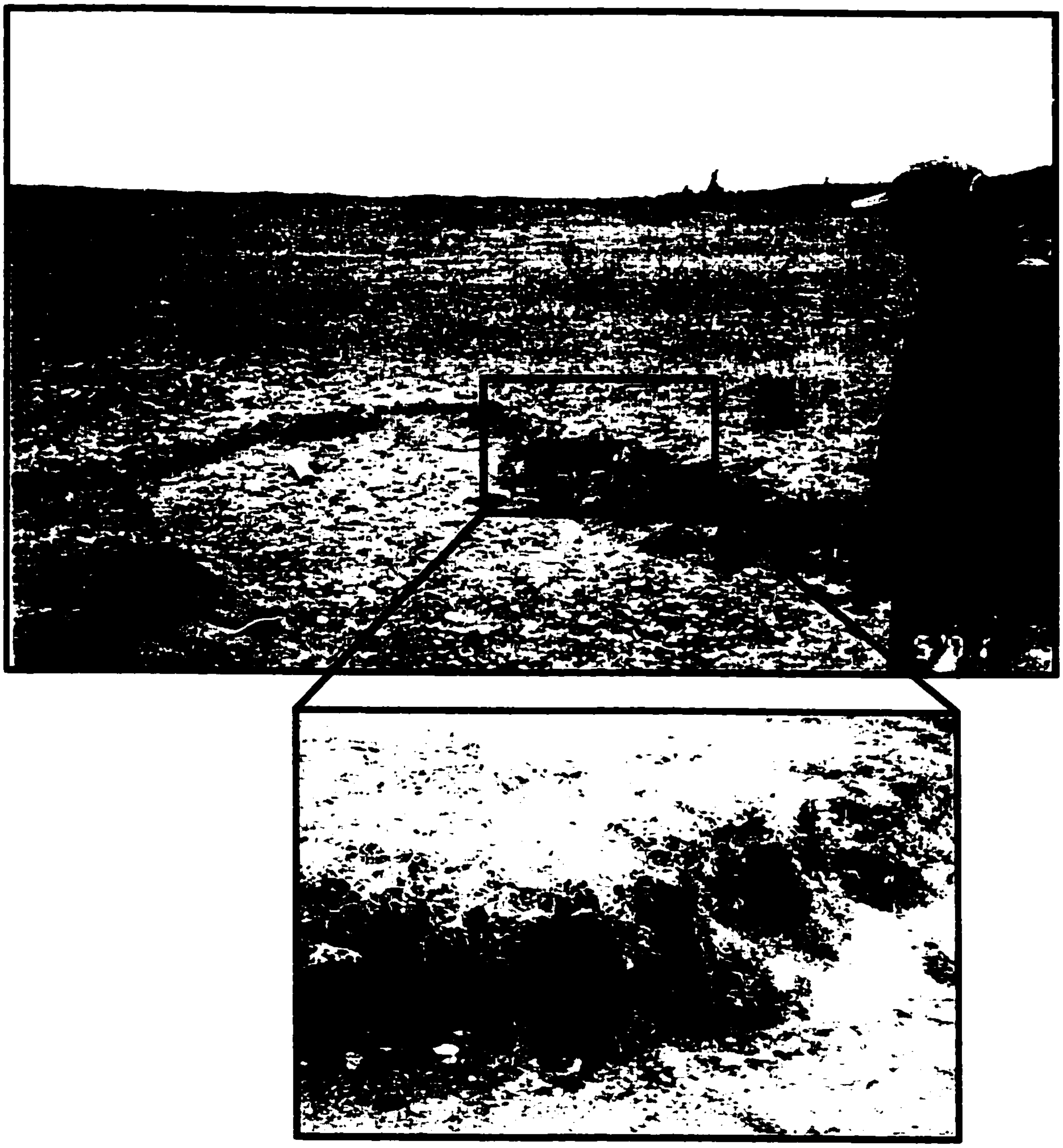
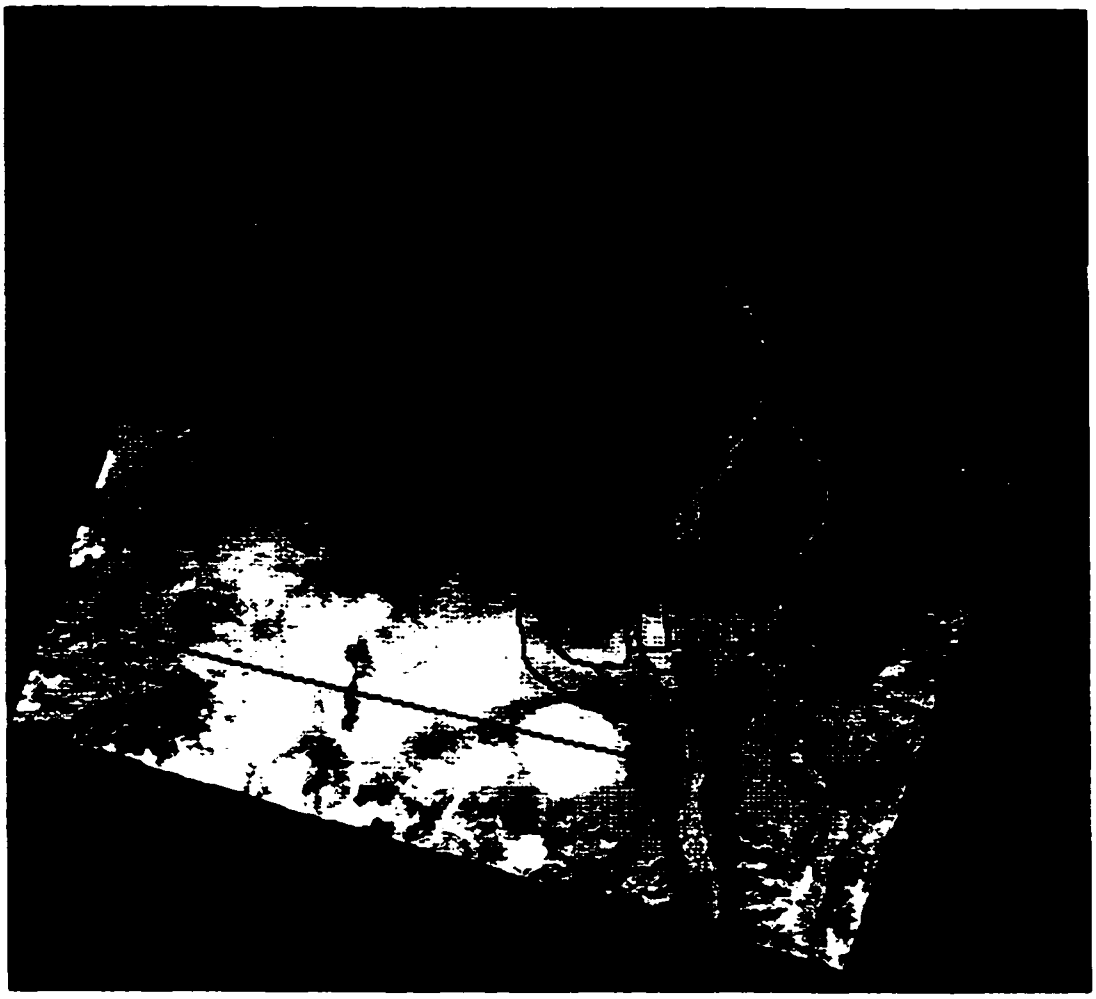


Photo 4. Wind blown erosion at Washington impact area, Fort Greely, Alaska. Inset shows exposed roots. Exposed gravel is approximately 10 cm from the surface.

Photo 5. Crater in the Washington Impact Area, Fort Greely Alaska.

Photo 6. 500lb bomb crater in the Washington Impact Area, Fort Greely Alaska.



Sept 10, 1999

Path 067 Row 015

Photo 7. Subsetted portion of a Landsat 7 Enhanced Thematic Mapper color infrared image (10 September 1999) of Fort Greely, Alaska and vicinity.

APPENDIX C

CENTURY Site File Parameterization

Appendix C

Site parameterization for CENTURY simulations of ecotypes at Fort Greely, Alaska. Bonanza Creek Long Term Ecological Research (BNZ LTER) site data is provided for comparison. For parameter definitions refer to the CENTURY Users Manual at http://www.nrel.colostate.edu/projects/century/nrel.htm

Parameter Climate parameters	BNZ LTER	Scrub	Broadleaf	Mixed Leaf	Needleleaf
PRECIP(1)	1.8	0.9	0.9	0.9	0.9
PRECIP(2)	1.2	0.8	0.8	0.8	0.8
PRECIP(3)	1.3	0.7	0.7	0.7	0.7
PRECIP(4)	0.8	0.6	0.6	0.6	0.6
PRECIP(5)	1.7	2.2	2.2	2.2	2.2
PRECIP(6)	3.5	5.9	5.9	5.9	5.9
PRECIP(7)	4.7	6.7	6.7	6.7	6.7
PRECIP(8)	5.1	5.1	5.1	5.1	5.1
PRECIP(9)	2.6	2.8	2.8	2.8	2.8
PRECIP(10)	2.2	1.7	1.7	1.7	1.7
PRECIP(11)	1.7	1.2	1.2	1.2	1.2
PRECIP(12)	1.7	1.0	1.0	1.0	1.0
PRCSTD(1)	2.3	0	0	0	0
PRCSTD(2)	1.3	0	0	0	0
PRCSTD(3)	1.7	0	0	0	0
PRCSTD(4)	0.8	0	0	0	0
PRCSTD(5)	1	0	0	0	0
PRCSTD(6)	1.8	0	0	0	0
PRCSTD(7)	2.6	0	0	0	0
PRCSTD(8)	2.9	0	0	0	0
PRCSTD(9)	2.3	0	0	0	0
PRCSTD(10)	1.4	0	0	0	0
PRCSTD(11)	1.4	0	0	0	0
PRCSTD(12)	1.7	0	0	0	0
PRCSKW(1)	0	0	0	0	0
PRCSKW(2)	0	0	0	0	0
PRCSKW(3)	0	0	0	0	0
PRCSKW(4)	0	0	0	0	0
PRCSKW(5)	0	0	0	0	0
PRCSKW(6)	0	0	0	0	0
PRCSKW(7)	0	0	0	0	0
PRCSKW(8)	0	0	0	0	0
PRCSKW(9)	0	0	0	0	0
PRCSKW(10)	0	0	0	0	0
PRCSKW(11)	0	0	0	0	0
PRCSKW(12)	0	0	0	0	0
TMN2M(1)	-30	-31	-31	-31	-31
TMN2M(2)	-26	-29	-29	-29	-29
TMN2M(3)	-20	-20	-20	-20	-20
TMN2M(4)	-8	-7	-7	-7	-7

Parameter	BNZ LTER	Scrub	Broadleaf	Mixed Leaf	Needleleaf
TMN2M(5)	3	3	3	3	3
TMN2M(6)	8	9	9	9	9
TMN2M(7)	10	13	13	13	13
TMN2M(8)	7	9	9	9	9
TMN2M(9)	2	3	3	3	3
TMN2M(10)	-7	-11	-11	-11	-11
TMN2M(11)	-21	-23	-23	-23	-23
TMN2M(12)	-28	-30	-30	-30	-30
TMX2M(1)	-19	-4	-4	-4	-4
TMX2M(2)	-12	-6	-6	-6	-6
TMX2M(3)	-5	0	0	0	0
TMX2M(4)	5	4	4	4	4
TMX2M(5)	15	12	12	12	12
TMX2M(6)	22	17	17	17	17
TMX2M(7)	23	17	17	17	17
TMX2M(8)	19	16	16	16	16
TMX2M(9)	13	11	11	11	11
TMX2M(10)	1	2	2	2	2
TMX2M(11)	-11	-4	-4	-4	-4
TMX2M(12)	-18	-9	-9	-9	-9
Site and control parameters					
IVAUTO	0	1	1	1	1
NELEM	1	1	1	1	1
SITLAT	64.75	64	64	64	64
SITLNG	148.25	145.44	145.44	145.44	145.44
SAND	0.1	0.53	0.39	0.46	0.45
SILT	0.89	0.43	0.5	0.45	0.45
CLAY	0.01	0.04	0.11	0.09	0.1
BULKD	0.75	1	0.8	0.8	0.75
NLAYER	5	5	5	5	5
NLAYPG	3	3	3	3	3
DRAIN	1	1	1	1	1
BASEF	0.3	0.3	0.3	0.3	0.3
STORMF	0.4	0.4	0.4	0.4	0.4
SWFLAG	1	1	1	1	1
AWILT(1)	0.2	0.2	0.2	0.2	0.2
AWILT(2)	0.2	0.2	0.2	0.2	0.2
AWILT(3)	0.2	0.2	0.2	0.2	0.2
AWILT(4)	0.2	0.2	0.2	0.2	0.2
AWILT(5)	0.2	0.2	0.2	0.2	0.2
AWILT(6)	0.2	0.2	0.2	0.2	0.2
AWILT(7)	0.2	0.2	0.2	0.2	0.2
AWILT(8)	0.2	0.2	0.2	0.2	0.2
AWILT(9)	0.2	0.2	0.2	0.2	0.2
AWILT(10)	0.3	0.3	0.3	0.3	0.3
AFIEL(1)	0.3	0.3	0.3	0.3	0.3
AFIEL(2)	0.3	0.3	0.3	0.3	0.3
AFIEL(3)	0.3	0.3	0.3	0.3	0.3

Parameter	BNZ LTER	Scrub	Broadleaf	Mixed Leaf	Needleleaf
AFIEL(4)	0.3	0.3	0.3	0.3	0.3
AFIEL(5)	0.3	0.3	0.3	0.3	0.3
AFIEL(6)	0.3	0.3	0.3	0.3	0.3
AFIEL(7)	0.3	0.3	0.3	0.3	0.3
AFIEL(8)	0.3	0.3	0.3	0.3	0.3
AFIEL(9)	0.3	0.3	0.3	0.3	0.3
AFIEL(10)	0	0	0	0	0
PH	4.7	7.5	6.0	5.7	5.0
PSLSRB	1	1	1	1	1
SORPMX	3	3	3	3	3
External nutrient input parameters					
EPNFA(1)	0.05	0.063	0.063	0.063	0.063
EPNFA(2)	0.007	0	0	0	0
EPNFS(1)	-0.9	-0.9	-0.9	-0.9	-0.9
EPNFS(2)	0.015	0.015	0.015	0.015	0.015
SATMOS(1)	0	0	0	0	0
SATMOS(2)	0	0	0	0	0
SIRRI	0	0	0	0	0
Organic matter initial values					
SOM1CI(1,1)	100	10	40	80	100
SOM1CI(1,2)	0	0	0	0	0
SOM1CI(2,1)	370	35	150	300	370
SOM1CI(2,2)	0	0	0	0	0
SOM2CI(1)	3750	375	1500	3000	3750
SOM2CI(2)	0	0	0	0	0
SOM3CI(1)	1250	125	500	1000	1250
SOM3CI(2)	0	0	0	0	0
RCES1(1,1)	15	15	15	15	15
RCES1(1,2)	200	100	230	100	100
RCES1(1,3)	200	100	9000	100	100
RCES1(2,1)	14	14	14	14	14
RCES1(2,2)	120	100	100	100	100
RCES1(2,3)	200	100	9000	100	100
RCES2(1)	25	15	18	21	21
RCES2(2)	200	120	145	170	200
RCES2(3)	200	120	145	170	200
RCES3(1)	12	15	15	15	15
RCES3(2)	100	80	80	80	80
RCES3(3)	100	80	8C	80	80
CLITTR(1,1)	180	20	90	145	180
CLITTR(1,2)	0	0	0	0	0
CLITTR(2,1)	230	25	90	185	230
CLITTR(2,2)	0	0	0	0	0
RCELIT(1,1)	88	88	90	88	88
RCELIT(1,2)	300	300	468	300	300
RCELIT(1,3)	300	300	100	300	300
RCELIT(2,1)	66	66	66	66	66
RCELIT(2,2)	300	300	300	300	300

Parameter	BNZ LTER	Scrub	Broadleaf	Mixed Leaf	Needleleaf
RCELIT(2,3)	300	300	300	300	300
AGLCIS(1)	0	0	0	0	0
AGLCIS(2)	0	0	0	0	0
AGLIVE(1)	0	0	0	0	0
AGLIVE(2)	0	0	0	0	0
AGLIVE(3)	0	0	0	0	0
BGLCIS(1)	0	0	0	0	0
BGLCIS(2)	0	0	0	0	0
BGLIVE(1)	0	0	0	0	0
BGLIVE(2)	0	0	0	0	0
BGLIVE(3)	0	0	0	0	0
STDCIS(1)	0	0	0	0	0
STDCIS(2)	0	0	0	0	0
STDEDE(1)	0	0	0	0	0
STDEDE(2)	0	0	0	0	0
STDEDE(3)	0	0	0	0	0
Forest organic matter initial parameters					
RLVCIS(1)	562	55	225	450	560
RLVCIS(2)	0	0	0	0	0
RLEAVE(1)	8.5	1	3	7	9
RLEAVE(2)	1.1	0.1	0.45	0.9	1.1
RLEAVE(3)	0	0	0	0	0
FBRCIS(1)	736	75	295	590	735
FBRCIS(2)	0	0	0	0	0
FBRCHE(1)	8.9	0.9	4	8	9
FBRCHE(2)	1.3	0.1	0.5	1	1.3
FBRCHE(3)	0	0	0	0	0
RLWCIS(1)	6263	650	2600	5010	6500
RLWCIS(2)	0	0	0	0	0
RLWODE(1)	10	1	4	8	10
RLWODE(2)	1.1	0.1	0.4	0.4	1.1
RLWODE(3)	0	0	0	0	0
FRTCIS(1)	500	50	200	400	500
FRTCIS(2)	0	0	0	0	0
FROOTE(1)	22.2	2	9	18	22
FROOTE(2)	0	0	0	0	0
FROOTE(3)	0	0	0	0	0
CRTCIS(1)	1000	100	400	800	1000
CRTCIS(2)	0	0	0	0	0
CROOTE(1)	1.6	0.2	0.6	1.3	1.6
CROOTE(2)	0.02	0.02	0.02	0.02	0.02
CROOTE(3)	44	5	20	35	45
WD1CIS(1)	50	5	20	40	50
WD1CIS(2)	0	0	0	0	0
WD2CIS(1)	500	50	200	400	500
WD2CIS(2)	0	0	0	0	0
WD3CIS(1)	100	10	40	80	100
WD3CIS(2)	0	0	0	0	0

Parameter	BNZ LTER	Scrub	Broadleaf	Mixed Leaf	Needleleaf
W1LIG	0.2	0.2	0.2	0.2	0.2
W2LIG	0.2	0.2	0.2	0.2	0.2
W3LIG	0.2	0.2	0.2	0.2	0.2
Mineral initial parameters					
MINERL(1,1)	0.42	0.42	0.42	0.42	0.42
MINERL(2,1)	0.00001	0.00001	0.00001	0.00001	0.00001
MINERL(3,1)	0	0	0	0	0
MINERL(4,1)	0	0	0	0	0
MINERL(5,1)	0	0	0	0	0
MINERL(6,1)	0	0	0	0	0
MINERL(7,1)	0	0	0	0	0
MINERL(8,1)	0	0	0	0	0
MINERL(9,1)	0	0	0	0	0
MINERL(10,1)	0	0	0	0	0
MINERL(1,2)	0.5	0.5	0.5	0.5	0.5
MINERL(2,2)	0	0	0	0	0
MINERL(3,2)	0	0	0	0	0
MINERL(4,2)	0	0	0	0	0
MINERL(5,2)	0	0	0	0	0
MINERL(6,2)	0	0	0	0	0
MINERL(7,2)	0	0	0	0	0
MINERL(8,2)	0	0	0	0	0
MINERL(9,2)	0	0	0	0	0
MINERL(10,2)	0	0	0	0	0
MINERL(1,3)	0.5	0.5	0.5	0.5	0.5
MINERL(2,3)	0	0	0	0	0
MINERL(3,3)	0	0	0	0	0
MINERL(4,3)	0	0	0	0	0
MINERL(5,3)	0	0	0	0	0
MINERL(6,3)	0	0	0	0	0
MINERL(7,3)	0	0	0	0	0
MINERL(8,3)	0	0	0	0	0
MINERL(9,3)	0	0	0	0	0
MINERL(10,3)	0	0	0	0	0
PARENT(1)	0	0	0	0	0
PARENT(2)	500	500	500	500	500
PARENT(3)	50	50	50	50	50
SECNDY(1)	0	0	0	0	0
SECNDY(2)	15	15	15	15	15
SECNDY(3)	2	2	2	2	2
OCCLUD	0	0	0	0	0
Water initial parameters					
RWCF(1)	0	0	0	0	0
RWCF(2)	0	0	0	0	0
RWCF(3)	0	0	0	0	0
RWCF(4)	0	0	0	0	0
RWCF(5)	0	0	0	0	0
RWCF(6)	0	0	0	0	0

Parameter	BNZ LTER	Scrub	Broadleaf	Mixed Leaf	Needleleaf
RWCF(7)	0	0	0	0	0
RWCF(8)	0	0	0	0	0
RWCF(9)	0	0	0	0	0
RWCF(10)	0	0	0	0	0
SNLQ	0	0	0	0	0
SNOW	5	5	5	5	5

APPENDIX D

CENTURY Tree and Crop File Parameterization

Appendix D

Tree and Crop file parameterization for CENTURY simulations of Fort Greely, Alaska ecotypes. For parameter definitions refer to the CENTURY Users Manual at http://www.nrel.colostate.edu/projects/century/nrel.htm

	CWT	MIX	BNZ
TREE100 File	Coweeta	50/50 CONIF DECID	Bonanza
Ecotype	Broadleaf/ Scrub	Mixed Leaf	Needle leaf
DECID	1	1	0
PRDX(3)	9999	9999	9999
PRDX(4)	400	300	300
PPDF(1)	30	19	15
PPDF(2)	45	35	32
PPDF(3)	1	1	1
PPDF(4)	2.5	3.5	3.5
CERFOR(1,1,1)	20	27.5	35
CERFOR(1,1,2)	396	396	697
CERFOR(1,1,3)	40	40	0
CERFOR(1,2,1)	40	45	50
CERFOR(1,2,2)	500	500	450
CERFOR(1,2,3)	83	83	0
CERFOR(1,3,1)	99	133	83
CERFOR(1,3,2)	500	500	566
CERFOR(1,3,3)	70	70	0
CERFOR(1,4,1)	140	516.5	626
CERFOR(1,4,2)	479	479	5694
CERFOR(1,4,3)	131	131	0
CERFOR(1,5,1)	83	319.5	626
CERFOR(1,5,2)	833	833	5694
CERFOR(1,5,3)	100	100	0
CERFOR(2,1,1)	60	60	60
CERFOR(2,1,2)	396	396	697
CERFOR(2,1,3)	40	40	0
CERFOR(2,2,1)	50	65.5	45
CERFOR(2,2,2)	500	500	450
CERFOR(2,2,3)	83	83	0
CERFOR(2,3,1)	99	133	83
CERFOR(2,3,2)	500	500	566
CERFOR(2,3,3)	70	70	0
CERFOR(2,4,1)	140	516.5	626
CERFOR(2,4,2)	479	479	5694
CERFOR(2,4,3)	131	131	0
CERFOR(2,5,1)	83	319.5	626
CERFOR(2,5,2)	833	833	5694

	NWT
CROP100 File	Niwot Ridge
Ecotype	Scrub
PRDX(1)	150
PPDF(1)	15
PPDF(2)	32
PPDF(3)	1
PPDF(4)	3.5
BIOFLG	1
BIOK5	60
PLTMRF	1
FULCAN	100
FRTC(1)	0
FRTC(2)	0
FRTC(3)	0
BIOMAX	400
PRAMN(1,1)	25
PRAMN(2,1)	390
PRAMN(3,1)	340
PRAMN(1,2)	30
PRAMN(2,2)	390
PRAMN(3,2)	340
PRAMX(1,1)	35
PRAMX(2,1)	440
PRAMX(3,1)	440
PRAMX(1,2)	60
PRAMX(2,2)	440
PRAMX(3,2)	440
PRBMN(1,1)	50
PRBMN(2,1)	390
PRBMN(3,1)	340
PRBMN(1,2)	0
PRBMN(2,2)	0
PRBMN(3,2)	0
PRBMX(1,1)	55
PRBMX(2,1)	420
PRBMX(3,1)	420
PRBMX(1,2)	0
PRBMX(2,2)	0

	CWT	MIX	BNZ
TREE100 File	Coweeta	50/50 CONIF DECID	Bonanza
Ecotype	Broadleaf/ Scrub	Mixed Leaf	Needle leaf
CERFOR(2,5,3)	100	100	0
CERFOR(3,1,1)	59	74.5	75
CERFOR(3,1,2)	396	396	697
CERFOR(3,1,3)	40	40	0
CERFOR(3,2,1)	50	65.5	45
CERFOR(3,2,2)	500	500	450
CERFOR(3,2,3)	83	83	0
CERFOR(3,3,1)	99	133	83
CERFOR(3,3,2)	500	500	566
CERFOR(3,3,3)	70	70	0
CERFOR(3,4,1)	140	516.5	626
CERFOR(3,4,2)	479	479	5694
CERFOR(3,4,3)	131	131	0
CERFOR(3,5,1)	83	319.5	626
CERFOR(3,5,2)	833	833	5694
CERFOR(3,5,3)	100	100	0
DECW1	1.5	1.5	1.5
DECW2	0.5	0.5	0.5
DECW3	0.6	0.6	0.6
FCFRAC(1,1)	0.34	0.34	0.19
FCFRAC(2,1)	0.4	0.4	0.42
FCFRAC(3,1)	0.09	0.09	0.05
FCFRAC(4,1)	0.15	0.15	0.28
FCFRAC(5,1)	0.02	0.02	0.06
FCFRAC(1,2)	0.28	0.3	0.19
FCFRAC(2,2)	0.27	0.3	0.42
FCFRAC(3,2)	0.08	0.25	0.05
FCFRAC(4,2)	0.32	0.1	0.28
FCFRAC(5,2)	0.05	0.05	0.06
LEAFDR(1)	0.01	0.04	0.01
LEAFDR(2)	0.01	0.04	0.01
LEAFDR(3)	0.01	0.04	0.01
LEAFDR(4)	0.01	0.04	0.01
LEAFDR(5)	0.01	0.04	0.01
LEAFDR(6)	0.01	0.04	0.01
LEAFDR(7)	0.01	0.04	0.01
LEAFDR(8)	0.01	0.04	0.01
LEAFDR(9)	0.01	0.04	0.01
LEAFDR(10)	0.01	0.04	0.01
LEAFDR(11)	0.01	0.04	0.01
LEAFDR(12)	0.01	0.04	0.01
BTOLAI	0.011	0.00823	0.003

	NWT
CROP100 File	Niwot Ridge
Ecotype	Scrub
PRBMX(3,2)	0
FLIGNI(1,1)	0.02
FLIGNI(2,1)	0.0012
FLIGNI(1,2)	0.26
FLIGNI(2,2)	-0.0015
HIMAX	0
HIWSF	0
HIMON(1)	0
HIMON(2)	0
EFRGRN(1)	0.5
EFRGRN(2)	0.5
EFRGRN(3)	0.5
VLOSSP	0.04
FSDETH(1)	0.2
FSDETH(2)	0.95
FSDETH(3)	0.2
FSDETH(4)	150
FALLRT	0.15
RDR	0.05
RTDTMP	0
CRPRTF(1)	0.4
CRPRTF(2)	0
CRPRTF(3)	0
SNFXMX(1)	0
DEL13C	27
CO2IPR	1.2
CO2ITR	0.8
CO2ICE(1,1,1)	1.2
CO2ICE(1,1,2)	1
CO2ICE(1,1,3)	1
CO2ICE(1,2,1)	1.2
CO2ICE(1,2,2)	1
CO2ICE(1,2,3)	1

	CWT	MIX	BNZ
TREE100 File	Coweeta	50/50 CONIF DECID	Bonanza
Ecotype	Broadleaf/ Scrub	Mixed Leaf	Needle leaf
KLAI	1	25	1
LAITOP	-0.47	-0.47	-0.47
MAXLAI	20	2	20
MAXLDR	1	1	1
FORRTF(1)	0.4	0.3	0.4
FORRTF(2)	0	0	0
FORRTF(3)	0	0	0
SAPK	1	200	1
SWOLD	0	5	0
WDLIG(1)	0.223	0.2015	0.14
WDLIG(2)	0.25	0.215	0.09
WDLIG(3)	0.25	0.235	0.2
WDLIG(4)	0.25	0.255	0.2
WDLIG(5)	0.25	0.255	0.2
WOODDR(1)	1	0.5	1
WOODDR(2)	0.04	0.045	0.017
WOODDR(3)	0.01	0.01	0.01
WOODDR(4)	0.002	0.0014	0.0008
WOODDR(5)	0.004	0.0025	0.001
SNFXMX(2)	0	0.0005	0
DEL13C	0	0	0
CO2IPR	1.2	1.2	1.2
CO2ITR	0.8	0.8	0.8
CO2ICE(1,1,1)	1.2	1.2	1.2
CO2ICE(1,1,2)	1	1	1
CO2ICE(1,1,3)	1	1	1
CO2ICE(1,2,1)	1.2	1.2	1.2
CO2ICE(1,2,2)	1	1	1
CO2ICE(1,2,3)	1	1	1
CO2IRS	1	1	1
BASFC2	1	1	1
BASFCT	400	1	400
SITPOT	2400	2400	2400