GULLY EROSION ASSESSMENT AND PREDICTION ON NON-AGRICULTURAL LANDS USING LOGISTIC REGRESSION

by

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Abstract

Gully erosion is a serious problem on military training lands resulting in not only soil erosion and environmental degradation, but also increased soldier injuries and equipment damage. Assessment of gully erosion occurring on Fort Riley was conducted in order to evaluate different gully location methods and to develop a gully prediction model based on logistic regression. Of the 360 sites visited, fifty two gullies were identified with the majority found using LiDAR based data.

Logistic regression model was developed using topographic, landuse/landcover, and soil variables. Tests for multicollinearity were used to reduce the input variables such that each model input had a unique effect on the model output. The logistic regression determined that available water content was one of the most important factors affecting the formation of gullies. Additional important factors included particle size classification, runoff class, erosion class, and drainage class.

Of the 1577 watersheds evaluated for the Fort Riley area, 192 watersheds were predicted to have gullies. Model accuracy was approximately 79% with an error of omission or false positive value of 10% and an error of commission or false negative value of 11%; which is a large improvement compared to previous methods used to locate gully erosion.

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Dedication

I would like to dedicate this to my family; without whom I would not be the person that I am today. Your support, encouragement, and faith in me are the foundation to any accomplishment I ever achieve.

CHAPTER 1 - Introduction

Gullies are small channels of erosion on landscapes, typically agricultural, that are caused by the concentration of overland flow usually between two opposing slopes. These are often formed during a single rainfall event. These gullies can generally be easily refilled, but reappear at or near the same location on a yearly basis because of the surface topography of the field does not change significantly (Casali et al. 2000).

Currently, gully erosion is not accounted for in soil-loss assessment programs, but its contribution and importance to total soil losses has been recognized for a long time. Accurate assessment of gully erosion is limited by a number of factors. At present few field studies have provided data on gully erosion rates, and these studies tend to be restricted by time and space (Casali et al. 2000). To obtain accurate erosion rates and projected soil losses, accurate rainfall data is needed.

Gullies form because of a variety of causes. Critical parameters for gully development include: a critical slope length and slope gradient that is dependent on slope characteristics and crop row direction; occurrence and depth of a fragipan; agricultural practices; and timing and total amount of precipitation (Smith 1993). However, soil erodibility and compaction play a significant role in the formation of gullies in many places such as Fort Riley.

Few studies have been performed to determine the military's effect on the rate of formation for gullies. Military training areas experience significant amounts of soil erosion which leads to nonpoint source pollution. The activities can cause significant land degradation, which lead to unfavorable environmental impacts, especially soil erosion. The extent of the resulting degradation depends on the vehicles involved, their operating features, and the existing soil conditions within the training area (Ayers et al. 2005). The vehicles' weight and its small turning radii associated with tracked vehicles have shown to cause severe compaction and rutting.

As of now, there is no single solution to prevent or mitigate ephemeral gully formation and erosion. Selection of best management practices is unique to each area of interest. These generally take land uses into consideration to determine the best combination of practices to reduce erosion and gully formation.

This study aims to begin the process of studying the formation and migration of gullies on a military base. Determining the factors involved and the rate of formation would significantly increase our knowledge of gully erosion resulting from military training activities. This could aid in the development of models to determine the amount of erosion occurring, the amount of soil loss, and the locations most likely to have gully formation. With this information, the best combination of management practices can be determined to reduce erosion without compromising the use of the land for military training.

CHAPTER 2 - Literature Review

The Clean Water Act and Nonpoint Source Pollution

The Clean Water Act of 1972 was established to regulate the discharge of pollutants from point sources to waters of the United States (USEPA 2008). After many revisions and amendments, the Environmental Protection Agency (EPA) defined point sources of pollution in section 502(14) of the U.S. Clean Water Act of 1987 as "any discernable, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft from which pollutants are or may be discharged" (Dressing 2003.). The term nonpoint source pollution is defined as any source of water pollution that is not specifically defined as point source pollution (Dressing 2003.).

Nonpoint Source pollution comes from various sources such as overland flow, infiltration, drainage, seepage, rainfall, hydraulic modification, and atmospheric deposition. It is caused by rainfall and snowmelt moving over and through the ground (U.S. EPA 2010). As the runoff moves, it picks up and carries natural and human-made pollutants and deposits them into water bodies (U.S. EPA 2010). Sedimentation that results from eroding stream banks and gullies contributes to the pollution of water bodies. While point source pollution has been significantly controlled through numerous pollution control activities such as wastewater treatment plants, studies have shown that nonpoint source pollution continues to impair water quality across the United States (U.S. Environmental Protection Agency 2004).

Under Section 305(b) of the Clean Water Act (U.S. EPA 2009) the USEPA assesses the water quality status of US water bodies approximately every 2 years. In 2008, water quality was assessed by determining whether waters were getting better or worse statewide and identifying key stressors that were both widespread and posed a significant risk to water quality (Table 2.1) (U.S. EPA 2011). Leading sources of impairment were identified for each waterbody type. Leading sources for rivers and streams include agriculture, atmospheric deposition, and hydrologic modifications (U.S. EPA 2011). Sources for lakes, reservoirs, and ponds included agriculture and atmospheric deposition; while sources for estuaries included atmospheric deposition and municipal discharges. Metals, nutrients, and oxygen depletion were leading causes of impairment for estuaries as well as lakes, ponds, and reservoirs (U.S. EPA 2011). Leading causes of impairment for rivers and streams included pathogens, habitat alterations, oxygen depletion, and sedimentation or siltation (U.S. EPA 2011).

According to the National Water Quality Inventory, NPS is the main cause of water quality impairment. Gully erosion adds to this problem when the overland flow accumulates silt and sediment in the water that results from eroding surfaces.

Table 2.1 Summary of the water quality of assessed waterbodies as reported in the National Water Quality Inventory Report 2010 (U.S. EPA 2011)

Waterbody Type	Total Size	Amt Assessed (% of Total)	Good Condition (% of Assessed)	Good but Threatened Condition (% of Assessed)	Impaired Condition (% of Assessed)
Rivers and Streams (miles)	3,533,205	934,808 (26.5%)	464,716 (49.7%)	6,355 (<1%)	463,736 (49.6%)
Lakes, Ponds, and Reservoirs(acres)	41,666,049	17,576,423 (42.2%)	5,926,646 (33.7%)	47,330 (<1%)	11,602,447 (66%)
Estuaries (sq. miles)	87,791	18,443 (21%)	6,687 (36.3%)	17 (<1%)	11,740 (63.7%)

U.S. Government Regulations

The federal government passed the Clean Water Act in 1972, marking a major change in U.S. water policy and management. This called for the regulation of point source pollution by the U.S. EPA through National Pollution Discharge Elimination System (NPDES) permits (USEPA 2007b). NPDES permits also require the implementation of Stormwater Pollution Prevention Plans to meet the water quality requirements of stormwater runoff from construction sites and urban areas. The Clean Water Act was amended in 1987 to include the control of nonpoint source pollution, also known as section 319. This amended version is called the 1987

Water Quality Act. Shortly after, section 401 was added to require federal agencies to obtain certification before issuing permits that would result in increased pollutant loads to a waterbody, while certification is issued only if such increased loads would not cause or contribute to exceedances of water quality standards. Section 404 was also added to regulate the placement of dredged or fill materials into wetlands and other waters of the United States. State Revolving Funds or SRFs are also included. These provide large amounts of money in the form of loans for municipal point sources, nonpoint sources, and other activities (USEPA 2008).

The Water Quality Standards included in the Clean Water Act apply over a broad range of policies. Antidegradation is a set of policies to keep clean waters clean. Antidegradation is generally considered to have three components of protection: protection and maintenance of existing uses of waters, protection of high quality waters, and outstanding national resource waters (USEPA 2008). These policies promote waters that are "better than standards." Unfortunately these waters are few and far between. As seen in Figure 2.1, many causes of impairment reduce the quality of waters through point and nonpoint pollution sources. One of the highest among these is sedimentation of our waterbodies, while the excess nutrients carried from overland flow and erosion constitutes a large amount as well. Even though the Clean Water Act provides no federal authority for requiring nonpoint sources to reduce their loadings of pollutants to the nation's waters, the Act does require states to develop strategies and controls such as Total Maximum Daily Loads (TMDLs). Research and planning will need to be done to gain funding and remediate erosion and water quality.

Currently, nonpoint source pollution is dealt with on a voluntary basis through Section 319 and the Nonpoint Source Program. Instead, Congress created a federal grant program that provides money to states, tribes, and territories for the development and implementation of nonpoint source pollution management programs. The Federal "319" Grants provide $237 million in FY 02 with 40% match required, either in dollars or in-kind services, using the EPA allocation formula. The allowed usages of these funds include: development and implementation of statewide nonpoint source pollution program plans; grants for on-the-ground controls such as best management practices; development and implementation of TMDLs and holistic watershed plans; and development of state regulatory programs. States and tribes must identify waters that are impaired or threatened by nonpoint sources of pollution, develop short- and long-term goals for cleaning them up, and identify best management practices (BMPs) that will be used. They

Figure 2.1 Impairment to water quality as reported by the National Water Quality Inventory Report 2010(U.S. EPA 2011)

Cause of Impairment Group	Miles Threatened or Impaired
Pathogens	141,789
Sediment	107,650
Nutrients	101,461
Organic Enrichment/Oxygen Depletion	83,583
Habitat Alterations	82,510
Polychlorinated Biphenyls (PCBs)	72,888
Metals (other than Mercury)	64,781
Flow Alteration(s)	56,813
Mercury	46,922
Temperature	46,799
Cause Unknown	35,394
Salinity/Total Dissolved Solids/Chlorides/Sulfates	32,492
Cause Unknown - Impaired Biota	30,991
pH/Acidity/Caustic Conditions	28,343
Turbidity	27,087
Pesticides	16,599
Other Cause	16,420
Ammonia	14,115
Fish Consumption Advisory	9,209
Toxic Inorganics	6,227

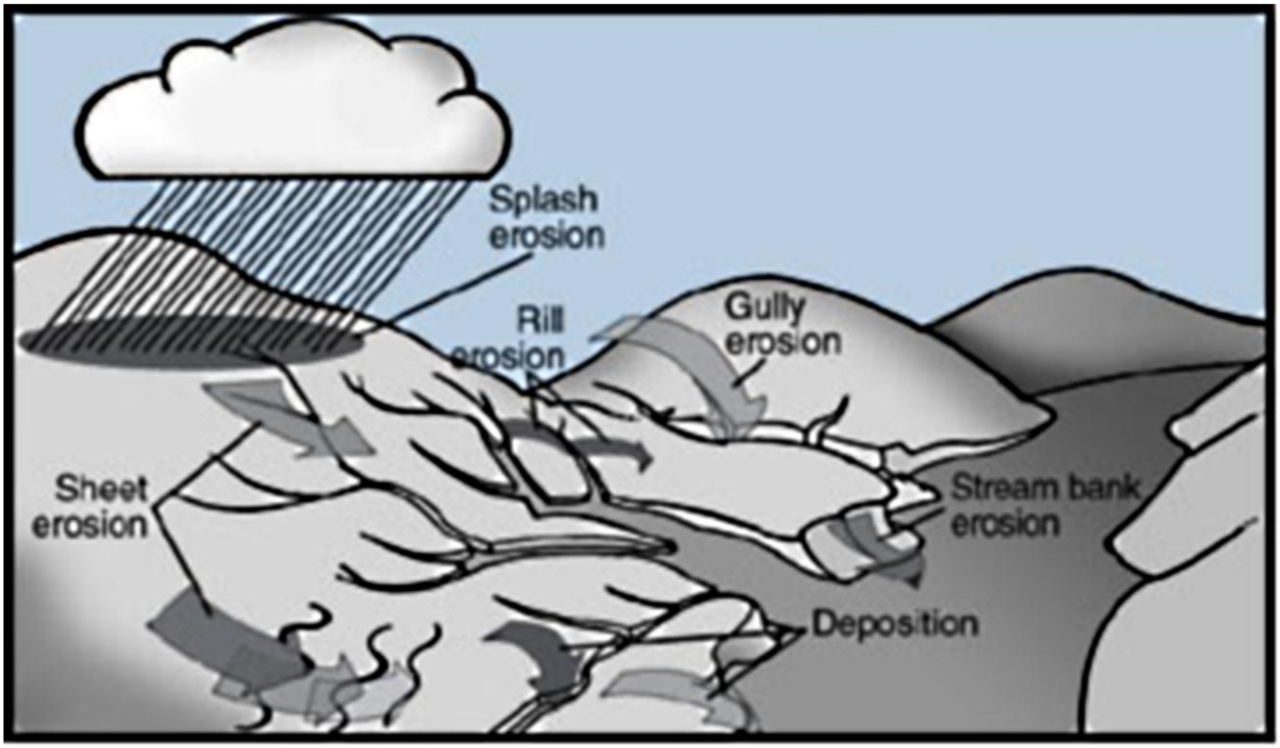
must also have a monitoring and evaluation plan. The BMP section of the plan requires identification of the most common types of stressors, the categories of sources of those stressors, and the types of BMPs that will be both effective and affordable in addressing the identified stressors and sources in general. However, as these nonpoint sources become more and more important in order to continue improving and maintaining our water and land quality, the pollution will begin to be dealt with on a strict regulatory basis. For instance, to reduce sedimentation, soil erosion will need to be remediated.

Soil Erosion

Soil erosion is a common term used to either mean soil degradation or the physical removal of soil. Soil erosion is the detachment and transportation of soil particles by agents such as wind or water (Toy et al. 2002). This term can apply easily to gullies because soil is removed and is usually caused by some sort of soil degradation. However, most classify the type of erosion by the erosive agent, wind or water, which causes the erosion. Water erosion can be caused by rainfall, surface runoff from rainfall, and surface runoff from irrigation. Runoff occurs once the precipitation rate exceeds the infiltration rate of the soil. As precipitation continues to exceed infiltration, water begins to move down slope as overland flow or in defined channels (Ward and Stanley W. Trimble 2004).

The detached soil particles that result from runoff and erosion are deposited in receiving water bodies, which has led to a higher impairment of water quality. Erosion is more likely to take place on lighter textured soils and on slopes rather than in valley floors (Boardman and Favis-Mortlock 1998). Soils containing more fine sand are more likely to give way and erode, which results in sedimentation (Dvořák and Novák 1994). Sedimentation is a major problem causing pollution in streams and rivers. Sediment does not only carry soil particles but also carries nutrients that are found in the soil such as large amounts of phosphorous. These excess nutrients can cause overgrowth of algae, leading to the depletion of oxygen and ecosystem disruption (USEPA 2007a). Sedimentation caused by erosion can alter aquatic habitat, suffocate fish eggs and bottom-dwelling organisms, and impair drinking water treatment processes and recreational use (USEPA 2007a). Erosion and nonpoint source pollution are interrelated. As erosion increases, so does nonpoint source pollution while water quality decreases. Therefore, if erosion can be controlled, nonpoint source pollution can be minimized and water quality can be improved. This can be done by gaining a better understanding of the causes of and processes involved in the formation of erosion.

Figure 2.2 Image of different forms of erosion (Broz et al. 2003)



Erosion is generally recognized in several different forms (see Figure 2.2). Table 2.2 describes the differences between rill erosion, ephemeral gully erosion, and classic gully erosion. Sheet erosion is a process in which detached soil is moved across the soil surface by sheet flow, usually in the early stages of runoff. Rill erosion occurs as runoff begins to concentrate in small channels or streamlets (Dressing 2003.). Sheet and rill erosion generally carry mostly fine-textured, small particles of soil. These particles will contain higher quantities of nutrients, pesticides, or other adsorbed pollutants than those contained in the surface soil as a whole (Dressing 2003.). This process of the movement of fine particulates carrying high concentrations of adsorbed pollutants is called sediment enrichment (Dressing 2003.). Water moving within the rills can concentrate to form larger, more persistent erosional channels known as gullies.

Table 2.2 Characteristics of erosion (Foster 1986.)

Rill Erosion	Ephemeral Gully Erosion	Classical Gully Erosion
Rills are normally erased by tillage; they usually do not recur in the same place	Ephemeral cropland gullies are temporary features, usually obscured by tillage; recur in the same location	Gullies are not obscured by normal tillage operations
May be of any size but are usually smaller than ephemeral cropland gullies	May be of any size but are usually larger than rills and smaller than permanent gullies	Usually larger than ephemeral cropland gullies
Cross sections tend to be narrow relative to depth	Cross sections tend to be wide relative to depth; sidewalls frequently are not well defined; headcuts are usually not readily visible and are not prominent because of tillage	Cross sections of many gullies tend to be narrow relative to depth; sidewalls are steep; headcut usually prominent
Flow pattern develops as many small disconnected parallel channels ending at ephemeral cropland gullies, terrace channels, or where deposition occurs; they are generally uniformly spaced and sized	Usually forms a dendritic pattern along depressional water courses, beginning where overland flow, including rills, converge; flow patterns may be influenced by tillage, crop rows, terraces, or other unnatural features	Tend to form a dendritic pattern along natural water courses; nondendritic patterns may occur in road ditches, terraces, or diversion channels
Occurs on smooth side slopes above drainageways	Occurs along shallow drainageways upstream from incised channels or gullies	Generally occurs in well-defined drainageways
Soil is removed in shallow channels but annual tillage causes the soil profile to become thinner over the entire slope	Soil is removed along a narrow flow path, typically to the depth of the tillage layer where the untilled layer is resistant to erosion, or deeper where the untilled layer is less resistant; soil is moved into the voided area from adjacent land by mechanical action (tillage) and rill erosion, damaging an area wider than the eroded channel	Soil may be eroded to depth of the profile and can erode into soft bedrock

Gully Erosion

Gullies most often occur on areas that have a low density vegetative cover and highly erodible soils. They are thought to form when a break in the vegetative cover allows erosional hollows to form; water accumulates here and results in even more erosion (Dressing 2003.). Gully erosion is the resultant of two main processes: downcutting and headcutting. Downcutting is the vertical lowering of the gully bottom that leads to gully deepening and widening (Ffolliott et al. 2003). Headcutting is the upslope movement that extends the gully length (Ffolliott et al. 2003). Erosion is focused at the gully head, where overland flow erodes the lip of the head as the water flows over it before plunging into the plunge pool at its base (Charlton 2008). This is where the deepening and undercutting of the gully take place. It undermines the headwall and allows the gully head to retreat further upslope. Subsurface flow moving towards the gully head can weaken the walls and result in the development of pipes or channels of aid within the soil that run along the side of the gully (Ffolliott et al. 2003). The collapse of pipes further contributes to gully head retreat (Charlton 2008). The presence of deep tension and desiccation cracks allow concentrated overland flow to penetrate the soil surface (Charlton 2008).

Gullies are classified as either ephemeral or classic. Ephemeral gullies occur on land where vegetation is removed. They are commonly found on cropland and are temporarily filled in by field operations, only to recur after concentrated flow runoff. This filling and recurrence of the ephemeral gully can occur numerous times throughout the year if left untreated. Classic gullies may occur in many places but are so large that they cannot be crossed by agricultural equipment or vehicles (Dressing 2003.). Classic gullies are characterized by headward migration and enlargement through a combination of headcut erosion and gravitational slumping, as well as stress of concentrated flows (Dressing 2003.). Erosion caused by water or runoff is a major contributor to nonpoint source pollution. Development of new gullies of the rapid expansion and deepening of older gullies can often be traced to removal of vegetative cover through some human activity (Ffolliott et al. 2003).

Gully Development

Gully development becomes active during the spring-summer period under the effect of flooding, snow melting, and precipitation, especially showers (Xi et al. 2004). The factor most important for gully development is not the total annual rainfall, but the occurrence of short flood rains when the soil is not able to absorb a substantial part of the precipitation. Gully development is widespread in upland areas and particularly common in areas with mineral soils and steep slopes (Park 2001). All soils are liable to be affected by natural erosion processes, but soils become more vulnerable depending on factors such as soil characteristics and land use.

Table 2.3 gives a summary of relevant data concerning ephemeral gully erosion. Methods used to measure gullies include: simple volumetric measurements with profilers and tapes, conventional photography, aerial photography, and digital terrain models (Casali et al. 2000). All studies in the United States except 2 and 6 used Universal Soil Loss Equation to estimate rill and interrill erosion. Data ranges are given in parentheses. Sources include: 1-Miller (1982), soil hydrologic Group A and B; 2-Spomer and Hjelmfelt (1986), loess, conventional till; 3-Laflen (1985), loess and glacial till; 4-Thomas et al. (1986), Thomas and Welch (1988), sandy loam, soybeans, conventional till; Grissinger and Murphey (1989), loess, soybean, conventional till; 6-Lentz et al. (1993), loess or glacial till loess, corn and soybeans, conservation till; 7-Smith (1993), loessial silt loams with fragipan, soybeans or corn, conventional till; 8-Moore et al. (1988), bare, salodic loam; 9-Auzet et al. (1993) variable crops and managements; 10-Vandaele (1993), loess, silty loam, variable crops; 11-Vandaele and Poesen (1995), loess, silty loam, variable crops; 12-Poesen et al. (1996), sandy loam, 20-50% rock fragments, inactive; 13-Vandaele et al. (1996) a-loess, silty loam, variable crops; b-lithosol, >30% rocks, winter wheat and barley; 14-Casali et al. (1998) loam or silt loam, winter grains, conventional till; 15-Hidalgo et al. (1998) clay soil (Casali et al. 2000).

As seen, despite the importance of ephemeral gully erosion, little data exists on rates of soil losses, data and criteria for gully formation, and physical characteristics of gully systems. The state of the gully erosion is often not recorded, whether the gully is actively eroding and what type of gully is occurring. Active gullies can be distinguished from those that are beginning to stabilize by the presence of steep, unvegetated banks, pedestaling or a column of soil protected by pebble or small rock, and erosion pavements or a surface covered with material that cannot be moved by the surface runoff that originally removed the soil material (Black 1996). Active gullies can further be classified as continuous or discontinuous.

Table 2.3 Summary of relevant data concerning ephemeral gully erosion (Casali et al. 2000)

Source	Location	Slope (%) Watershed (W) or Gully (G)	Drainage Area (ha) (W:G)	Soil loss, Ephemeral Gullies kg/m2-y	Total Soil Loss kg/m2-y	Soil Loss, Rill/Sheet Erosion kg/m2-y	% of total soil loss due to ephemeral gullies
United States							
1	Alabama	n.a.	n.a.	0.80, 1.45	1.34, 2.90	0.54, 1.45	60, 50
2	Iowa	4.0-14.0 (W)	24.3 (W)	1.70, 0.68	8.9, 0.62	7.20, 0	19, 100
3	Iowa	2.0-11.0 (W)	12.2 (W)	0.19-0.73	0.97-3.75	0.78-3.02	19-20
4	Georgia	4.5 (G)	5.3 (W)	4.00, 5.06	10.73	6.2	42
			2.0 (G)				
5	Mississippi	n.a.	1.9 (W)	1.47	2.45	0.98	60
6	Minnesota	3.4-6.1 (W)	7.4 (W)	0.3	n.a.	n.a.	n.a.
				(0.15-0.54)			
7	Mississippi	0.8-2.0 (G)	2.2 (G)	1.68	6.04	4.36	36
				(1.21-2.02)	(4.51-10.3)	(0.96-8.74)	(16-67)
Australia							
8	Australia	12.5 (W)	7.5 (W)	1.3	n.a.	n.a.	n.a.
Europe							
9	France	1.9-7.9 (W)	ca. 650 (W)	0.2	20	0.09	72
			ca. 410 (G)	(0.09-0.70)	(0.05-0.93)	(0-0.25)	(36-100)
10	Belgium	gentle	170.0 (W)	0.21-0.35	0.56-0.82	0.35-0.50	37-39
11	Belgium	gentle	25.0 (W)	ca. 0.40	0.85	0.41	52
12	Spain	3.0-25.0 (W)	10.0 (W)	1.26	1.52	0.26	80
13a	Belgium	gentle	4,000.0 (W)	0.15-1.32	1.9	0.36-0.58	30-69
13b	Portugal	gentle	550.0 (W)	0.10-0.68	0.12-0.80	0.02-0.13	83-84
14	Spain	0.5-9.5 (G)	88.0 (W)	0.87	n.a.	n.a.	n.a.
			ca. 5.0 (G)	(0.16-2.66)			
15	Spain	n.a.	4.9 (W)	6.49	ca 8.83*	n.a.	ca. 74
			4.9 (G)				

n.a.: not available

* Minimum value, rill and sheet erosion not considered

Continuous Gullies

Gullies that exhibit upstream extension by drainage net “fingers” and a relatively smooth longitudinal bottom profile are continuous gullies (Ffolliott et al. 2003). A continuous gully generally gains depth rapidly from the headcut and then maintains a relatively constant gradient to the mouth, where the most active changes take place. Continuous gullies nearly always form systems and are found in different vegetation types but are prominent in dryland regions. Frequently, a series of discontinuous gullies will coalesce into a continuous gully (Ffolliott et al. 2003). When the gullies coalesce into a single uninterrupted channel, the gully has a gradient practically identical to the gradient of the original valley floor. This indicates that there is a progressive steepening of the gully bed.

Discontinuous Gullies

Discontinuous gullies may exhibit many headcuts including one at the upstream limit of the gully that extends its length, each of which exhibits upstream migration and promotes gully growth, and a stepped longitudinal profile (Black 1996). Discontinuous gullies can be found at any location on a hillslope and can occur singly or in a system of downslope steps in which one gully follows the next (Ffolliott et al. 2003). Where the plane of the gully floor intersects the more steeply sloping plane of the original valley floor, the gully walls have decreased to zero in height and a fan occurs (Leopold and Miller 1995). The fan is characterized by a concentration of water along the topographic high of the cone-shaped deposit of debris (Leopold and Miller 1995). As a result, the position of this watercourse frequently shifts and gives the symmetry to the flat cone of deposition.

The discontinuous gully is a semicyclic phenomenon in which alleviation on a valley floor develops locally a gradient that is too steep to be stable, so it subsequently erodes (Leopold and Miller 1995). The fan formed at the mouth of a discontinuous gully has a local slope steeper than the average for the valley. The intersection of the two planes of different slope gives the discontinuous gully its particular character (Leopold and Miller 1995). Hydraulic considerations indicate that where roughness is constant a relatively large depth at any given velocity requires a small value of slope (Leopold and Miller 1995). As widening progresses, an increased shear as the width-depth ratio increases is required to carry a particular sediment load at a given discharge. Therefore, a low gradient of the channel bed should characterize the early and narrow stage of the discontinuous gully, while slope should be expected to increase as the channel widens (Leopold and Miller 1995).

Hydraulic stress and pressure forces have a major influence on the development and movement of a gully headcut or overfall (Robinson 1992). A headcut is a vertical or near-vertical drop or discontinuity on the bed of a stream channel, rill, or gully and occurs where flow is concentrated at a point. Headcuts migrate upstream by hydraulic stresses at the overfall such as weathering processes of drying, wetting, freezing, and thawing; basal sapping; or a combination of these processes (Hanson et al. 1997). As flowing water encounters an abrupt change in elevation, the resulting action can create a reverse roller that undercuts the upper surface and allows the gully to move upstream. The impact is increased soil erosion, dissection of land with retreating gullies, and decreased safety of hydraulic structures (Robinson 1992).

The ability to understand these stresses and the rate of headcut migration could influence our ability to determine where gullies are most likely to develop and our ability to choose the correct best management practices to use. The prevention of headcut migration would result in fewer gullies, especially ones that impact military training. It would help prevent new gullies from forming and help remediate the gullies that have already been formed. Therefore, the rate of headcut migration could greatly enhance our understanding of gullies. In order to do so, factors affecting the rate of erosion need to be determined.

Factors Affecting Erosion Rates

Water erosion rates are affected by rainfall energy, soil properties, slope, slope length, vegetative and residue cover, and land management practices. Kinetic energy from raindrops and runoff cause the removal of soil particles. Soil properties such as particle size distribution, texture, and composition influence the susceptibility of soil particles to be moved by the flowing water (Dressing 2003.).

Vegetative cover and residue protects the soil surface from rainfall impact and the force of moving water. Natural vegetation not only breaks the fall of raindrops, but also helps to bind loose soil on slopes (Charlton 2008). In addition, vegetation reduces the frequency of overland flow by encouraging infiltration. Organic material such as plant litter helps hold topsoil together, increases permeability, and provides a supply of nutrients (Charlton 2008). The removal of vegetation reduces soil protection and results in the acceleration of the rate of soil erosion. There are many environmental impacts associated with accelerated soil erosion. Once the fertile topsoil has been removed, the lower soil layers are exposed. These lower soil layers generally have a poor structure and are low in organic matter and nutrients. They are less permeable, which increases overland flow and leads to more erosion (Toy et al. 2002).

Erosion can either prevent vegetation from growing or seriously affect its composition and structure. Erosion also affects the availability of nutrients in the soil for plant growth. Nitrogen can be lost in surface runoff. Phosphorus and organic matter are preferentially removed when absorbed to the clay particles, which are often selectively eroded while the coarser material remains behind (Rickson 1995). Soluble phosphorous is also removed in the surface runoff. However, under most circumstances, water availability operates as a limiting factor to vegetation growth long before any effects of the loss of mineral matter are observed (Rickson 1995).

The factors that affect the rate of erosion are essential in developing a model to predict where and when gullies form in the landscape and how their position, frequency of occurrence, and erosion intensity is affect by factors such as climate or land use changes.

Models and Gully Erosion

Models capable of predicting size, location, timing, frequency, and intensity are needed to more accurately predict the effects of environmental change on soil losses due to gully erosion. For the development of an accurate model, more detailed monitoring, experimenting, and modeling of the development and infilling of both ephemeral gullies and bank gullies in a variety of environments to better stimulate gully erosion subprocesses needs to occur. There is also a need to predict gully cross-sectional size and shape and soil loss rates due to gully erosion (Boardman and Favis-Mortlock 1998). Many models are available today to estimate soil losses.

Water Erosion Prediction Project

The Water Erosion Prediction Project (WEPP) model is a process-based, distributed parameter, continuous simulation, erosion prediction model. It is applicable to sheet and rill erosion based on the simulation of the hydrologic and erosion processes on small watersheds (National Soil Erosion Research Laboratory). It was developed by the United States

Department of Agriculture's Agricultural Research Service for use on personal computers and can be downloaded from their website for free. The model requires specific climate, topography, soil and management inputs. WEPP attempts to mimic the natural processes that affect soil erosion and updates soil and crop conditions daily (National Soil Erosion Research Laboratory). It includes conceptual components such as rainfall, freeze, furrow, runoff, drainage, soils, crop growth, residue management and decomposition, tillage, rill erosion, channel deposition, and sediment delivery to predict and calculate estimates of soil detachment and deposition (National Soil Erosion Research Laboratory). WEPP can provide various types of outputs, including water balance, soil detachment, deposition, sediment delivery, and vegetation growth.

Developments have been made to not only run multiple simulations to see the effects of landuse changes, but also allow users to run a watershed simulation using digital elevation data from Geographic Information Systems (GIS) (National Soil Erosion Research Laboratory). The GIS application is in its preliminary stages, but is also available online at http://www.ars.usda.gov/Research/docs.htm?docid=10621. However, WEPP does not predict gully erosion, erosion processes in continuously flowing streams such as stream bank sloughing, tillage erosion or mass wasting.

Revised Universal Soil Loss Equation

The USDA also developed in the Revised Universal Soil Loss Equation (RUSLE), an empirical formula widely used to predict soil loss in sheet and rill erosion (Figure 2.3) that uses soil characteristic and land use factors (Dressing 2003.). RUSLE may be used as a framework for considering the principal factors affecting sheet and rill erosion: climate (R), soil characteristics (K), topography (LS), and land use and management (C and P). Except for climate, these factors suggest areas where changes in management can influence soil loss from water erosion. It is important to note that the RUSLE predicts soil loss, not sediment delivery to receiving waters (Dressing, 2003).

The current model, RUSLE2, is an advanced software model that makes its computations on a daily time step rather than a half month time step. It also uses a full mathematical integration procedure rather than the previously used approximate procedure. The RUSLE2 can be found on the NRCS website and may be downloaded for free at the following website: http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm.

Figure 2.3 Description of the Revised Universal Soil Loss Equation (Dressing 2003.)

Revised Universal Soil Loss Equation (RUSLE)

$$A = R * K * LS * C * P$$

where

A = estimated average annual soil loss (tons/acre/year)

R = rainfall/runoff factor, quantifying the effect of raindrop impact and the amount and rate of runoff associated with the rain, based on long term rainfall record

K = soil erodibility factor based on the combined effects of soil properties influencing erosion rates

LS = slope length factor, a combination of slope gradient and continuous extent

C = cover and management factor, incorporating influences of crop sequence, residue management, and tillage

P = practice factor, incorporating influences of conservation practices such as contouring or terraces

Ephemeral gully erosion is not accounted for in soil loss assessment programs such as RUSLE and WEPP, but its contribution and importance to total soil losses has long been acknowledged. The USDA-NRCS estimated the ratio of ephemeral gully erosion to rill and sheet erosion, which range from 21% for New York to 274% for Washington. The average percentage for these selected areas is near 80% for the 19 states surveyed (Figure 2.4) (USDA-NRCS. 1997). New York has the highest estimated annual sheet and rill erosion, while Washington has the lowest. Virginia has the highest amount of measured ephemeral gully erosion, while Michigan has the lowest. Kansas has a high estimated annual sheet and rill erosion, while the gully erosion as a percentage of sheet and rill erosion is approximately 36% even though the amount of measured ephemeral gully erosion is high as well.

Table 2.4 Assessment of Ephemeral Gully Erosion Rates in Selected Areas of the U.S. reported by the National Resources Conservation Service (USDA-NRCS. 1997)

Location	Estimated Annual Sheet and Rill Erosion (kg m^{-2} y^{-1})	Measured Ephemeral Gully Erosion (kg m^{-2} y^{-1})	Ephemeral Gully Erosion as a Percentage of Sheet and Rill Erosion (%)
Alabama	0.573	0.342	60
Delaware	0.038	0.093	245
Illinois	0.261	0.191	73
Iowa	0.353	0.110	31
Kansas	0.807	0.294	36
Louisiana	0.654	0.222	34
Maine	0.412	0.189	46
Maryland	0.195	0.147	75
Michigan	0.172	0.045	26
Mississippi	0.646	0.275	43
New Jersey	0.246	0.191	78
New York	0.873	0.185	21
North Dakota	0.277	0.130	47
Pennsylvania	0.093	0.065	70
Rhode Island	0.331	0.136	41
Vermont	0.165	0.224	136
Virginia	0.477	0.470	98
Washington	0.025	0.069	274
Wisconsin	0.289	0.154	53

Annualized Agricultural Non-Point Source model

The Annualized Agricultural Non-Point Source (AnnAGNPS) model was developed to facilitate assessment of watershed and landscape processes in agricultural areas (Bingner and Theurer 2002). Currently, AnnAGNPS cannot predict ephemeral gully erosion. However, studies are now underway to do so (Bingner and Theurer 2002; Gordon et al. 2007). A conceptual and numerical framework was constructed to simulate the development and upstream extension of an ephemeral gully based on a migrating headcut and discharge-dependent gully dimensions in unsteady, spatially varied runoff events (Gordon, n.d.). The model simulations illustrate the initial formation and the temporal and spatial evolution of ephemeral gullies in response to a range of runoff events, tillage conditions, and indices of soil erodibility. The model requires several assumptions, but is the necessary first step in addressing ephemeral gully erosion using common technology such as the use of root mean square with AnnAGNPS with easily accessible data like tillage conditions and soil characteristics.

Sequential Aerial Photographs

In New Zealand, gullies are common due to a combination of bedrock susceptible to erosion, mountainous topography, extreme rainfall events, and drastic land use changes. Most gully systems in this region are termed fluvio-mass movement, due to the major role that mass movement plays in sediment production and gully enlargement (Parkner et al. 2006). Here, sequential aerial photographs were interpreted to measure and analyze temporal changes for a long time span with higher temporal resolution. The area of gullies and complexes affected by gully incision and mass movement erosion was measured for each time slice after digitizing in ArcGIS. Gully erosion is considered a threshold phenomenon because it occurs only when a threshold in terms of rainfall, topography, and land use is surpassed. The air photographs were interpreted to determine land use and land cover (Parkner et al. 2006). Rainfall data was collected from stations close to the study area at their highest temporal resolution, while a history of major storms records was also used. Studies with lower time resolution showed the same pattern of overall gully complex development with expansion and stabilization. The topographic threshold line developed for gully initiation allows for the prediction of which catchments will develop gullies and gully complexes (Parkner et al. 2006). However, this could not be used in other areas where mass movement does not play as significant a role as it does in New Zealand. Sequential aerial photographs would be useful within the United States to study the migration of gully heads, but could not be used to estimate total erosion because it puts less emphasis on erosion occurring along the channel side slope.

Photogrammetry and Ground Control Points

Another method uses images taken from a blimp or kite allow for the gully systems to be surface modeled and monitored, while gully growth and soil loss are measured using geographic information systems (GIS) and digital photogrammetric analysis. At all gully sites, ground control points (GCPs) were installed to help provide more accurate modeling and monitoring

(Marzolff and Poesen 2009). These are located at points that are clearly identifiable places in the image because it has to be possible to derive location and elevation of the point from the map. Automatic digital elevation model (DEM) generation in digital photogrammetry systems uses image matching and DEM interpolation. A hybrid method of automatic and interactive feature extraction was used to eliminate false matches and reduce problems such as shadowing (Marzolff and Poesen 2009). Assessment of errors associated with DEM accuracy was done by examination of the bundle block adjustment results and by visual inspection of the concordance of the surfaces with the 3D dataset of GCPs. The change of gully area and volume were determined by differencing the raster files with a simple subtraction operation in the GIS and separating areas of loss and gain. Total gully volume was then calculated by using the ArcGIS cut/fill operation. Small format aerial photogrammetry can be considered an important tool for the monitoring of gully erosion sites (Marzolff and Poesen 2009). Gully extent, volume, and change can be derived with accuracy and detail that corresponds to the magnitudes and geomorphic characteristics of gully erosion processes. However, problems such as the sidewall erosion being omitted can distort the morphology and volumetric measurements, which cannot be solved without a combination of aerial and terrestrial imagery.

The Rate Law of Geomorphology

Prior to human disturbance, systems are usually in a condition that approximates a steady state where erosion, transport, and deposition are adjusted to the climatic and geologic conditions. Human activities that disturb the land affect the steady state. The period between the beginning of the change and the establishment of the new steady state is known as the relaxation time. A rate law in the form of a negative exponential function similar to the equation used to describe relaxation times of radioactive materials and chemical mixtures provides a useful model for relaxation times in geomorphic systems (Graf 1977). Half-life values for adjustment periods of the gully networks after natural changes may be useful in predicting adjustment periods after man-induced changes (Graf 1977). This rate law could help predict gully headcut rates, especially when a contributing factor is the human impact on the natural environment. Climatic and anthropogenic changes are similar in terms of their impacts on geomorphic systems. Both changes are rapid, affect fluvial systems by changing vegetation and land surfaces, and have the potential of affecting complete drainage areas (Graf 1977). The rate law links the original amount of material (A_o) with the amount remaining after a given period of decay:

$$(1/2)^{t/T}=A_t/A_o$$

where t=time elapsed, T=half-life, A_t=amount of original material remaining at time t, and ½=rate of change. The rate law may be used to describe changes in gully length. If t equals the time since disruption, A_o equals the potential equilibrium length of the gully, A_x equals the length of the gully, and At equals the length yet to be eroded. This equation can be put into linear form:

$$\ln A_t=\ln A - bt$$

If enough points are available, the rate constant, b, can be determined (Graf 1977). Unfortunately, this equation to predict the headcut migration of gullies has not been tested in various geologic, vegetative, and climatic conditions. It has not seen wide acknowledgment within the research of headcut migration of gullies.

The rate law has an enormous potential to predict the amount of headcut migration within the United States, while taking anthropogenic and climatic changes into consideration. However, more testing would need to be done in different areas to ascertain the accuracy of the equation's ability to predict headcut migration. If the rate law was studied to determine the relationships associated with headcut migration and properties such as soil texture and vegetation, then the process of gully erosion would be better understood and more models would be able to accurately predict soil losses due to gully erosion.

In order to develop an accurate model to determine the location and formation of gullies, more field data is needed to determine the factors involved in gully erosion. Few studies have been performed to determine the military's effect on the rate of formation of gullies.

Military Activities and Erosion

The Integrated Training Area Management (ITAM) Program is the Army's program for managing training lands. A major objective has been to develop a method for estimating the amount of training that a given parcel of land can accommodate in a sustainable manner, based on a balance of use, condition, and maintenance practices. The Army Training and Testing Area

Carrying Capacity (ATTACC) methodology is an initiative to estimate training land carrying capacity (Li et al. 2007). The methodology is also used to determine land rehabilitation and maintenance costs associated with land-based training. Knowledge of water quality throughout an installation allows the selective implementation of this methodology as a verification tool to enhance the information gleaned from water quality analysis of military lands (Svendsen et al. 2006). Water quality is affected by nonpoint source pollution from sources such as gullies.

Military training areas experience significant amounts of soil erosion which leads to nonpoint source pollution. Military activities lead to changes in the surrounding natural environment. The activities can cause significant land degradation, which lead to unfavorable environmental impacts, especially soil erosion. Training activities such as field maneuvers, mortar and artillery fire, small arms fire, and combat vehicle operations have led to soil disturbance. Most of the mechanized maneuvers take place on the northern 75% of Fort Riley (Abel et al. 2009). Wildfires resulting from training and management activities such as mowing, prescribed burning, chemical weed control, and small scale timber harvest have also caused soil disturbances on Fort Riley (Althoff et al. 2006). Since the National Environmental Policy Act of 1969 (NEPA) was passed and the U.S. Army Regulation 200-2 (Department of Defense 2002) was published, the military has been required to minimize these environmental impacts. It requires the Department of Defense to consider the environmental consequences of their actions and to document these considerations (Department of Defense 2002). The Army has developed the Integrated Training and Management (ITAM) program to optimize the sustainability of training areas. This program supports the management and maintenance of training areas while it also encourages military preparedness.

The Environmental Conservation Program of the Department of Defense describes natural resource policy on lands under the control of the Department in the United States, its Territories, trusts, and possessions (Walker 1999). Plans for natural resource management have been developed in accordance with principles of ecosystem management. Activities of the Department of Defense must promote conservation of biological diversity when practicable and consistent with the military mission (Walker 1999). The goal of the ecosystem management program is to ensure that military lands support present and future training requirements while preserving and enhancing ecosystem integrity. This goal includes restoring and maintaining native ecosystems, reestablishing and maintaining viable populations of native species, maintaining evolutionary and ecological processes, and managing the sites over time periods compatible with ecosystem dynamics (Walker 1999).

The military must maintain training exercises to remain ready for any upcoming missions, which means that land management practices must be flexible with minimal impacts on training exercises. Most Army installations suffer from degraded plant communities, excessive numbers of and poorly oriented roads and firebreaks, and compacted soils. Even light infantry training can lead to land degradation and erosion (Harmon and Doe 2001). The secondary and tertiary effects of erosion are often as serious as the primary effects and range from alterations in wildlife habitat to lowering of water tables. Training land erosion is associated with a combination of training activity and the ecological resiliency or the capacity of the land to sustain use (Harmon and Doe 2001).

Continuous long-term, or intense short-term, traffic by military vehicles can cause soil compaction and changes in soil bulk density and soil strength that adversely affect a soil's ability to sustain plant life (Milchunas et al. 1999). Military training exercises often include numerous military vehicles that are large, heavy, and have the capability of covering significant areas of land (Quist et al. 2003). The movement of these vehicles can cause considerable land degradation by compacting the soil and removing the vegetative cover (Milchunas et al. 1999). This results in exposure of the ground surface to rainfall and runoff water, increasing the potential for erosion. The extent of the resulting degradation depends on the vehicles involved, their operating features, and the existing soil conditions within the training area (Ayers et al. 2005). Not only the vehicles' weight but also the small turning radii associated with tracked vehicles have shown to cause severe compaction and rutting (Liu et al. 2007) as shown in Figure 2.4. Military land use is frequently intensive, especially where maneuvers are conducted with tracked vehicles.

Ruts are potential sites of high soil erosion, especially when aligned directly up and down a slope. They are hydraulically similar to natural rills in the erosivity of the flows in them. Water flow is faster and more turbulent in natural rills than it is in overland sheet wash and has more energy to detach and transport sediment (Gatto 2001). Ruts can act as channels to concentrate surface runoff, which increases its sediment transport capacity and subsequent soil erosion. Foltz determined that there is 200-400% more erosion on rutted roads than on unrutted roads (Foltz 1993). The intermittent flows in rills and ruts are usually appreciably deeper than the height of the coarsest roughness elements within them and are hydraulically similar to conventional open-channel flows in rivers (Harmon and Doe 2001). Flow velocity near the soil bed increased with compaction because the surface roughness of the compacted soil was less and infiltration into the more compacted soil was reduced, resulting in high, near bed water velocities and more soil particle detachment. This rapid runoff transported more sediment. The increased velocity from compaction had more effect on erosion than the increased soil shear strength that accompanies compaction. These factors can lead to gullies on training lands that form and enlarge faster than they do on undisturbed soils (Harmon and Doe 2001).

Tracked vehicles such as tanks are more damaging than wheeled vehicles to the soil surface. Tracked vehicles crush and uproot vegetation, while compacting the soil. When soil compaction occurs, air and water volume available in the soil, which is necessary for vegetation is reduced. The collapsed pore structure of the soil slows infiltration and may result in poor soil aeration that can inhibit root growth, nutrient uptake, and seedling emergence (Chancellor 1977). The alteration of the soil's physical properties may limit or prevent the reestablishment of former plants, resulting in long-term reductions of vegetative cover. This loss of cover results in less interception and dissipation of raindrop energy and contributes to a reduction of infiltration rates and an increase in erosion rates (Thurow 1991). The degree of hydrologic impact associated with tracked vehicles and the rate of recovery are dependent on characteristics including vegetation type, soil texture, soil moisture content at time of impact, and subsequent climatic characteristics (Thurow et al. 1993). However, plant root growth and soil microfauna can aid in the remediation of soil compaction.

Tracks left by a tracked vehicle were found in training area 34. The vehicle, likely used by conservation or public works, removed all vegetation and left ruts up to two feet deep. This was an example of a tracked vehicle causing severe land degradation. Standing water was found in many portions of the track because the soil was compacted to such an extent that there was no available space within the soil for the water to infiltrate. This lack of ground cover will most likely result in new formations of gullies as time progresses.

For wheeled off-road vehicles, the speed and turning radius had strong interaction on terrain impact severity (Li et al. 2007). The impact was most severe when the wheeled vehicle made sharp turns at high speed. For tracked vehicles, the interaction between speed and turning radius was not considered strong (Li et al. 2007). However, a smaller turning radius of tracked vehicles causes higher impact severity regardless of the magnitude of vehicle speed.

Figure 2.4 Soil disturbance caused by a tank on a single pass (St. Clair 2007)

Rut depth, width, and index increase as turning radius decreases (Liu et al. 2007). The decreased turning radius increases soil disturbance because the width and depth of track increased along with the height of soil piled up next to the tracks. A turning vehicle can produce deeper ruts than one that is following a straight path. The rut formation for a curve is also significantly greater for the outside track than for the inside track (Liu et al. 2007). These ruts can concentrate the surface water flow, which increases the potential of erosion. Ruts not only cause severe environmental damages but also reduce the vehicle mobility. They damage vegetation, break up soil crusts, loosen surface soils, weaken soil aggregates, compact soils, and change soil surface geometry. These changes increase soil bulk density, reduce infiltration and hydraulic conductivity, increase runoff volumes, lengthen runoff periods, and accelerate soil erosion (Harmon and Doe 2001). Reduced infiltration and frictional resistance to flow on areas used by vehicles cause overland runoff to form more rapidly and attain an eroding discharge over a larger portion of a used hillslope than on an unused slope. Compacted soil restricts soil aeration, which impairs root growth, plant nutrient uptake, and seedling emergence (Gatto 2001).

Paths taken by military vehicles are typically determined by military doctrine, which results in certain areas such as stream crossings to have significantly higher traffic. Military trails have highly dynamic sediment regimes and trails with tracked ruts are more dynamic than wheeled ruts due to the intensity of soil disturbance in tracked ruts (Gatto 2001). Vehicle use on military installations is widespread and the majority of the vehicle movement occurs on trails and roadways. The military's heavy use of vehicles can significantly affect vegetation, exacerbate erosion levels, and contribute to environmental compliance issues on military bases (Svendsen et al. 2006).

Training land erosion produces hydrologic deterioration of watersheds that extend beyond installation boundaries. Erosion causes increased runoff and sediment transport, which creates even more erosion. Erosion factors increase exponentially as water advances to rivers; gullies on training areas can produce a large amount of sediment that is carried with the runoff and can damage off-site resources. Many installations have significant concerns over off-site sediment transport (Harmon and Doe 2001). Water flow originating on or flowing through installation lands is also subject to installation contaminants and the potential for producing off-site contamination (Harmon and Doe 2001).

The uses of the land as well as the land cover classification on Fort Riley greatly affect the erodibility of the land. An area that is used for training activities that involve tanks and maneuvering exercises are more likely to increase the area's erodibility than an area near a stream that is not used by the military for example. Urban areas contain impermeable surfaces, which causes overland flow and runoff that increases the erosion. The areas that are covered with vegetation are least likely to have erosion because their surfaces are more permeable and allow for more infiltration.

In addition to these factors, climate plays an important part in soil erosion. Temperature, rainfall amount and intensity, and storm frequency can have considerable impacts on land degradation (Lal 1994). The rainfall intensity affects soil erosion because the harder the rain falls, the higher the energy of the raindrops are, and the more easily the ground would be eroded, leading to soil degradation. The amount of storms affect the ability of the military to continue with their scheduled activities and the amount the soil is saturated. Because of these various factors, military training activities can lead to significant land degradation but can also be impeded by land degradation. The land degradation that causes gully formation can be remediated using Best Management Practices (BMPs).

Best Management Practices (BMP)

There are several ways to control or even alleviate nonpoint source pollution and these are collectively called Best Management Practices (BMPs). BMPs are designed to reduce the amount of pollutants that are created and/or transported from the source to the receiving water body. They can be structural (e.g. waste treatment lagoons), which use physical formations to alter hydrologic pathways; vegetative (e.g. grass waterways), which use plants with root systems that stabilize the soil as well as absorb and store water; or techniques (e.g. conservation tillage, nutrient management) that reduce negative impacts (Novotny 2003). Generally BMPs are used in combination to achieve maximum benefits from them. BMPs reduce nonpoint source pollution by reducing the available pollutants at the source, preventing the transport of pollutants, and remediating the area by chemical or biological means (Dressing 2003.). Guidance on the use of BMPs is provided by the USDA-NRCS.

Since nonpoint source pollution and soil erosion are interconnected, most BMPs tend to reduce erosion by reducing soil detachment, reducing sediment transport, and trapping sediment before it enters a water body (Dressing 2003.). BMPs also reduce the amount of water that reaches water bodies by increasing infiltration of water into the ground. Some BMPs increase retention time and reduce peak flow to reduce in-channel erosion. Many BMPs focus on agricultural or urban applications. While they can be applied in many different ways, there are some important differences between these practices and the practices needed for military installations.

For urban areas, BMPs such as surface basins, infiltration and exfiltration trenches, pervious pavement, and swales are typically used (Livingston 2000). Unlike BMPs that are suitable for the training areas on military installations, these practices focus on the impervious surfaces and limited space that are characteristic of an urban environment. Most BMPs focus on reducing water runoff and increasing soil infiltration, but for applications outside of urban areas tend to be more expansive in a spatial context.

For agricultural areas, BMPs such as terracing, contour farming, cover crops, buffer strips, stream fencing, brush management, and various management techniques are often used (NRCS 2010a; NRCS 2002; NRCS 2010b; NRCS 2010c; NRCS 2010d). The BMPs focus on reducing the negative impacts of agricultural activities, while retaining the land's productivity (Mostaghimi et al. 1997). While these practices focus primarily on agricultural land, many can be applied to military training areas.

To successfully employ these techniques on military installations, the major differences between military and agricultural practices must be taken into consideration. While agricultural areas experience a great deal of erosion due to farming and ranching practices, the majority of environmental problems on military installations are due to training activities (Liu et al. 2007). Military vehicles can be considerably heavier than farming equipment; and tracked vehicles can cause significant damage to vegetation and soil (Liu et al. 2007). These vehicles, with a turning radius that is much smaller than agricultural equipment, form deep ruts and have a much larger cumulative impact width (Ayers et al. 2005; Liu et al. 2007). While the movement of agricultural equipment is typically uniform across entire fields, the movement of military vehicles and personnel is governed by military doctrine. This results in distinctively different erosion patterns between agricultural and military practices.

Excessive erosion and sedimentation occur if proper erosion and sediment control practices are not installed and maintained. Conservation is the selection of erosion and sediment control practices that provide the desired control while allowing the desired land use (Toy et al. 2002). Erosion control practices are selected so that the site's soil and land resources are protected and can be used to control sediment delivery. Sediment control practices are applied specifically to control the amount, concentration, and size of sediment leaving the site. This sediment can cause downstream and downwind sedimentation as well as water and air quality degradation. Therefore, it needs to be taken into consideration. The best way to control erosion and protect the soil resource, is by reducing detachment because control of erosion by reducing local transport capacity is a selective process where erosion removes fine particles and causes an increase in coarse particles in the soil.

Erosion and sediment control practices can be classified as cultural management, supporting, and structural practices. Cultural management practices typically are agronomic practices where vegetation and soil management are used to control erosion (Toy et al. 2002). Examples include using plant litter for ground cover and applied ground cover materials. Supporting practices are applied along with cultural management practices. These often involve ridges and strips of vegetation oriented perpendicular to the direction of the runoff. Other examples include terraces, diversions, and subsurface drainage systems. Structural practices are located at specific points to control erosion by channel bed scour, headcuts in a permanent gully, or erosion on the outside bank of a stream bend (Toy et al. 2002). Examples of structural practices include windbreaks, fabric fences, and check dams.

Due to the diverse conditions found on military installations, the implementation of BMPs within these areas is unique. One important practice for military installations is the appropriate timing of training exercises. By avoiding times when the land is especially susceptible such as after a precipitation event when the soil is more easily compacted and vegetation is vulnerable, land degradation can be reduced.

To direct hydrologic flow, terraces, diversions, and dikes can be used to decrease erosion. These land-forming techniques can reduce soil erosion and nonpoint source pollution while taking up a small amount of the training area. Terraces, which are earthen embankments constructed across the slope, can reduce erosion by reducing water runoff and decreasing the slope length (NRCS 2010d). Diversions, which are channels constructed across the slope, can be used to break up water concentrations and divert surface flow away from eroding areas (NRCS 2010a). Dikes, which are earthen barriers, can be used to protect susceptible areas from excessive water flows and control water levels (NRCS 2002). On military installations, these structures could be applied around areas with high traffic flow, where soil compaction is greatest. Compacted ruts formed by military vehicles cause water runoff to concentrate, which leads to increased sediment transport capacity (Gatto 2001). By redirecting the hydrologic flow path, runoff concentration can be reduced and increased erosion can be prevented.

The maintenance of vegetative cover is also important for preventing excessive erosion. A method that could be applied to military rangeland is the use of vegetative barriers. Strips of stiff, dense vegetation are planted along the overall contour of the terrain or across concentrated flow areas to manage water problems (NRCS 2010b). This practice can be used to reduce sheet, rill, and ephemeral gully erosion, trap sediment, and stabilize steep slopes. On military installations, vegetative barriers could be placed along stream banks to minimize the loss of valuable training areas, while reducing the amount of sediment that enters the streams. Critical Area Planting is another vegetative BMP that can help reduce erosion. By establishing permanent vegetation such as trees, shrubs, vines, grasses, or legumes, this practice can stabilize areas with high levels of soil erosion (NRCS 2010c). This technique is useful for areas that have had significant land degradation from military training exercises. By re-establishing the vegetation at vital locations within a training area, environmental impacts can be reduced. The increased vegetation would result in reduced erosion through the reduction of the impact of rainfall energy and sedimentation through the entrapment of particles within the vegetative cover.

BMPs such as field borders or filter strips that trap sediment leaving the field before it reaches a wetland or riparian area could also be implemented. Field borders are strips of perennial vegetation established at the edge of a field by planting or by converting it from trees to herbaceous vegetation or shrubs (Dressing 2003.). Field borders could be successfully implemented without compromising large portions of the training areas. Filter strips are strips or areas of vegetation for removing sediment, organic matter, and other pollutants from runoff and wastewater (Dressing 2003.). These could also be used without creating a large hindrance to military training activities.

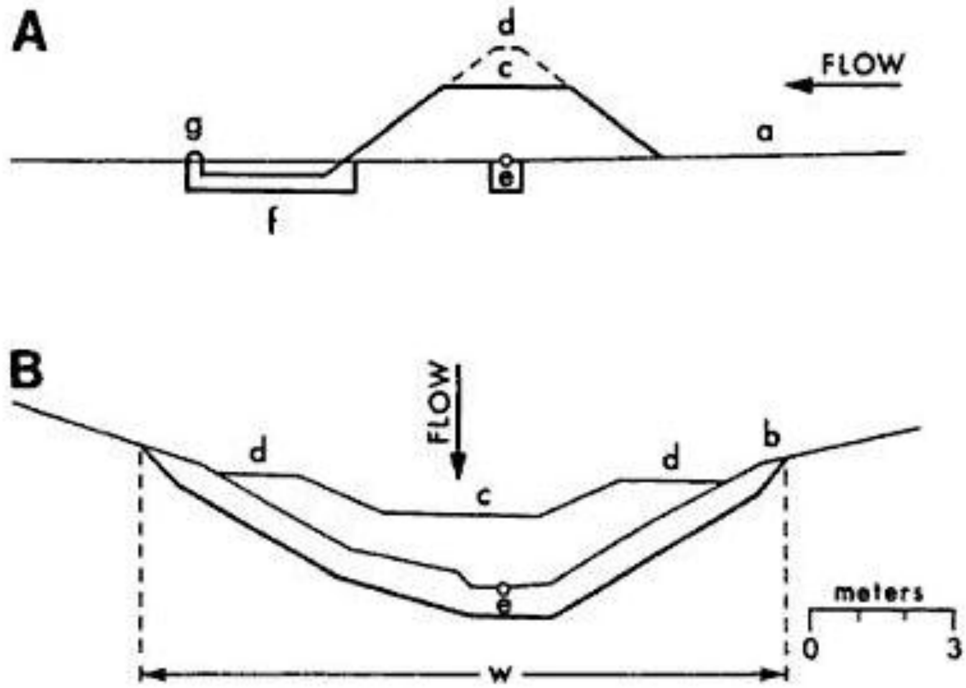
A check dam is a barrier placed in an actively eroding gully to trap sediment carried down the gully during periodic flow events (Ffolliott et al. 2003). Sediment backed up behind the check dam develops a new channel bottom with a gentler gradient than the original gully bottom and therefore reduces the velocity and erosive force of gully flow; stabilizes the side slopes of the gully and encourages their adjustment to their natural angle of repose, which reduces further erosion of the channel banks; promotes the establishment of vegetation on the gully slopes and bottom; and stores soil water so that the water table can be raised, which enhances vegetative growth outside the gully (Ffolliott et al. 2003).

There are two types of check dams: nonporous dams (without weep holes) and porous dams that release part of the flow through the structure. A weep hole is a porous material located in an otherwise impermeable structure that allows water to seep through and drain the structure (Ffolliott et al. 2003). Nonporous dams, such as those built from concrete, sheet metal, wet masonry, or earth, receive heavy impact from the hydrostatic forces of gully flow. Earthen dams should only be used for gully control in exceptional cases, but if they are constructed at the gully mouth, also known as gully plugs, then they can be effective in areas where the watershed can be revegetated quickly and where the storage upstream from the plug is adequate for larger stormflow containment (Ffolliott et al. 2003). Porous dams transmit less pressure to the banks of gullies. Because gullies generally form in erodible, soft soils, constructing porous dams is easier, cheaper, and often more effective (Ffolliott et al. 2003). Porous dams can be constructed from old car tires, logs, brush, and many different materials.

The cross section of a check dam can be seen in Figure 2.5. The purpose of check dams is to stabilize the gully bottom to prevent further downcutting and subsequent headcutting and extension of the gully. Each dam should be spaced upstream at the toe of the expected sediment wedge formed by the dam below. The first dam should be constructed where downcutting does not occur. The spacing of subsequent dams constructed upstream from the base dam depends on the gradient of the gully floor, the gradient of the sediment wedges deposited upstream of the dams, and the effective height of the dams as measured from the gully floor to the bottom of the spillway (Ffolliott et al. 2003). Equations have been developed to determine the spacing of these dams, but are not always accurate. Therefore, field measurements and individual site characteristics such as nickpoints should be used to determine where check dams are installed. Nickpoints are areas where an abrupt change of elevation and slope gradient and a lack of protective vegetative cover occur.

Long-term impacts of installing check dams and deep subsoil ripping can significantly reduce sediment erosion in highly erodible areas. Amount of reduction in a case study at Fort Hood was 7% but was dependent on the extent of implementation. By implementing these practices over a larger area, a greater reduction in sediment loading is possible (Rosenthal et al. 2003). Through proper maintenance such as the removal and disposal of the entrapped sediment, check dams and subsoil ripping are effective in reducing sediment loads. This BMP combination, however, does not reduce soil erosion and gully formation.

Figure 2.5 Cross section of a check dam (Ffolliott et al. 2003)



A: section of the dam parallel to the centerline of the gully; B: section of the dam at the cross section of the gully. a = original gully bottom, b = original gully cross section, c = spillway, d = crest of freeboard, e = excavation for anchoring key, f = apron, g = end sill, w = width of bank (Ffolliott et al. 2003)

Another practice that could be used is imprinting. When land is disturbed by activities that strip vegetation from the land surface, a secondary succession of plant types follows, usually beginning with short lived annuals and ending with perennials. The speed and direction of this secondary succession can be controlled to achieve desired results, but the process occurs naturally and is often quite slow, taking decades, centuries, and even millennia depending on the degree of land disturbance, soil type, and climate (Dixon and Carr 2001). Land imprinting was developed to accelerate the secondary succession toward a productive and sustainable ecosystem. This is done by impressing seedbeds and seedling cradles that become moist enough to germinate and establish the seeds of perennial species even in severely degraded soils. With the use of these imprints, infiltration is rapid and moisture penetration is deep, which provides the moisture required to germinate and establish the seeds (Dixon and Carr 2001).

The establishment of a brush head plug will work to stabilize the headcut if it is shallow and narrow. This is done by laying brushwood onto the headcut bottom, starting at the highest point and proceeding downstream towards the gully channel itself (Dvořák and Novák 1994). The thick ends of the brushwood are stuck into the bottom, the thin end is left to point against the slope of the headcut. The layer of brushwood is fixed to the ground using poles nailed to stakes and stones are put on top to provide additional weight (Dvořák and Novák 1994). This works to slow the flow velocity and trap a portion of the sediment flowing through the gully.

Where a vegetative cover can be established, channel gradients can sometimes be stabilized without using mechanical or engineering measures. However, vegetation alone can rarely stabilize headcuts because of the concentrated flow that occurs at these locations (Ffolliott et al. 2003). Vegetation types that grow rapidly and establish a high plant density and dense root systems are most effective at stabilizing gullies. Tall grasses that lie down on the gully bottom under flow conditions provide a smooth interface between the flow and original gully bed and can increase flow velocities; these plants are not suitable for gully stabilization (Ffolliott et al. 2003). The higher flow velocities can widen the gully even though the gully bottom is protected.

Trees and shrubs can restrict high flow volumes and velocities and cause diversion against the bank. Where diverted flows are concentrated, new gullies can develop and new headcuts can form where the flow reenters the original gully (Ffolliott et al. 2003). However, on low gradients and in wide gullies, trees and shrubs can be planted, especially at the mouth of the gully, to form live dams to build up sediment deposits by reducing flow velocities. If climate or site conditions do not permit the establishment of vegetation, mechanical measures or control structures are required to stabilize the gully (Ffolliott et al. 2003). To remediate land and eliminate gullies, structures are usually required at critical locations such as nickpoints on the gully bed, headcuts, and gully reaches close to the gully mouth. At the gully mouth, changes in flow cause frequent changes in deepening, widening, and deposition (Ffolliott et al. 2003). As expected, different rain events cause different rates of erosion.

An effective control structure design must help vegetation to become established and survive. Once the gully gradient is stabilized, vegetation can become established on the gully bottom, which leads to the stabilization of the banks (Ffolliott et al. 2003). Vegetation can be established rapidly if substantial deposits of sediment accumulate in the gully above control structures. Such deposits can store moisture and decrease channel gradients. The net effect of vegetation establishment in the channel and reduced channel gradient is a decrease in peak discharge (Ffolliott et al. 2003). Most often, mechanical treatments are needed to provide the short-term stability necessary for vegetation establishment. Other considerations such as soil type, rate of sedimentation, hydraulics, and the logistics needed to manage a watershed also enter into the development of a solution (Ffolliott et al. 2003). For example, if gullies are large, the construction of large dams across the gullies to accumulate sufficient sediment is necessary to allow equipment to move across the gully. Large check dams may be undesirable or uneconomical. Other mechanical or structural controls must then be considered.

All of these BMPs are important, and their correct implementation across the landscape can help reduce runoff and soil erosion. Maintenance of the vegetation across susceptible areas is of vital importance to achieve significant positive impacts. By dissipating the erosive force of water runoff, vegetation can significantly decrease nonpoint source pollution. Additionally, the root structure of the vegetation can help increase the infiltration of rainfall into the soil and can lead to increased retention times as well. Also extremely important for areas that are susceptible to erosion is the placement of appropriate structures, including terraces, dikes, and diversions, that can improve hydrologic flow.

BMPs are not only efficient in reducing runoff and erosion while improving water quality but are also cost effective (as shown in Table 2.5). BMPs that require smaller construction such as diversions are cheaper than ones that require more work such as terraces and waterways. However, the BMPs would be well worth the money spent because they would improve land and water quality by reducing runoff, erosion, and sedimentation.

While the timing of training exercises can aid in improving the conditions of vegetation and soil, the need for quality training may make it difficult to avoid military exercises at times when the land is more susceptible to degradation. The erosive processes should be monitored and studied to determine the factors that cause erosion, which would help determine the best approach to achieve remediation.

Table 2.5 Representative Costs of Selected Erosion Control Practices (Dressing 2003.)

Practice	Unit	Range of Capital Costs	References
Diversions	ft	1.97-5.51	Sanders et al., 1991 Smolen and Humenik, 1989
Terraces	ft a.s.[2]	3.32-14.79 24.15-66.77	Smolen and Humenik, 1989 Russell and Christiansen, 1984
Waterways	ft ac a.e.[3]	5.88-8.87 113-4257 1250-2174	Sanders et al., 1991 Barbarika, 1987; NCAES, 1982; Smolen and Humenik, 1989 Russell and Christiansen, 1984
Permanent Vegetative Cover	ac	69-270	Barbarika, 1987; Russell and Christiansen, 1984; Sanders et al., 1991; Smolen and Humenik, 1989
Conservation Tillage	ac	9.50-63.35	NCAES, 1982; Russell and Christiansen, 1984; Smolen and Humenik, 1989

1 Reported costs inflated to 1998 dollars by the ratio of indices of prices paid by farmers for all production items, 1991=100

2 acre served

3 acre established

[Note: 1991 dollars from CZARA were adjusted by +15%, based on ratio of 1998 Prices Paid by Farmers/1991 Prices Paid by Farmers, according to USDA National Agricultural Statistics Service, http://www.usda.gov/nass/sources.htm, 28 September, 1998]

Erosion Monitoring Methods

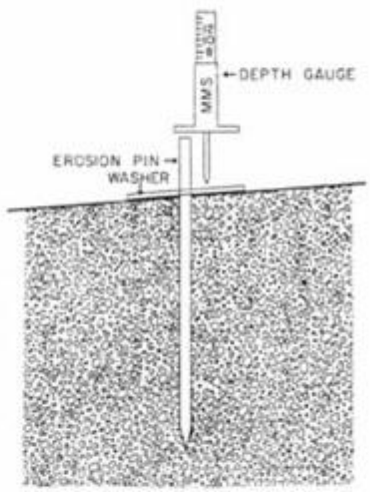
It has been shown that certain parameters such as the particle size distribution, slope steepness, and slope length may greatly affect the rate of erosion, but this is not clear cut (Charlton 2008). To determine the factors that impact the rate of erosion, more data is needed.

To gather this data, erosion must be monitored over a long period of time. Conventional field erosion monitoring methods are generally manual and include erosion pins, cross-section resurveys, or terrestrial photogrammetry. These reveal net change in the position of a bank or gully surface since the previous measurement. Several cautions are given in connection with measuring gully erosion including: gully erosion is likely to be highly variable depending on geomorphic characteristics such as soils, slope, cover, climatic variability, and land use; changes in prevailing cultural practices are likely to make estimates from samples across the landscape unreliable predictors of current erosion rates; changes in susceptibility to erosion with vegetative stage and stochastic variability of erosive precipitation necessitate the collection of erosion data from many storms over several years to develop reliable estimates; and projections of data from one climatic region to another is inadvisable (Boardman and Favis-Mortlock 1998). Measurements done in the field generally have fewer errors and produce necessary data to understanding gully erosion.

A common method researchers use to determine gully measurements and their changes over time is erosion pins. Erosion pins are used by driving a pin into the soil so that the top of the pin gives a datum from which changes in the soil surface level can be measured (Hudson 1993). These pins can be made of any material that will not rot or decay and is readily and cheaply available. The pin should be a length that can be driven into the soil to give a firm stable datum, while they should also be thin enough to not interfere with the surface flow and cause scour. An example of an erosion pin is shown in Figure 2.6.

Some researchers use metal washers over the pin to give a better base to measure from. The washer method, if employed in a place such as a gully floor, may give useful information by falling to the lowest erosion level and being covered by any later deposition (Hudson 1993). However, the presence of the washer may cause turbulence and scour, or it could reduce splash erosion and leave the washer sitting on a pedestal of soil (Hudson 1993). These pins do not directly measure erosion but measure the changes in ground surface elevation. This can be affected by changes in soil moisture content, frost action, and changes in soil density so they should not be measured between October and March (Haigh 2000). To prevent miscalculations, the pins should extend below the frost line in the soil so that they are not lifted by frost heave. This linear measurement of erosion or the change of depth in the surface elevation can be converted to a mass measurement by multiplying it by the soil bulk density (Toy et al. 2002).

Figure 2.6 Example of Erosion Pins (Hudson 1993)



Pins were not inserted into the gully head because they would affect the erosion occurring at those spots and cause erroneous results. If they were inserted too close to the gully head, they would get washed away as the gully head migrated upstream. This would not only make it impossible to determine where the gully head was previously located, but would also cause problems downstream because of the amount of erosion the pin would cause when it hit the various surfaces of the gully.

Measurements related to the exposure of the installed pins are taken, especially after large rain events, to monitor gully migration and evolution. The measurements are taken with the bottom of the rebar caps, used to protect vehicles and personnel from being injured by the rebar, as the beginning point or datum from which to base future growth measurements. Figure 2.7 shows what the rebar caps used look like. The ones used in the study are bright orange, so that they can help locate the pin locations along with the GPS coordinates that are recorded. The caps are also made of plastic, so that they will last a long time and are cost effective. These measurements compare the amount of each pin exposed using new measurements such as the width and depth with the measurements taken previously. The reference pins will show the extent of erosion because they can be used to determine the amount that the gully head has migrated, which will allow us to determine how quickly a gully is eroding. An approximation of the amount of soil eroded by gully erosion can be done by measuring the size of the gully's volume and correlating it with the bulk density of the soil.

Figure 2.7 Rebar Caps Used

Gully erosion is generally measured by the increase in the volume of the gully over time, especially the retreat of the headwall. By complementing the measurements with further analyses, a good idea of the development of gully erosion can be obtained. With this, the factors which are important can be identified for more accurate erosion control recommendations. Further analyses and repeated measurements of gully dimensions may help determine the development of the erosion curve, the intensity of erosion, and various other important factors.

Erosion measurements are central to the study of erosion. Studies of erosion mechanics, interrelationships among erosion processes, and relationships between erosion processes and environmental conditions are based on erosion measurements. The development of erosion prediction technologies requires erosion measurements. The development and evaluation of erosion control practices also rely on erosion measurements. Without erosion measurements from the site, no new data involving erosion would be found or describe the erosion processes on the site accurately. Measurements should also be made of the site characteristics that influence erosion and sedimentation such as weather and climate; soil properties; topography; vegetation; and land management, including the types and intensities of land-disturbing activities. All of this information describes the environmental setting in which erosion and sedimentation occur and is required for selecting erosion measurement techniques, explaining the variability of erosion rates, developing and applying erosion prediction technologies, and designing conservation and reclamation plans.

Erosion measurements should be taken at intervals ranging from a single rainstorm event to many years. Years of data are used to design erosion and sediment control practices. Research of erosion can be very difficult for several reasons, but particularly because it is an intermittent process and is extremely difficult to observe, so in most cases only the consequences of erosion are investigated. Erosion varies from season to season and identification of high and low erosion-hazard periods can be used in scheduling land disturbances and installing erosion control practices. Another difficulty in researching erosion is the fact that erosion does not occur as an isolated phenomenon, but takes place together with other factors (Zachar 1982).

Logistic Regression

Generalized linear models are used for responses such as logistic regression, which produces categorical response data (Agresti 2002). Logistic Regression is a statistical model that predicts when the target variable is a categorical variable with two categories. In this case, our two categories are gully or no gully based on the potential of a gully forming. Using logistic regression is beneficial because predictor variables can be numerical or categorical (Agresti 2002).

The logistic function, shown in Equation 1, uses z to represent the exposure to a set of independent variables and produces the probability of a particular outcome (Agresti 2002). The variable *z* is a measure of the total contribution of all the independent variables

Equation 1 Logistic Function

$$f(z) = \frac{e^z}{e^z + 1} = \frac{1}{1 + e^{-z}}$$

used in the model and is known as the logit. This is defined in Equation 2, where β_0 is the intercept and β_1, β_2, β_3, and so on, are the regression coefficients (Agresti 2002). The intercept is the value of z when the value of all the independent variables is zero. Each of the regression

Equation 2 Logit Function

$$z = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_k x_k$$

coefficients describe the size of the contribution of that risk factor. A positive regression coefficient means that the variable increases the probability of the outcome, while a negative regression coefficient decreases the probability (Agresti 2002). The simplified version of the model is shown in Equation 3 where p is the probability that the

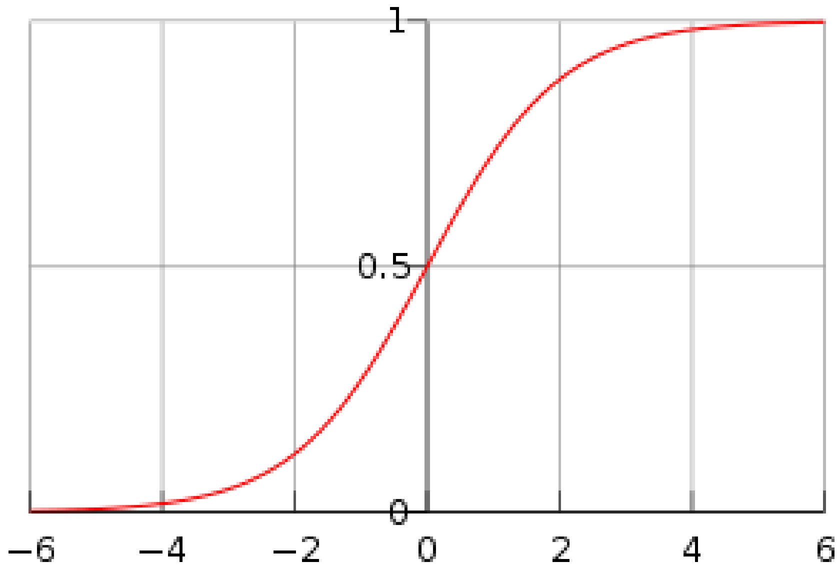
Equation 3 Simplified Regression Function

$$\log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k$$

outcome does occur (or is equal to 1). The logistic function's graph is shown in Figure 2.8, where z is on the horizontal axis and $f(z)$ is on the vertical axis. The logistic regression is extremely useful because it can take any value as an input from negative infinity to positive infinity, whereas the output is confined to values between 0 and 1 (Agresti 2002).

Logistic regression efficiency is sample size dependent, so a minimum of ten events per independent variable is strongly recommended. It varies from linear regression because it does not assume that the relationship between the independent variables and the dependent variable is a linear one. It also does not assume that the dependent variable or the error terms are normally distributed. Logistic regressions work with odds rather than proportions (Agresti 2002).

Figure 2.8 Graph of the Logistic Function



Not only will using logistic regression help predict where gullies occur on Fort Riley, but it will also help determine the factors that contribute to gully and the amount that each of these factors affect gully formation.

Regression Software

XLSTAT (Version Pro 2011, Addinsoft, Paris, France) is a statistical analysis add –in for Microsoft Excel developed by Addinsoft. Addinsoft is a privately-owned company managed by Thierry Fahmy, a PhD in Statistics (Addinsoft 2011). It was designed to help users gain time by eliminating the complicated and risky data transfers between applications that had been a requisite for previous data analysis (Addinsoft 2011). It was chosen for this project because it is easy to install and use (Addinsoft 2011).

It allows the user to run the logistic regression on raw data or aggregated data. Using a datasheet in excel, information can be entered and used in the logistic regression. Not only does the model output the response, but it also provides model parameters, goodness of fit statistics, and a test of the null hypothesis (Addinsoft 2011). The model parameters provide the influence of each variable on the response. It also shows the standard error. The goodness of fit statistics provides an analysis of variance and how well the model applies.

The likelihood-ratio test uses the ratio of the maximized value of the likelihood function for the full model (L_1) over the maximized value of the likelihood function for the simpler model (L_0) (Anonymous 2002). The likelihood ratio test statistic is shown in Equation 4. The log transformation yields a chi-squared statistic and is used to test a model's goodness of fit as well as a variable's significance (Anonymous 2002).

Equation 4 Likelihood Ratio Test

$$-2\log\left(\frac{L_0}{L_1}\right) = -2[\log(L_0) - \log(L_1)] = -2(L_0 - L_1)$$

A Wald test is used to test the statistical significance of each coefficient in the model by Equation 4. The z value obtained is then squared, which yields a Wald statistic with another chi-square distribution (Anonymous 2002). This is another test for goodness of fit. However, it is known to be overly conservative, which is why XLSTAT program returns several tests to determine goodness of fit.

Equation 5 Wald Statistic Equation (Anonymous 2002)

$$z = \frac{\hat{\mathrm{B}}}{SE}$$

The measures to simulate the R-squared analysis give an approximate variance in the outcome of an equation. These are used to determine the goodness of fit for the equation and are based on the ordinary least squares equation. The pseudo-R^2 formulas output from XLSTAT are McFadden, Cox and Snell, and Nagelkerke. They all use full models, which use predictors, and intercept models, which do not use predictors. In each formula, L is the estimated likelihood(Statistical Consulting Services n.d.).

McFadden's uses a ratio of the log of likelihood of the intercept model treated as a total sum of squares over the log of the full model treated as the sum of squared errors as seen in equation 6 (Statistical Consulting Services n.d.). Here, if a model has a very low likelihood, then the log of the likelihood will have a larger magnitude than the log of a more likely model (Statistical Consulting Services n.d.). However, since the likelihood falls between 0 and 1, the log of a likelihood is less than or equal to zero.

Equation 6 McFadden's R^2 (Statistical Consulting Services n.d.)

$$R^2 = 1 - \frac{\ln \hat{L}(M_{Full})}{\ln \hat{L}(M_{Intercept})}$$

Cox and Snell uses a ratio of the likelihoods to reflect the improvement of the full model over the intercept model (Statistical Consulting Services n.d.). It takes the Nth root of the product, where N is the number of observations in the dataset (Statistical Consulting Services n.d.). The pseudo R squared is shown in equation 7. The pseudo R-squared has a value of just less than one if the model predicts the outcome perfectly. If not, the value is less than one (Statistical Consulting Services n.d.).

Equation 7 Cox and Snell's R^2 (Statistical Consulting Services n.d.)

$$R^2 = 1 - \left\{ \frac{L(M_{Intercept})}{L(M_{Full})} \right\}^{2/N}$$

Nagelkerke adjusts the Cox and Snell R-squared so that the range of possible values extends to 1. Nagelkerke's R-squared equation, shown in equation 8, divides the Cox and Snell value by its maximum possible value (Statistical Consulting Services n.d.).

Equation 8 Nagelkerke's R^2 (Statistical Consulting Services n.d.)

$$R^2 = \frac{1 - \left\{ \frac{L(M_{Intercept})}{L(M_{Full})} \right\}^{2/N}}{1 - L(M_{Intercept})^{2/N}}$$

Provided with these various pseudo R-squared values, the quality of the model will be determined accurately because of the various models being compared that are provided in the goodness of fit statistics that is present in the output.

Research Objectives

Many studies have been conducted to gain a better understanding of the location, formation, and migration of gullies (Casali et al. 2000; Smith 1993; Foster 1986.; Hanson et al. 1997; Parkner et al. 2006; Gatto 2001; Chancellor 1977; Wang et al. 2003; Wells et al. 2009)and how to best model these erosional features (Boardman and Favis-Mortlock 1998; Gordon et al. 2007; Marzolff and Poesen 2009; Betts et al. 2003). The majority of these studies focus on either natural (Parkner et al. 2006; Marzolff and Poesen 2009; Thurow 1991; Betts et al. 2003) or agricultural (Smith 1993; Gatto 2001; Chancellor 1977; Mostaghimi et al. 1997) landscapes with no work on the specific problem of military maneuvers and gully formation. The overall goal of this study is to locate and assess gullies on Fort Riley training areas. This information will determine factors that cause the formation of gullies and locate areas vulnerable to gully formation.

CHAPTER 3 - Methods and Materials

Description of Site

Location and Topography

Fort Riley is a United States military base located in Northeast Kansas (39°11'N, 96°48'W), on the Kansas River, between Junction City and Manhattan within Geary, Riley, and Clay counties (Figure 3.1). The total installation area is 41,128 hectares and is located within the Flint Hills ecoregion (Bailey 1995), which consists of over 1.6 million hectares of the largest, undisturbed tall-grass prairie in North America (Figure 3.2). This region covers the majority of east central Kansas from near the Kansas-Nebraska border and extends into northeastern Oklahoma. More specifically, according to the USDA's Land Resource Region divisions, Fort Riley is part of the Great Plains Winter Wheat and Range Soil Resource Region.

Fort Riley consists of three physiographic types: High upland prairies, alluvial bottomland flood plains, and broken and hilly transition zones. The high upland prairies have alternating layers of gently sloping (less than one degree) Permian limestone and shale. The uplands often contain various shale types that cover the escarpment-forming limestones. The stream cuts on the thick shale units have sculpted much of the area into a rolling plateau. Two types of alluvial bottomlands occur on Fort Riley. One contains wide floodplains of major rivers with associated terraces, while the other is created by smaller creeks and streams that cut the uplands. The transitional areas between the upland prairies and stream networks are composed of alternating limestones and shales (U.S. Department of Agriculture-Soil Conservation Service 1975).

The elevation of Fort Riley ranges from 312 to 420 meters above mean sea level according to the three meter digital elevation model (DEM), with the highest elevations located along a north-south axis through the center of the installation and generally decreasing towards the southwest and southeast directions (Figure 3.3). The average slope is 4.1% with a standard deviation of 4.6. The highest slope values occur in the south and east parts of the base, mainly near the bottomlands (Figure 3.4). The aspect map of Fort Riley shows varying topography

Figure 3.1 Location of Fort Riley and surrounding areas (Data Sources: U.S. Census Bureau 2000 and U.S. Geological Survey 2010)

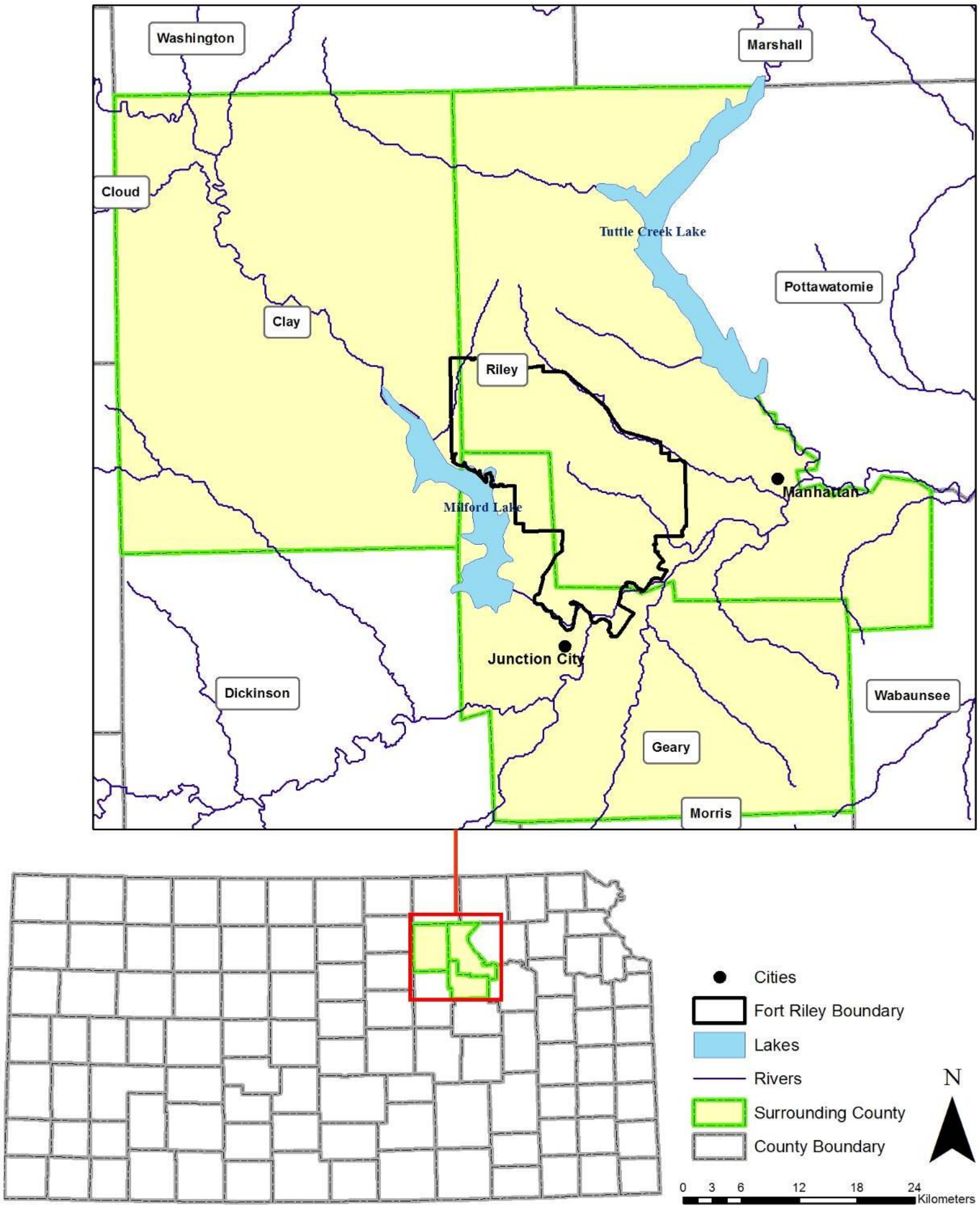


Figure 3.2 Kansas Ecoregion Map (Data Source: U.S. Environmental Protection Agency 2003 and U.S. Census Bureau 2000)

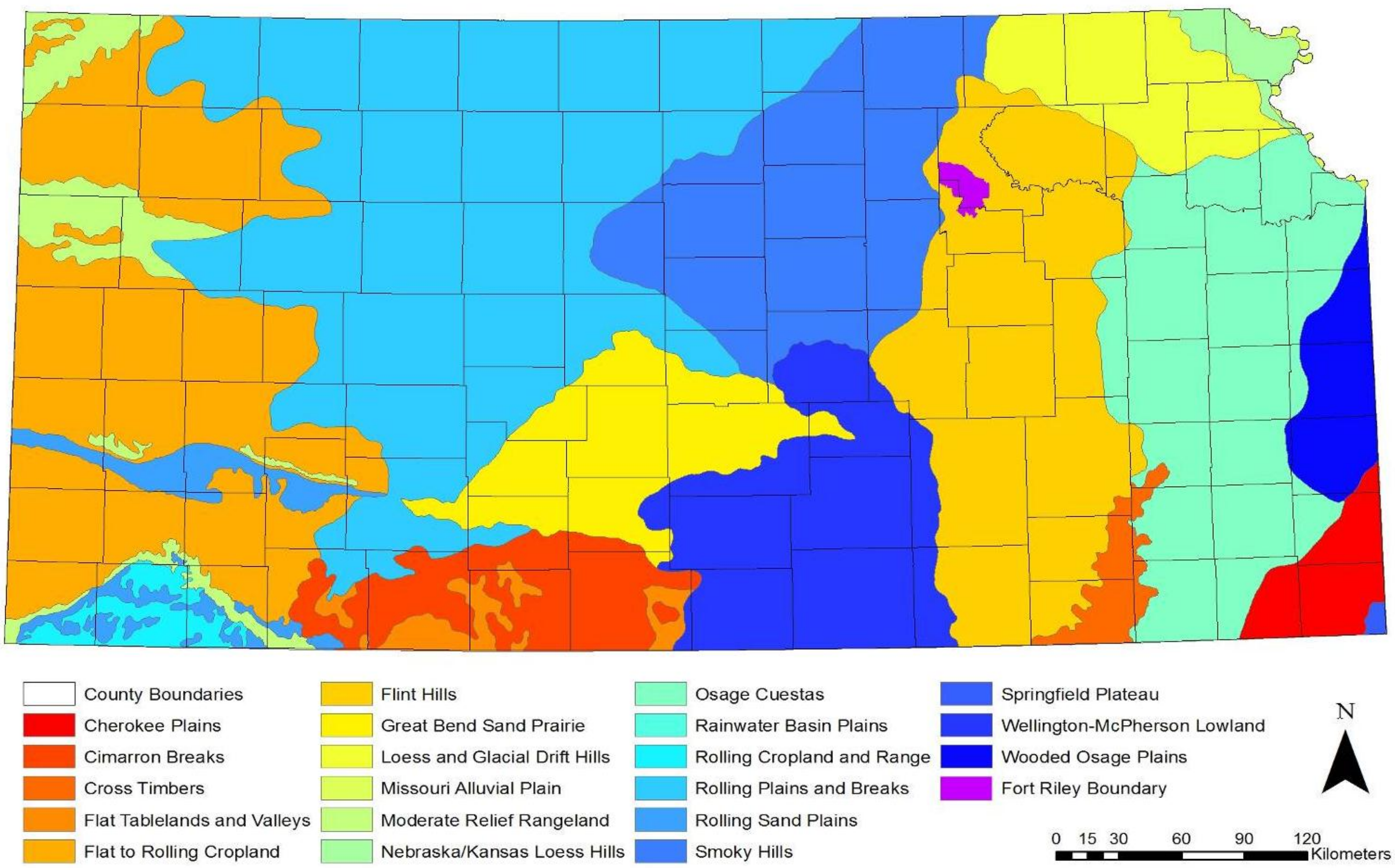


Figure 3.3 Elevation map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Area Management Program 2007)

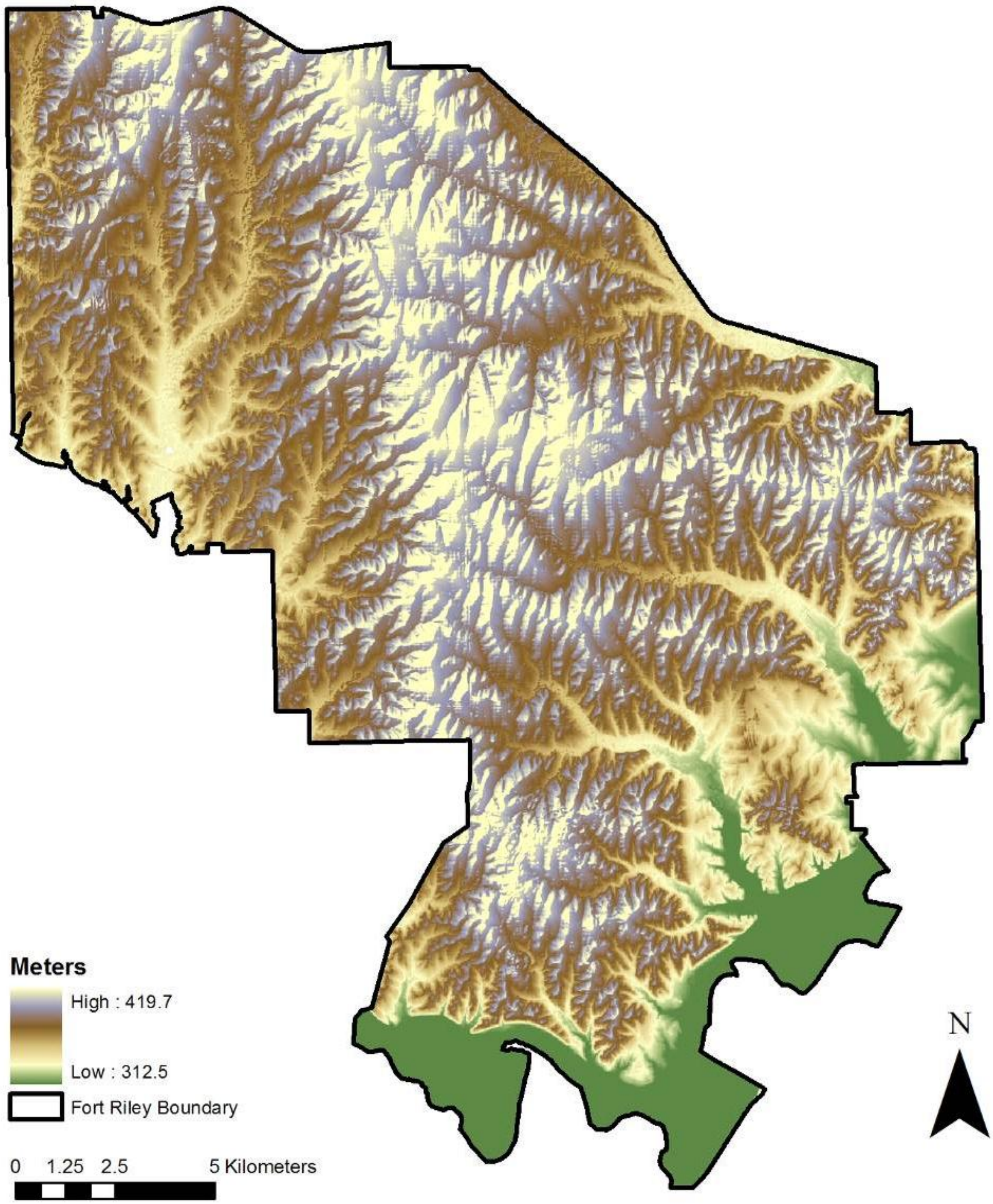


Figure 3.4 Map of the slope on Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Area Management Program 2007)

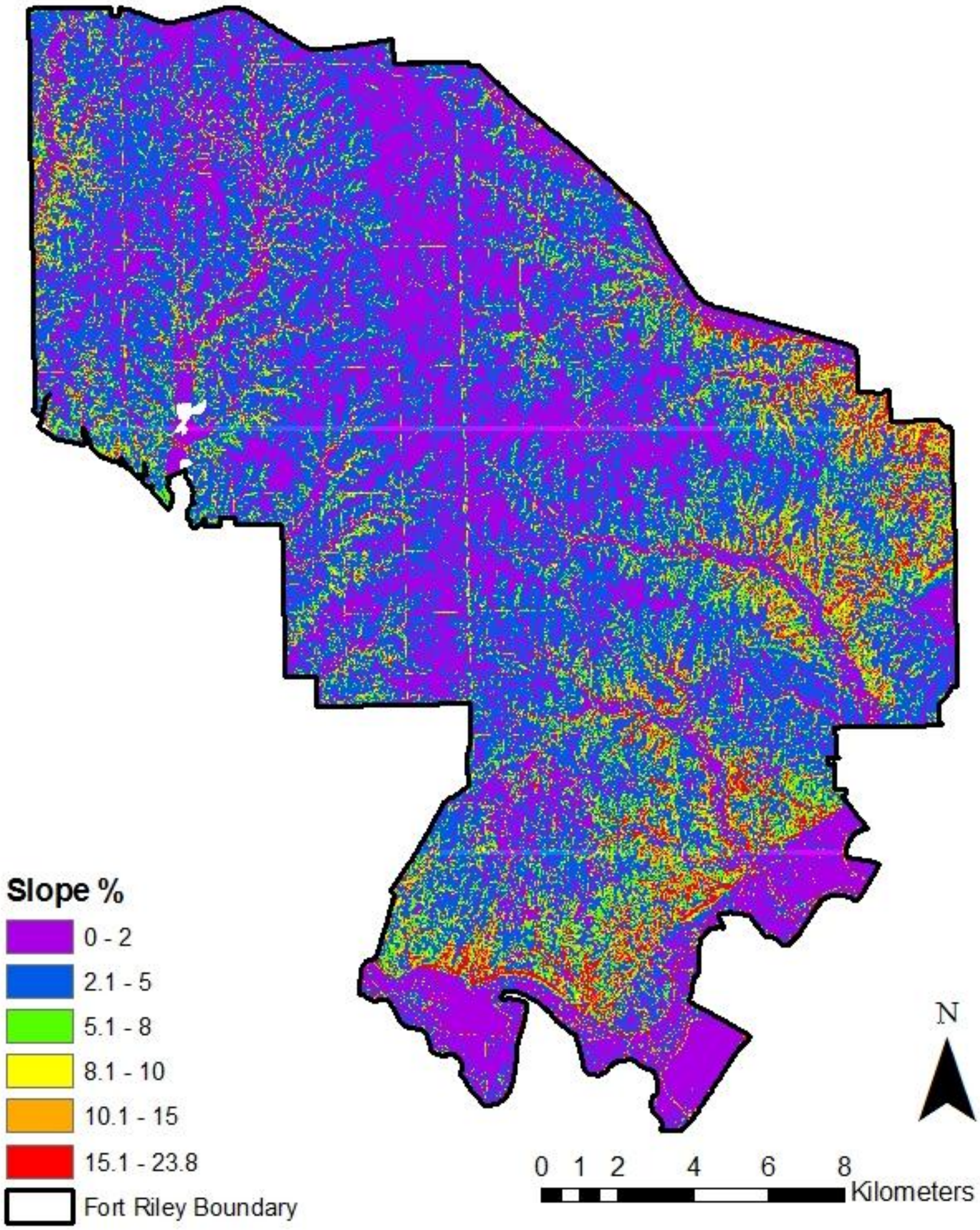
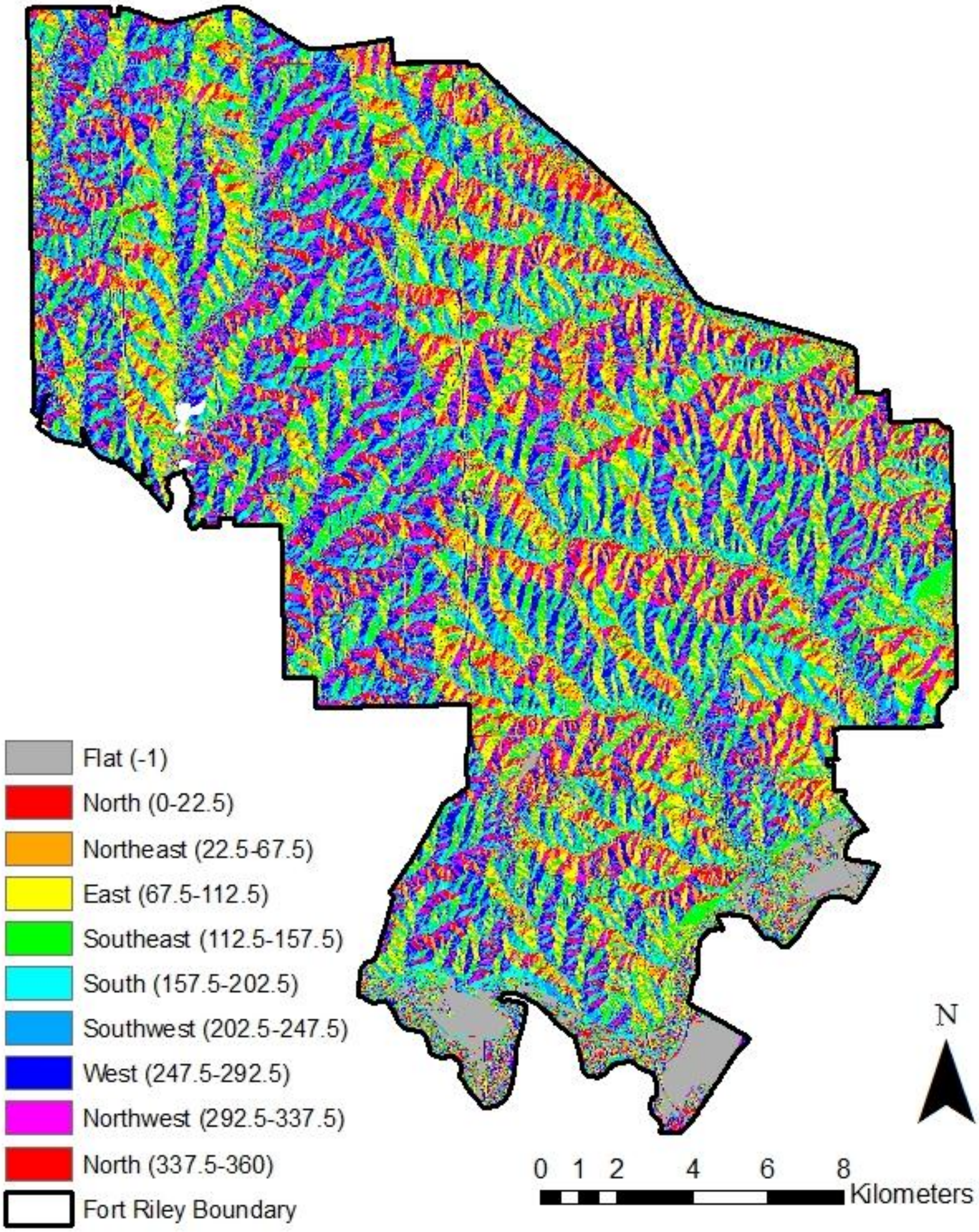


Figure 3.5 Map of aspect on Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Area Management Program 2007)

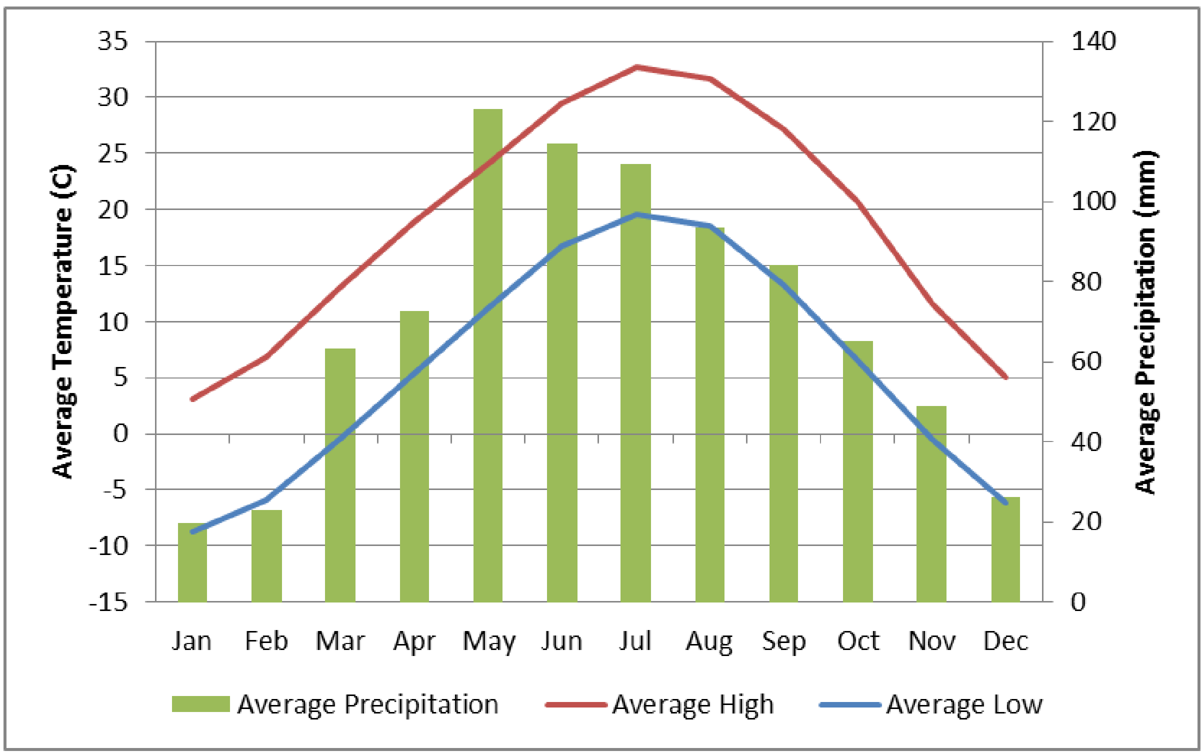


with the east part of the base exhibiting more east facing slopes, while the west part exhibits more west facing slopes (Figure 3.5). The study area contains 11 HUC classified watersheds that empty into the Kansas River.

Climate and Soil

Fort Riley's climate is generally considered a temperate continental climate. It has high variability in its weather and is characterized by hot summers, cold, dry winters, moderate winds, low humidity, and a pronounced peak in rainfall late in the spring and in the first half of summer and is far enough away from any water body that could act as a buffer between the atmosphere and the Earth. Average monthly temperatures range from approximately -3°C in January to 26°C in July (PRISM Climate Group 2011). Mean annual precipitation is approximately 843 mm with75% of precipitation occurring during the growing season and extreme variability from year to year (Figure 3.6). Most of the rainfall arises from thunderstorms, which typically have intense rainfall rates of approximately 60 mm/hr ()and occur approximately 55 days each year in this area (U.S. Department of Agriculture-Soil Conservation Service 1975; Knapp 1998).

Figure 3.6 Climograph for Manhattan, Kansas based on monthly average temperature and precipitation data for the period 1971-2000 (PRISM Climate Group 2011)

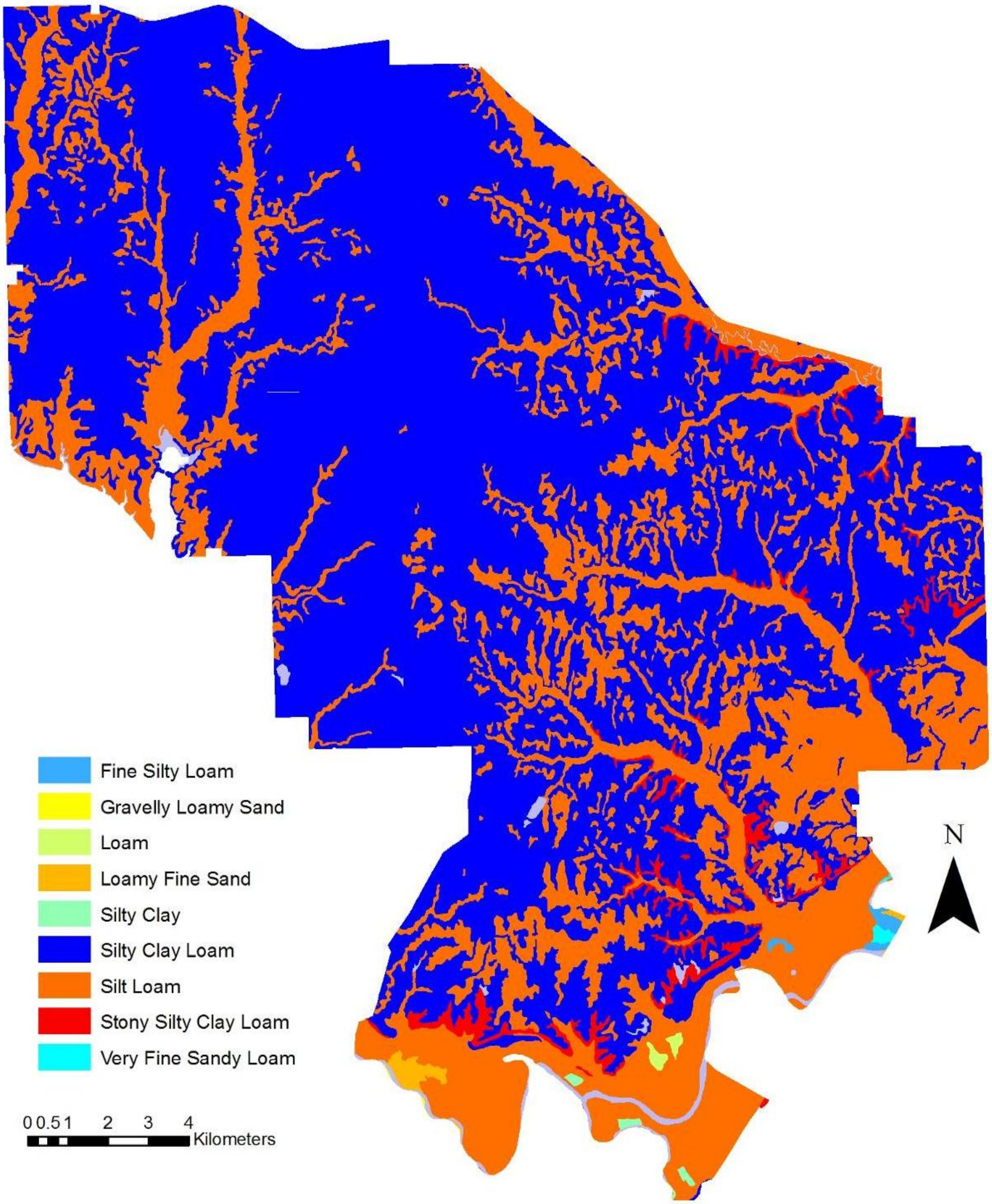


The area is covered with 0.3 meters or less of windblown material or loess, where the loess rests upon alternating layers of limestone and shale. Most of the soils are friable, overlying nearly impervious clays and were developed residually from parent materials and/or from other materials carried by water or wind and deposited on the base. Soil permeability varies from excessively drained sandy lowland soils to tight clays with very slow permeability. Bedrock depths under these soils vary from less than 0.3 meters in upland areas to twelve to eighteen meters in other areas. The USDA National Resources Conservation Service (NRCS) mapped thirty-six soil series on Fort Riley and categorized them taxonomically into six soil associations in 1996. Figure 3.7 shows a simplified soil type map of Fort Riley (U.S. Department of Agriculture-Natural Resources Conservation Service 1996). Simplified soil classifications show that the majority of the soil is a clay upland that is combined with loamy uplands, limy soils, and loamy lowlands (Table 3.1). Loamy terraces, sands, sandy lowlands, claypans, and miscellaneous soil types are also included, but only account for a small portion of the base.

Table 3.1 Soil Types based on simplified classifications by NRCS (U.S. Department of Agriculture-Natural Resources Conservation Service 1996)

Soil Type	Area (hectares)	Area (%)
Clay Upland	16259.8	39.5%
Loamy Upland	10112.5	24.6%
Limy Soils	7269.8	17.7%
Loamy Lowland	4498.4	15.7%
Loamy Terrace	497.9	1.2%
Sands	88.1	0.2%
Sandy Lowlands	50.0	0.1%
Claypan	22.5	0.1%
Miscellaneous	353.6	0.9%

Figure 3.7 Simplified Soils Map of Fort Riley based on soil classification data from Natural Resources Conservation Service (Data Source: SSURGO 2002)


Fine Silty Loam
Gravelly Loamy Sand
Loam
Loamy Fine Sand
Silty Clay
Silty Clay Loam
Silt Loam
Stony Silty Clay Loam
Very Fine Sandy Loam
0 0.5 1 2 3 4
Kilometers
N

Vegetation

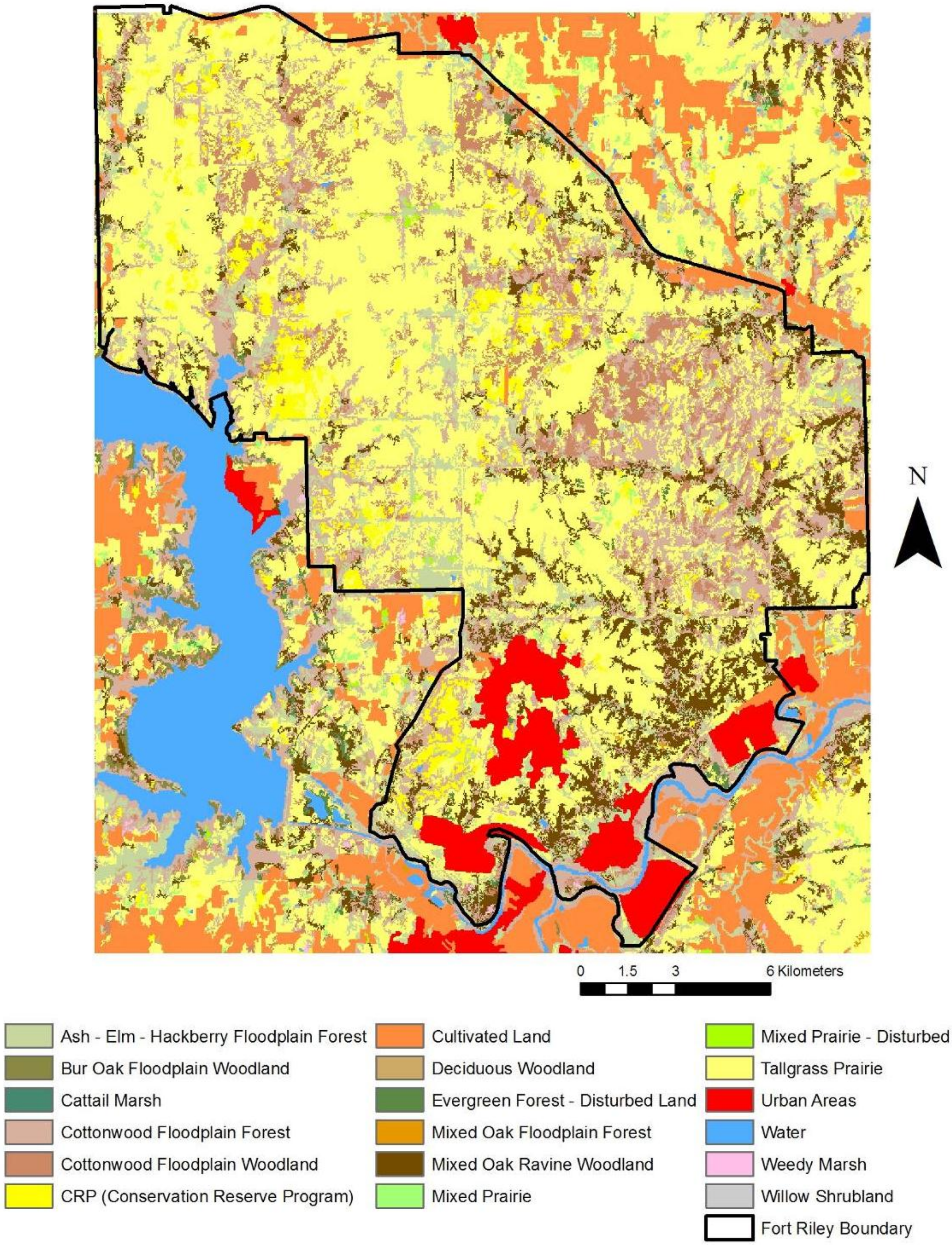
Fort Riley's soils allow for productive vegetation and the base is comprised of three major landuse/landcover (LULC) types (Egbert et al. 2001) (Figure 3.8). Grasslands make up the majority of land (81%), followed by woodlands (16%) and then shrublands (3%). Dominant plant species in the grassland areas include big bluestem (*Andropogon gerardii*), Indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), and little bluestem (*Schizachyrium scoparium*) with other grasses and forbs comprising a lower presence. Woodlands are located along waterways and contain chinquapin oak (*Quercus muhlenbergii*), bur oak (*Q. macrocarpa*), American elm (*Ulmus americana*), hackberry (*Celtis occidnetalis*), and black walnut (*Juglans nigra*) (Althoff et al. 2006). Shrublands occur along woodland edges and in isolated pieces of land in grassland areas with dominant species such as buckbrush (*Symphoricarpos orbiculatas*), smooth sumac (*Rhus glabra*), and rough-leafed dogwood (*Comus drummondii*) with various secondary grasses and forbs. The vegetation is affected by mowing, prescribed burning, wildfires, and military training exercises that can result in the formation of gullies.

Gully Definition

As defined by the Soil Science Society of America (2011), a gully is a channel resulting from erosion and caused by the concentrated but intermittent flow of water during and immediately following heavy rains. It was proposed to be deep enough (usually less than half a meter) to interfere with, and not be obliterated by, normal tillage operations (Soil Science Glossary Terms Committee 2008).

For this study, a gully was defined as a channel of erosion that is at least one meter wide and was chosen based on military vehicle mobility criteria. The Army uses the term "military gap" to refer to any terrain feature that is too wide for self-bridging and lists maximum self-bridging and step heights for tracked and wheeled vehicles (Department of the Army 1985). The maximum and minimum armored vehicle gap crossing capability is reported to be 2.74 meters (M1 Abrams) and 1.6 meters (M113) respectively (Department of the Army 1985). The U.S. Army Tank Automotive RDE Center (TARDEC) reported that the limited gap crossing capability of wheeled military vehicles is a major immobilization threat and provided

Figure 3.8 Landuse/Landcover types for Fort Riley, Kansas as derived from classified remotely-sensed images (Data Source: Kansas Gap Analysis Program 2001)



information on vehicle gap crossing capabilities as studied in Germany, stating that just over 50% of Army wheeled vehicles have less than a 1.0 meter self-bridging capability, including the HMMWV (0.85 meters) (Overholt 2001). Gully depth was not used as a defining criterion because it is highly improbable that a gully with a width of one meter or greater will not have a significant depth that would exceed the depth that most single-axle tactical wheeled vehicles can cross.

Gully Identification

Gully locations at Fort Riley were located using three methods. First, LiDAR (Light Detection and Ranging) imagery flown in March 2007 was used to develop a high resolution DEM that showed locations of potential gullies (Figure 3.9). The second method was obtained using information gathered from Fort Riley personnel that they had personally come across, while the third method used was field reconnaissance.

The first gully identification method used the March 2007 LiDAR data, from which a DEM was generated using Quick Terrain Modeler (Version 7.1.2, Applied Imagery, Silver Spring, Maryland) by Fort Riley GIS analyst Troy Livingston. An interpolation was done to create a surface with values that reflect mean elevation variation; this provided a mathematical representation of the approximate depth of hazardous structures in the terrain below the mean elevation (Figure 3.10). Depth parameters were set to display calculated values between 0.5 and 3.5 meters; and obvious features such as stream beds and roadside drainage ditches were removed.

Using this method, a total of 365 potential gullies were identified; these potential gully point features were then uploaded to a Trimble GeoXT 2005 Series Pocket PC Global Positioning System (GPS) equipped with the ArcPad mobile GIS (Version 8.0, ESRI, Redlands, California). 336 potential gully locations (92%) were verified in the field. If a gully was present at the predicted location, its width was recorded and, if it met the one meter wide criterion, a complete gully assessment was performed (described in the next section).

Figure 3.9 Possible Gullies on Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Area Management Program 2007)

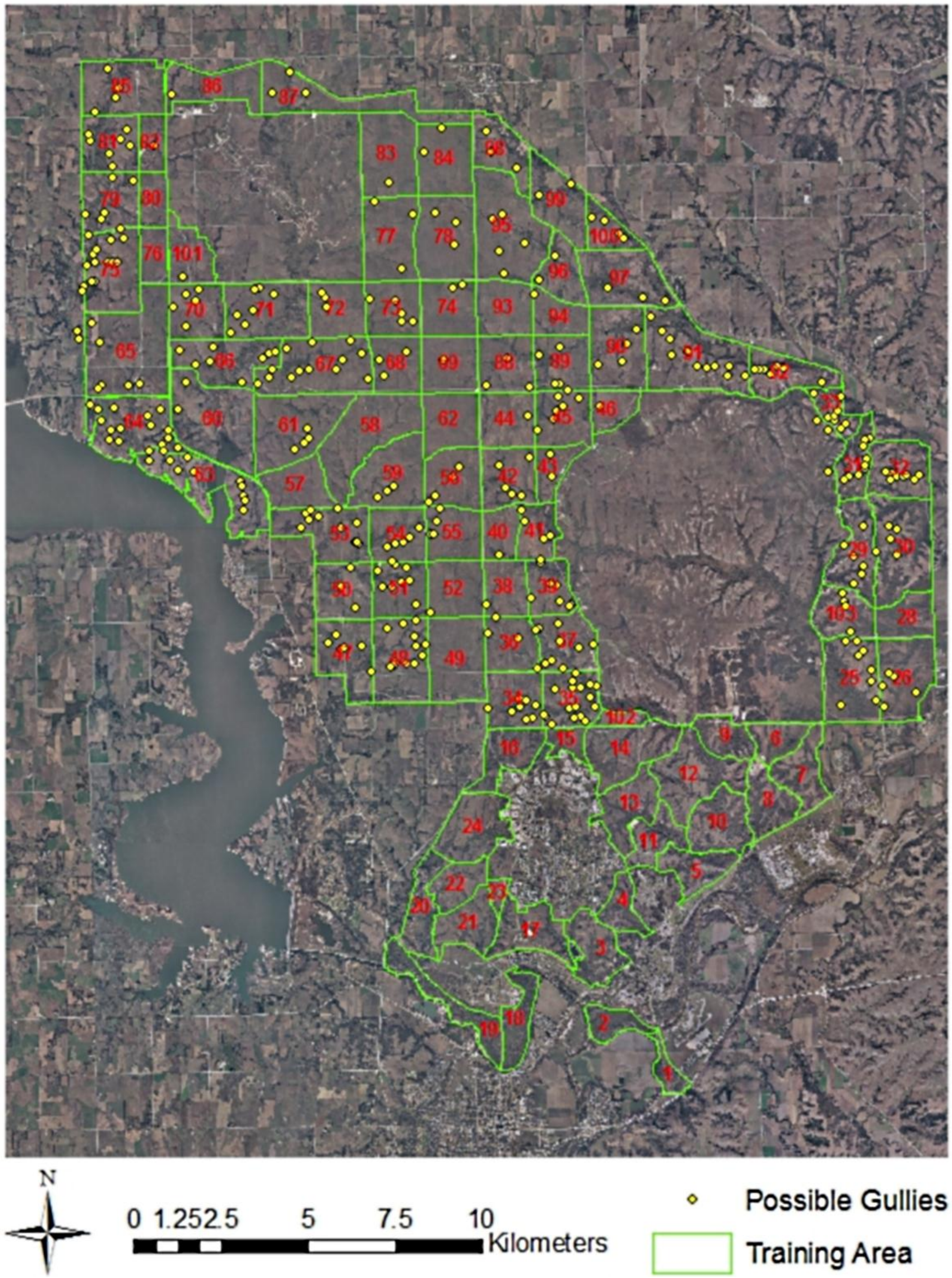
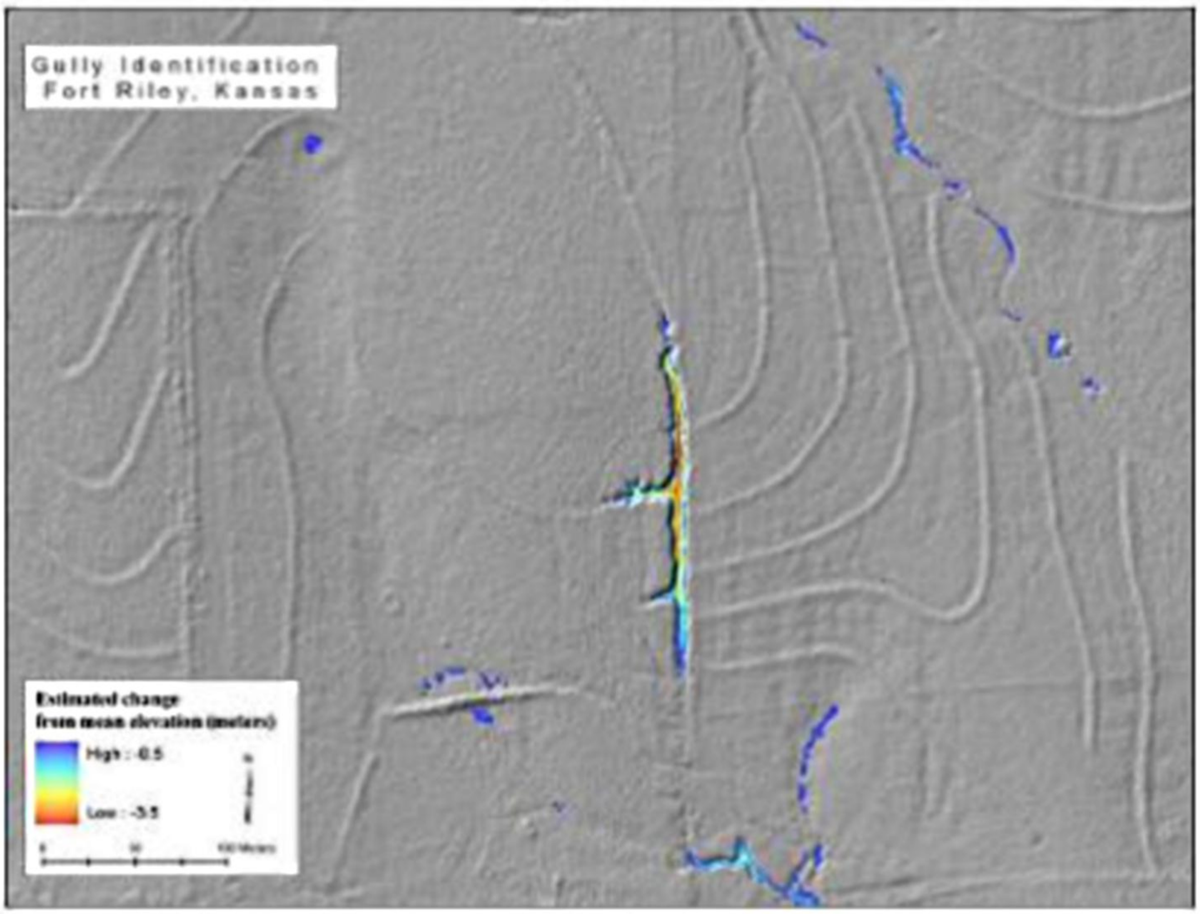


Figure 3.10 Gully identification layer based on elevation variations in a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Area Management Program 2007)



The second method used to identify gully locations, reports by Installation Training Area Management (ITAM) staff that provided gully locations, sometimes in the form of specific map coordinates, other times as general descriptions of where in a training area a gully was found, was verified in the field. As with the first method, confirmed gully locations meeting the one meter width criterion were added as point features in a GIS, while locations that did not meet the one meter width criterion were photographed but not instrumented.

The third, and final, method used to identify gullies was field reconnaissance. Gullies were found by driving around the Fort checking areas that looked especially vulnerable to gully erosion such as areas with little vegetation, high slopes, and/or recent disturbance from military vehicles. If gullies were found, the point was marked and instrumented if the one meter width criterion was met.

Gully Assessment

Areas of concentrated erosion were assessed in the field to determine if the area met the gully definition as described above. Each gully that met the definition of one meter or greater width was instrumented with two gully pins to reference where the head occurred as well as where the widest and deepest points occurred; widest and deepest points were measured and recorded. Instrumented gullies were photographed several times in order to establish the current condition so that changes over time can be monitored. If the area of concentrated erosion did not meet the gully definition (i.e. less than one meter wide), then the head of the gully was not instrumented, but one photograph was taken of the smaller erosional areas looking upstream at the initiation point. In future studies, this data will be used to determine rates of erosion and erosional processes.

The widest and deepest points of each gully were measured using a plastic measuring tape. First, the width was measured going across the gully, perpendicular to water flow within the gully. This was compared at several points along the gully to determine the widest point, at which point the gully width was recorded. Next, depth was measured using two tape measures; one was used to set an equal line across the top of the gully and one to measure the depth from the bottom of the gully to the line created by the other tape measure. These were compared to various depths within the gully and the depth of the deepest point was recorded.

A minimum of two photographs were taken for each gully location; one from inside the gully facing the gully head approximately three meters from the head and the second taken from the gully head looking down the length of the gully feature. If the gully was longer than approximately five meters, additional photos were taken along the length both upstream and downstream for better documentation (Figures 3.11 and 3.12). A Ricoh Caplio 500SE 8.0 Megapixel 3x Optical Zoom GPS camera (Model W, Ricoh, Tokyo, Japan) was used to take the pictures and record the date, coordinates of the camera, and the bearing in degrees that the camera was facing.

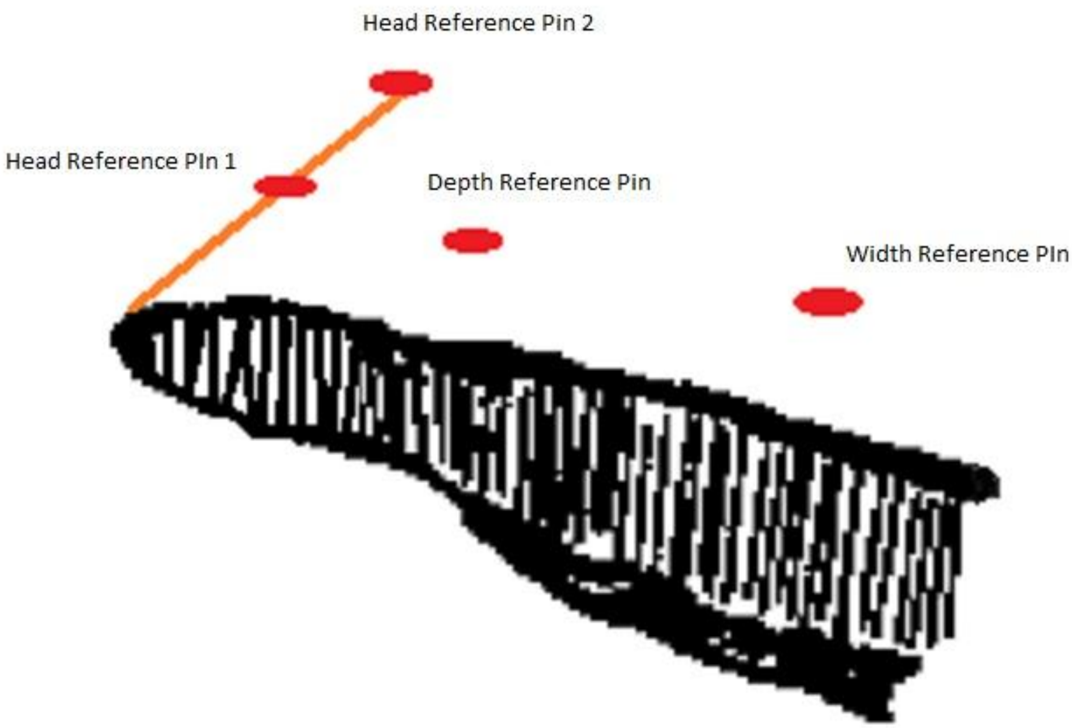
Figure 3.11 "Upstream" photograph of the head of gully number 46 located at 39.2^{o} N – 96.9^{o}W in Training Area 54 at Fort Riley, Kansas.

Figure 3.12 "Downstream" photograph of the head of gully number 46 located at 39.2° N – 96.9°W in Training Area 54 at Fort Riley, Kansas.

Erosion Pins

Erosion pins were used to provide a stable datum from which changes in the soil surface level can be measured. Pins were made of quarter-inch rebar and cut to approximately a half-meter in length; these were set to mark the gully's widest and deepest points to allow for repeat measurements to assess the extent of active erosion (Figure 3.13). The pin locations were recorded using a Trimble GeoXT 2005 Series Pocket PC GPS along with the initial measurements, width at widest point and depth at deepest point, taken in order to locate them easily and compare the values to future measurements.

Figure 3.13 Schematic of Gully Pin Locations (Cleveland and Soleri 1991)



Pins were installed at two locations parallel to the gully head to allow for future measurements and were also recorded in a GPS for future comparisons. These pins are known as the gully head reference pins. They are in line with the present gully head and can be used in the future to determine how far the gully head migrates over time. This is shown in Figure 3.14, where the first reference head pin is being inserted at approximately one meter from the gully head, unless bedrock prevented it from being placed this close. If bedrock did prevent the pin from being inserted here, a pin location was chosen by checking approximately one meter from this location (and so on). The measuring stick or a ruler was used to ensure that the reference pins were in a straight line from the gully head. A second reference pin was inserted next so that the gully head position could be determined accurately instead of using a single pin and trying to arbitrarily determine where the gully head was located in previous measurements. This pin was placed approximately one meter apart from the first reference pin. From the change in the gully head location and measurements, bank retreat and gully development can be estimated (Gordon et al. 2004).

Figure 3.14 Location of Reference Head Pin of gully number 48 located at 39.1^{o} N –96.8^{o}W in Training Area 36 at Fort Riley, Kansas.

Next, a pin was inserted where the gully was at its widest. The pin was inserted far enough away from the gully edge so that the pin is not washed away over time if erosion continues to occur, as seen in Figure 3.15. This was typically one meter away from the gully. In some cases, the pin had to be located further away than the typical placement due to the variation in rock layers and how the gully's erosion appeared to be progressing. The width of the gully was then inserted into the Trimble so that a comparison can be made with later measurements to estimate the volume change occurring, while also showing the way a gully changes shape over time. The distance that the reference pin was located from the gully's side was also recorded to aid in the estimation of volume change. The location of the pin was recorded in the GPS, so that it could be located quickly during re-measurements.

Figure 3.15 Gully Width Reference Pin of gully number 4 located at 39.2^{o} N –96.8^{o}W in Training Area 55 at Fort Riley, Kansas.

Another pin was inserted to reference the gully's deepest point (Figure 3.16). The depth was recorded in the Trimble so that it can be used to compare values over time, which will again help estimate volume changes over time as well as demonstrate the changes in shape a gully undergoes. This was also located far enough away from the erosion occurring so that it will not be washed out, typically one meter away from the gully. The pin location was recorded in the GPS so that it could be located easily during future measurements. The distance the pin was from the gully edge was also located to aid in the estimation of the change in volume and shape of the gully and were placed so that they were not likely to be run over by field personnel.

Figure 3.16 Depth Reference Pin of gully number 39 located at 39.1^{o} N –96.8^{o}W in Training Area 12 at Fort Riley, Kansas.

Spatial Data Development

Gullies

A spatial database of the gully features was created for cataloging gully information and to facilitate further analysis. The gully points recorded in the field were uploaded from a GPS to a desktop GIS system in a point shapefile format, which was then converted into a point feature class within a geodatabase. Photographs of gullies, in JPG format, were also uploaded into the computer and stored outside of the geodatabase environment. A single gully photograph showing the upstream perspective was incorporated within the geodatabase point feature class as a raster attribute. Coordinates from the GPS unit and the camera were matched to ensure the correct photos were associated with each gully. Spatial Data development was achieved with various data sets from several different sources (Table 3.2).

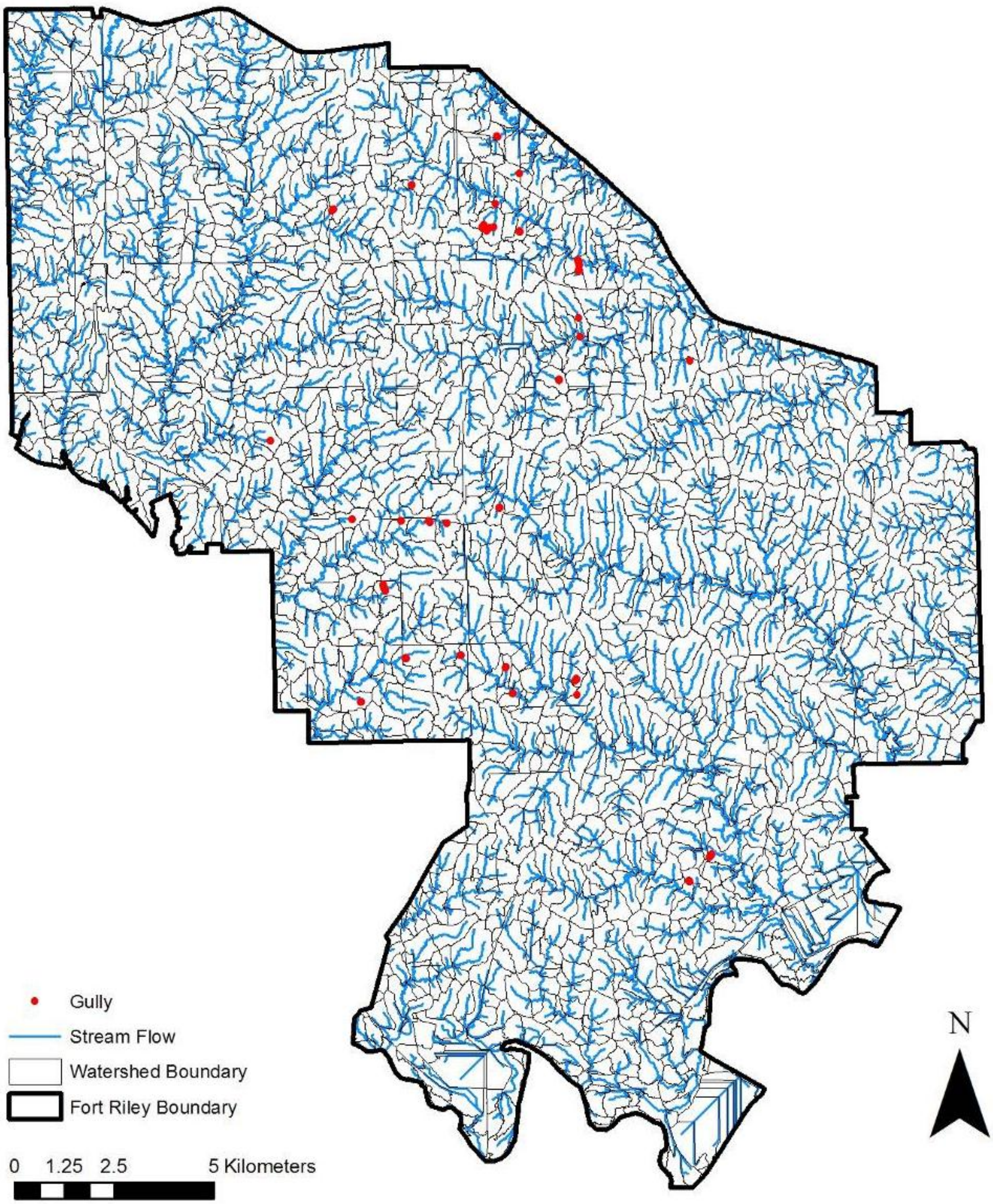
Topographic

A three meter DEM of Fort Riley and surrounding areas obtained using LiDAR (flown in 2007) was used to evaluate and produce topographic data including slope, aspect, flow direction, flow accumulation, and flow length to create stream and watershed features. A threshold of a certain area that drains to a point was used to develop a stream network with Strahler stream order data. This stream order system is a method where the stream order increases only when two streams of the same value meet such as a two first order streams meeting to produce a second order stream. Using this data and high cumulative flow cells, watersheds were delineated. The area of each watershed was calculated and watershed slivers were removed. Areas were partitioned by these delineated watersheds, which allowed the contributing area to be considered as a variable in the logistic regression when determining what factors affect the formation of a gully (Figure 3.17). Data layers were developed for slope and aspect by performing a zonal summary based on the mean of each within the watersheds delineated; the zonal data was then exported for further analysis.

Table 3.2 Data used for the development of a gully model with variable category, variable name, source and date of variable, and scale of variable source

Category	Variable	Source	Scale
Topographic	Digital Elevation Model (DEM)	Fort Riley Integrated Training Management Program 2007	3-meter
	Aspect	Fort Riley Integrated Training Management Program 2007	3-meter
	Slope	Fort Riley Integrated Training Management Program 2007	3-meter
Landuse/Landcover	National Land Cover Data	U.S. EPA 2001	30-meter
Soil Characteristic	Runoff Class	SSURGO 2002	1:24,000
	Erosion Class	SSURGO 2002	1:24,000
	Drainage Class	SSURGO 2002	1:24,000
	Frost Action Class	SSURGO 2002	1:24,000
	Hydrography Group	SSURGO 2002	1:24,000
	Particle Size	SSURGO 2002	1:24,000
	Depth to Bedrock	SSURGO 2002	1:24,000
	Flood Frequency	SSURGO 2002	1:24,000
	Hydric Classification	SSURGO 2002	1:24,000
	Depth to Horizon	SSURGO 2002	1:24,000
	Percent of Sand	SSURGO 2002	1:24,000
	Percent of Silt	SSURGO 2002	1:24,000
	Percent of Clay	SSURGO 2002	1:24,000
	Organic Matter	SSURGO 2002	1:24,000
	Dry Basis Weight	SSURGO 2002	1:24,000
	Saturated Hydraulic Conductivity	SSURGO 2002	1:24,000
	Available Water Content	SSURGO 2002	1:24,000
	Soil Water at 15 bar	SSURGO 2002	1:24,000
	Erodibility Factor	SSURGO 2002	1:24,000
	Sodium Adsorption Ratio	SSURGO 2002	1:24,000

Figure 3.17 Watershed and gully location map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007)



Soils and Landuse/Landcover

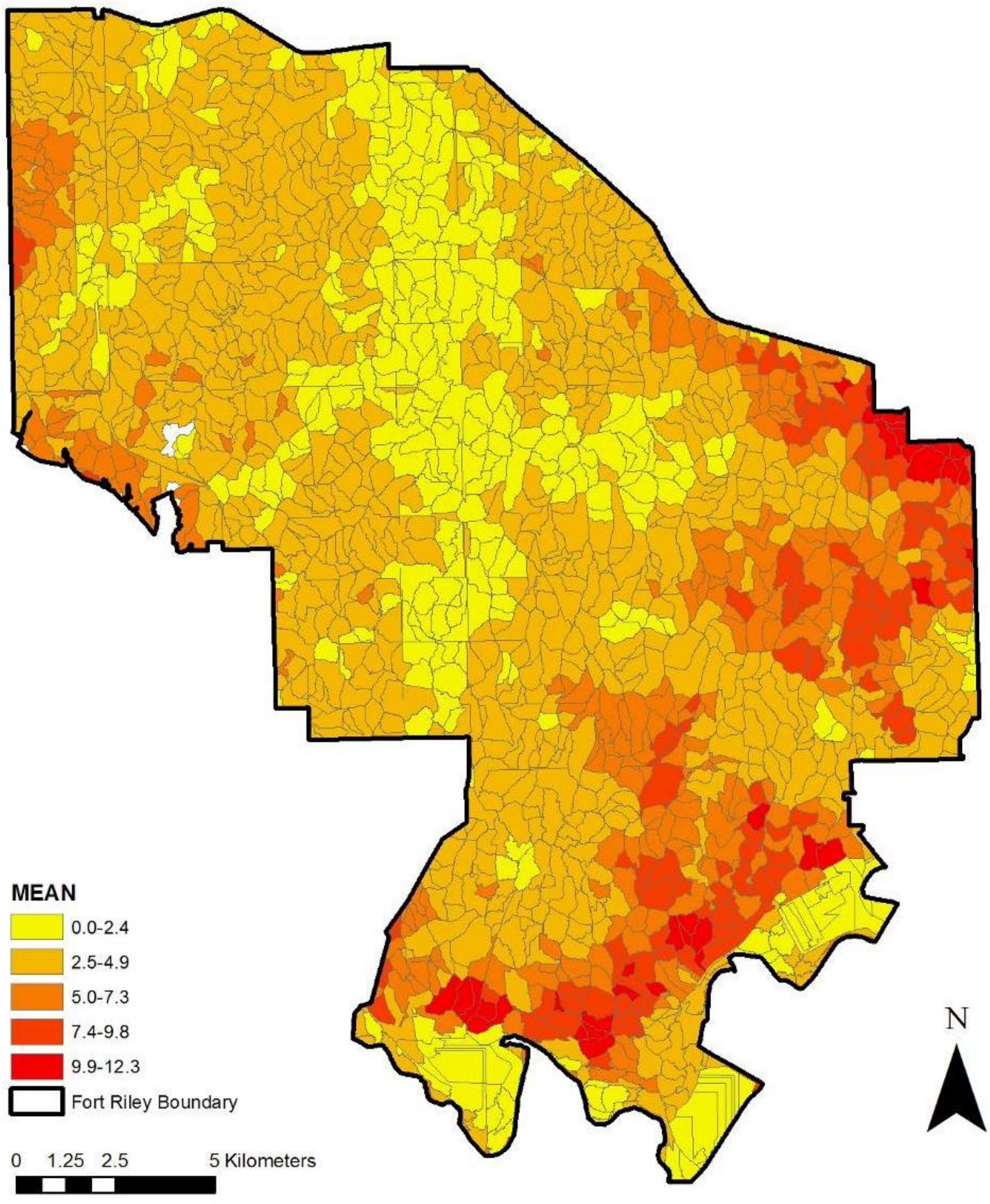
Soils data was obtained from the Soil Survey Geographic (SSURGO) database developed by the United States Department of Agriculture's National Resources Conservation Service (NRCS). Several soil properties from the SSURGO dataset were used to produce data layers developed by performing a zonal summary based on the watershed delineated for Fort Riley and exporting the data for each property. Specific soil properties included: runoff classification, erosion classification, drainage classification, frost action, hydrologic group, particle size, bedrock depth, horizon depth, hydric classification, flood frequency, sand content, silt content, clay content, organic matter content, dry basis weight, saturated hydraulic conductivity, available water content, amount of water retained at tension of fifteen bars, erodibility factor, and sodium adsorption ratio. Data layers developed for categorical soil properties were based on the majority of the property within subwatersheds, while layers developed for numerical soil properties were based on the mean of each property within the subwatersheds. Data for each property was exported as a table for further analysis.

Land use/Land Cover Data was obtained from the National Land Cover Data (NLCD), developed by the United States EPA. This information was also used to develop a data layer for land cover by performing a zonal summary based on the majority of the land cover within each subwatershed, which was then exported for further analysis.

Watershed Development

Data that was exported for each watershed was used to develop a table consisting of each watershed's variables. The mean statistic was used for numerical variables such as slope, while the majority statistic was used for categorical variables such as hydrologic group. An example is shown in Figure 3.18. Next, subwatersheds with gullies were identified using the gully point file, and the information was added to the watershed data table. Subwatersheds that were checked and did not have gullies present were identified using the possible gullies point file; this information was also added to the watershed data table. Multicollinearity testing was then done on the watershed characteristic data within the table to eliminate variables that have a strong correlation between other independent variables using Variance Inflation Factors (VIF). The

Figure 3.18 Slope map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007)



VIF is the number of times the variance of the corresponding parameter estimate is increased due to multicollinearity as compared to as it would be if there were no multicollinearity or 1/Tolerance.

Logistic Regression

A logistic regression analysis was performed using XLSTAT (Version Pro 2011, Addinsoft, Paris, France) with data for each watershed. The data was selected so that quantitative and qualitative variables were used to develop a model that predicts the presence of gullies. However, data that was found to exhibit multicolinearity was not used in the model.

The logistic regression was run using a Logit model, so that the presence or absence of gullies was in a binary form, where 1 indicated the presence of a gully and 0 indicated its absence. The Logit model equation is shown in Equation 9.

Equation 9 Logit Model Equation

$$Y=1/[1+Exp(-(L(x)))]$$

The model parameters, goodness of fit statistics, and test of the null hypothesis tables are displayed in the output and further discussed in the Results section. The model was also tested with 80 watersheds for validation.

CHAPTER 4 - Results and Discussion

Gully Identification

Methods for identifying gullies were not accurate, which is why it is critical to develop a model to predict where gullies form. The number of gullies identified with each method is shown in Table 4.1, where the majority of gullies were found using method one based on LiDAR data. Using the field reconnaissance method, twelve gullies and seven concentrated areas of erosion were identified. The second method identified three gullies. A total of fifty-two points

Table 4.1 Number of Gullies Found with each identification method

	Gully Erosion Found
Method 1	30
Method 2	3
Method 3	12

of erosion were identified (Table 4.2). The seven concentrated areas of erosion identified were left unpinned, so these are not included in the previous table because they do not fit into our gully definition. The majority of the gullies occur in the middle of the military base, where the soil is silty clay loam and the majority of the land cover is herbaceous. Gullies identified occurred in areas with high elevation and relatively low slope values. Gullies tend to occur in areas of with fine particles and high silt content. Gullies identified were either v-shaped or u-shaped with the majority being u-shaped. Many of them appeared to have been caused by human activity and unstable, where active erosion was occurring. Gullies that were re-measured did not have significant changes, but this is most likely caused by the low amount of precipitation events that occurred during the study period.

Table 4.2 Gully Attribute Data Table with gully ID number, date the gully was identified, widest width in meters, deepest depth in meters, shape of gully where 1 is v-shaped and 0 is u-shaped, cause of the gully where 1 is anthropogenic and 0 is non-anthropogenic, comments of each gully, re-measure date, change in the deepest depth, change in the widest width, and stability where 1 is stable and 0 is unstable or active

ID	DATE	Width	Depth	SHAPE_V	ANTHRO	Comments	Re_measure	Depth	Width	Stable
1	5/17/2010	8.46	1.57	0	1		8/31/2010	0	0	1
2	5/17/2010	8.92	2.18	1	1		<Null>	0	0	0
3	5/17/2010	10.72	2.31	1	1		<Null>	0	0	0
4	5/17/2010	9.75	1.83	1	1		<Null>	0	0	0
5	5/18/2010	3.38	0.91	0	1	Road ditch gully	8/31/2010	37	0	0
6	5/18/2010	2.36	0.91	1	1	tracking	<Null>	0	0	0
7	5/18/2010	2.46	1.22	1	1	tracking	<Null>	0	0	0
8	5/24/2010	10.41	2.44	1	1	terracing	<Null>	0	0	0
9	5/24/2010	8.53	1.35	1	1	terracing	<Null>	0	0	0
10	5/24/2010	10.57	1.52	1	1	terracing	<Null>	0	0	0
11	5/24/2010	10.03	2.26	1	1	terracing	<Null>	0	0	0
12	5/24/2010	0	0	1	1	unpinned	8/31/2010	0	0	0
13	5/24/2010	3.91	1.32	1	1	waterway breach	8/31/2010	0	0	0
14	5/27/2010	2.95	0.99	1	1		8/31/2010	0	0	0
15	5/27/2010	2.72	1.35	1	1		8/31/2010	0	0	0
16	5/27/2010	1.83	0.86	1	1		8/31/2010	0	0	0
17	5/27/2010	6.05	1.37	1	0		9/13/2010	0	0	1
18	6/10/2010	3.28	1.74	0	1	tracking crossing	<Null>	0	0	0
19	6/10/2010	5.56	1.7	0	1	pond	9/13/2010	0	0	0
20	6/10/2010	2.84	1.31	1	1	tracking	<Null>	0	0	0
21	6/10/2010	1.22	1.02	1	1	secondary gully	<Null>	0	0	0
22	7/19/2010	4.7	1.82	0	1	ditch	9/13/2010	0	0	0
23	7/19/2010	3.73	0.67	0	1	ditch upstream	9/13/2010	0	0	0
24	7/19/2010	3.66	0.79	1	1	old road	9/13/2010	0	0	0
25	7/22/2010	4.75	1.04	0	0		9/13/2010	0	0	0
26	7/23/2010	5.97	1.68	0	0		<Null>	0	0	0
27	7/23/2010	4.22	1.27	0	1	pond overflow	<Null>	0	0	0
28	7/26/2010	3.1	1.31	0	0	natural	<Null>	0	0	0
29	7/26/2010	2.39	1.22	0	0	natural	<Null>	0	0	0
30	7/26/2010	3.38	1.02	0	0		<Null>	0	0	0
31	7/26/2010	3.91	0.86	0	0	accelerated by crossing	8/31/2010	0	0	0
32	7/27/2010	0	0	0	0	unpinned	<Null>	0	0	0
33	8/3/2010	3.02	0.91	0	0	natural	<Null>	0	0	0
34	8/5/2010	2.08	1.07	0	0	natural	<Null>	0	0	0
35	8/5/2010	1.8	0.81	0	1	crossing	<Null>	0	0	0
36	8/12/2010	3.33	0.62	0	1	ditch	<Null>	0	0	0
37	8/12/2010	5.56	1.17	0	1	ditch	<Null>	0	0	0
38	8/12/2010	8.69	0.72	0	1	ditch	<Null>	0	0	0
39	8/12/2010	3.43	0.81	1	1	tracks	<Null>	0	0	0
40	8/12/2010	5	1.41	1	1	tracks	<Null>	0	0	0
41	8/12/2010	3.61	0.81	1	1	tracks	<Null>	0	0	0
42	9/13/2010			0	0	unpinned	9/13/2010	0	0	0
43	9/13/2010			0	1	unpinned	9/13/2010	0	0	0
44	9/13/2010			0	1	unpinned	9/13/2010	0	0	0
45	9/13/2010			0	1	unpinned	9/13/2010	0	0	0
46	4/26/2010	1.47	1.45	0	1		<Null>	0	0	0
47	4/26/2010	1.07	1.35	0	1		<Null>	0	0	0
48	4/26/2010	0.76	1.17	0	1		<Null>	0	0	0
49	4/26/2010	1.83	1.88	0	1		<Null>	0	0	0
50	4/26/2010			0	1	unpinned	<Null>	0	0	0
51	4/26/2010			0	1	unpinned	<Null>	0	0	0
52	4/26/2010			0	1	unpinned	<Null>	0	0	0

Method 1-LiDAR

The first method, as discussed in the methods and materials section, was based on a shapefile created using the slope of the area. This resulted in a total number of possibly 365 gullies. However, only thirty gullies were identified using this method, even though 92% of the possible gully locations were checked. Actual negative values were determined by either knowledge gained by field reconnaissance or by using expert analysis of the watershed map based on gullies found, slope, and aspect. The accuracy of this method is approximately 25%

Table 4.3 Error Matrix based on gully prediction based on Method 1

	Predicted Positive	Predicted Negative
Actual Positive	16	17
Actual Negative	241	68

based on the error matrix, where accuracy is the amount correctly predicted outcomes over the total number of outcomes (Table 4.3). Errors of omission, or false negatives, are approximately 52%, while errors of commission, or false positives, are approximately 78%. These errors show that this method is not extremely reliable or accurate. However, accuracy is highly dependent on the number of watersheds found to be absent of gullies. The false positive value is extremely high, resulting in an overestimation to the number of gullies present. The kappa statistic is the measure of the difference between the observed agreement between the actual and predicted outcomes and the agreement that might be contributed solely by chance matching them, which attempts to give a measurement of agreement that is adjusted for chance agreement. This received a kappa statistic of -0.07, which means that it is poorly classified because of the negative value.

Method 2-Range Manager

Gullies that were identified by Fort Riley ITAM personnel were found by instructions given by employees on the training area along with the general region or coordinates of the gully. Points found using this method were extremely accurate because personnel had already seen the gullies that occur in the area and were able to give precise directions. Three gullies were identified using this method.

Method 3-Field Reconnaissance

Gullies were also found by driving around the Fort checking areas that looked especially vulnerable to gully erosion such as areas with little vegetation, high slopes, and/or recent disturbance from military vehicles. This method identified twelve gullies and seven concentrated areas of erosion.

Logistic Regression Analysis

The logistic regression analysis yielded interesting results with significant interactions between available water content, land use classification, and gully formation. However, varying soil characteristic data caused by different NRCS staff completing surveys on the two counties that Fort Riley occupies dramatically changed the gully prediction equation. The gully prediction model developed by the regression identified 192 out of 1577 watersheds where a gully is present.

Correlation Matrix

The correlation matrix shows the relationship of each variable with all of the other variables (Table 4.4). Correlation values are determined by the Pearson correlation formula (Equation 10). Values range from zero to positive or negative one, depending on the variables

Equation 10 Correlation formula used to develop a correlation matrix

$$r = \frac{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)\left(Y_i - \bar{Y}\right)}{(n-1)S_X S_Y}$$

correlation with one another. If a relationship value is close to one, then the variables exhibit multicollinearity.

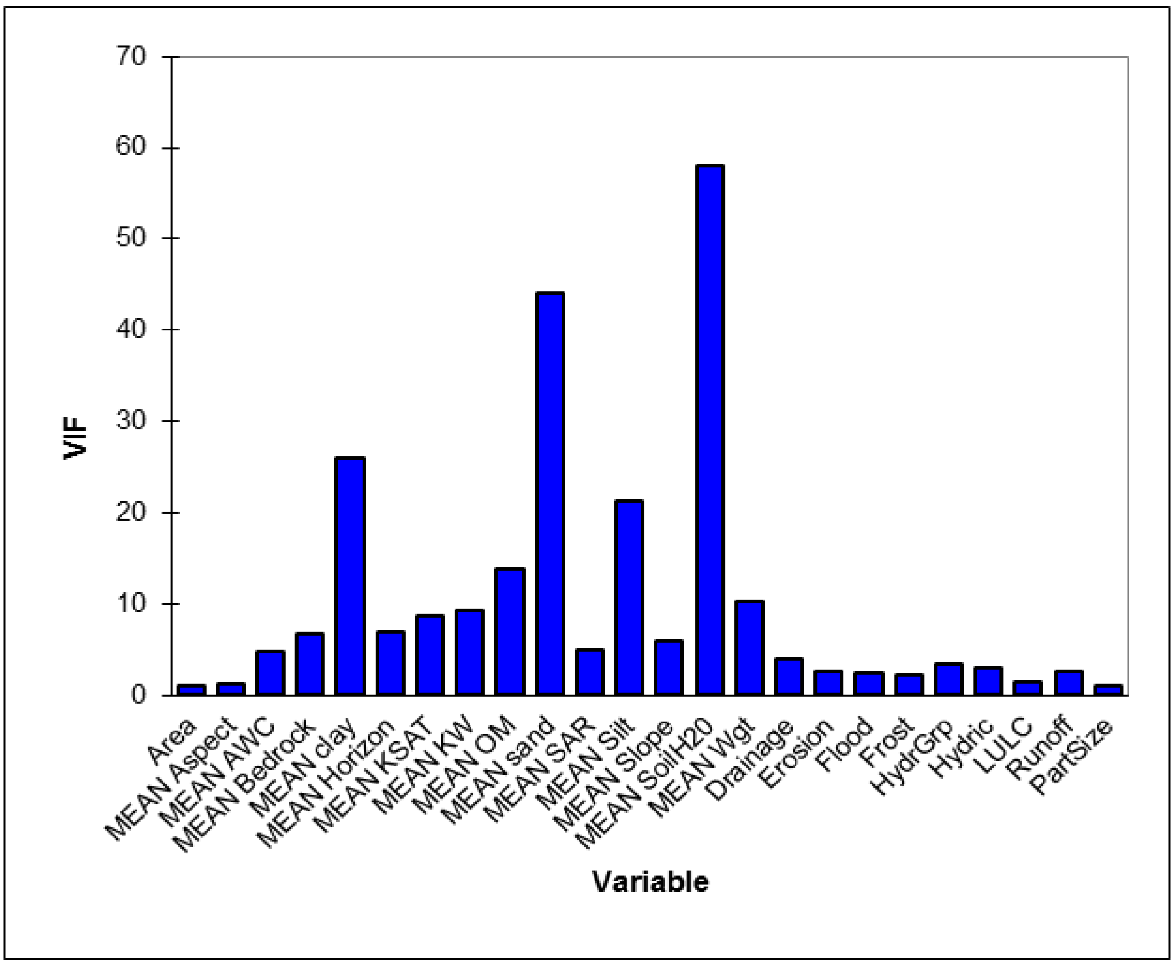
Table 4.4 Correlation matrix of topographic, landuse/landcover, and soil variables

Variables	Area	Aspect	AWC	Bedrock	Clay	Horizon	KSAT	KW	OM	Sand	SAR	Silt	Slope	SoilH20	Wgt	Drainage	Erosion	Flood	Frost	HydrGrp	Hydric	LULC	Runoff	PartSize
Area	**1.0**	0.1	0.1	0.0	0.0	-0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0	-0.1	0.0
Aspect	0.1	**1.0**	0.0	-0.1	0.0	-0.1	-0.2	0.0	0.0	0.0	-0.1	0.1	0.0	-0.1	0.0	0.0	0.0	-0.1	0.1	0.0	-0.1	0.1	-0.1	0.0
AWC	0.1	0.0	**1.0**	0.2	-0.1	-0.4	0.0	-0.1	0.6	0.2	0.1	0.1	0.0	0.0	0.0	0.0	-0.3	-0.3	0.1	0.0	0.1	0.1	0.3	0.1
Bedrock	0.0	-0.1	0.2	**1.0**	0.1	-0.1	0.2	-0.2	0.0	0.5	0.0	-0.6	0.4	0.1	0.0	0.2	0.0	-0.1	0.5	0.2	0.5	0.0	0.4	0.0
Clay	0.0	0.0	-0.1	0.1	**1.0**	0.0	-0.7	0.2	-0.1	-0.6	0.0	-0.2	-0.1	0.9	0.2	-0.1	0.3	0.0	-0.3	0.4	-0.2	0.2	0.0	-0.1
Horizon	-0.1	-0.1	-0.4	-0.1	0.0	**1.0**	0.4	0.0	-0.7	0.0	-0.1	-0.1	0.1	0.0	0.2	0.3	0.2	0.7	-0.2	-0.4	0.0	-0.3	-0.1	-0.1
KSAT	0.0	-0.2	0.0	0.2	-0.7	0.4	**1.0**	-0.1	-0.3	0.6	-0.1	0.0	0.2	-0.7	-0.1	0.3	0.0	0.2	0.3	-0.4	0.3	-0.3	0.0	0.0
KW	0.0	0.0	-0.1	-0.2	0.2	0.0	-0.1	**1.0**	-0.3	-0.2	0.3	0.2	-0.8	0.3	-0.1	-0.7	0.6	0.1	-0.3	0.5	-0.6	0.3	-0.2	0.0
OM	0.1	0.0	0.6	0.0	-0.1	-0.7	-0.3	-0.3	**1.0**	0.2	0.1	0.0	0.1	0.1	0.1	-0.1	-0.4	-0.5	0.2	0.1	0.1	0.1	0.4	0.1
Sand	0.0	0.0	0.2	0.5	-0.6	0.0	0.6	-0.2	0.2	**1.0**	0.2	-0.5	0.4	-0.5	0.1	0.3	-0.3	0.0	0.5	-0.2	0.5	-0.1	0.4	0.1
SAR	0.0	-0.1	0.1	0.0	0.0	-0.1	-0.1	0.3	0.1	0.2	**1.0**	-0.2	-0.2	0.3	0.2	-0.3	-0.1	-0.1	0.0	0.4	0.1	0.1	0.1	0.0
Silt	0.1	0.1	0.1	-0.6	-0.2	-0.1	0.0	0.2	0.0	-0.5	-0.2	**1.0**	-0.4	-0.1	0.0	-0.2	0.1	0.0	-0.3	0.0	-0.4	0.1	-0.5	0.0
Slope	0.0	0.0	0.0	0.4	-0.1	0.1	0.2	-0.8	0.1	0.4	-0.2	-0.4	**1.0**	-0.3	0.1	0.7	-0.4	0.0	0.4	-0.4	0.6	-0.2	0.4	0.0
SoilH20	0.0	-0.1	0.0	0.1	0.9	0.0	-0.7	0.3	0.1	-0.5	0.3	-0.1	-0.3	**1.0**	0.4	-0.3	0.3	0.0	-0.2	0.4	-0.2	0.2	0.2	-0.1
Wgt	-0.1	0.0	0.0	0.0	0.2	0.2	-0.1	-0.1	0.1	0.1	0.2	0.0	0.1	0.4	**1.0**	0.2	-0.1	0.2	0.2	-0.1	0.1	0.1	0.3	0.0
Drainage	-0.1	0.0	0.0	0.2	-0.1	0.3	0.3	-0.7	-0.1	0.3	-0.3	-0.2	0.7	-0.3	0.2	**1.0**	-0.3	0.2	0.2	-0.5	0.6	-0.2	0.1	0.0
Erosion	-0.1	0.0	-0.3	0.0	0.3	0.2	0.0	0.6	-0.4	-0.3	-0.1	0.1	-0.4	0.3	-0.1	-0.3	**1.0**	0.3	-0.2	0.2	-0.3	0.0	-0.2	0.0
Flood	-0.1	-0.1	-0.3	-0.1	0.0	0.7	0.2	0.1	-0.5	0.0	-0.1	0.0	0.0	0.0	0.2	0.2	0.3	**1.0**	-0.2	-0.3	-0.1	-0.3	-0.1	0.0
Frost	0.0	0.1	0.1	0.5	-0.3	-0.2	0.3	-0.3	0.2	0.5	0.0	-0.3	0.4	-0.2	0.2	0.2	-0.2	-0.2	**1.0**	-0.1	0.4	0.0	0.3	0.0
HydrGrp	0.0	0.0	0.0	0.2	0.4	-0.4	-0.4	0.5	0.1	-0.2	0.4	0.0	-0.4	0.4	-0.1	-0.5	0.2	-0.3	-0.1	**1.0**	-0.2	0.3	0.0	0.0
Hydric	0.0	-0.1	0.1	0.5	-0.2	0.0	0.3	-0.6	0.1	0.5	0.1	-0.4	0.6	-0.2	0.1	0.6	-0.3	-0.1	0.4	-0.2	**1.0**	-0.1	0.4	0.0
LULC	0.0	0.1	0.1	0.0	0.2	-0.3	-0.3	0.3	0.1	-0.1	0.1	0.1	-0.2	0.2	0.1	-0.2	0.0	-0.3	0.0	0.3	-0.1	**1.0**	0.0	0.1
Runoff	-0.1	-0.1	0.3	0.4	0.0	-0.1	0.0	-0.2	0.4	0.4	0.1	-0.5	0.4	0.2	0.3	0.1	-0.2	-0.1	0.3	0.0	0.4	0.0	**1.0**	0.0
PartSize	0.0	0.0	0.1	0.0	-0.1	-0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	**1.0**

Multicollinearity Test

Characteristic data was tested to determine if variables exhibited multicollinearity more vigorously using the Variance Inflation Factor (VIF) values. The existence of multicollinearity leads to many problems including incorrect signs and magnitudes of regression coefficient estimates, which would result in incorrect conclusions about relationships between independent and dependent variables. If the Variance Inflation Factor (VIF) values exceed ten, they were regarded as displaying multicollinearity (Allison 1999). Soil water, sand content, clay content, silt content, organic matter content, and dry basis weight all exhibit multicollinearity (Figure 4.1). Variables that exhibited multicollinearity were removed from the logistic regression analysis to prevent any incorrect conclusions from the gully prediction model.

Figure 4.1 Variance Inflation Factor Values based on watershed characteristic data



Gully Prediction Variables

Within the gully prediction model, the variables with the highest corresponding coefficients have the greatest effect on the formation of gullies. Negative coefficients mean that as the variable increases, the probability of erosion decreases; while positive coefficients mean that as the variable increases, so does the probability of erosion. The variable with the highest effect on gully formation was available water capacity, which is due to the fact that these values occur on higher than average slopes and higher clay contents. While clay has a high capacity to store water, it has very low infiltration rates. This results in more runoff and erosion occurring in these areas. The variable with the smallest effect on gully formation was watershed area. This result was unexpected because runoff volume is directly tied to watershed size, but this study used a very small range of watershed sizes, which resulted in the lack of importance in the model. Aspect, depth to bedrock, depth to horizon, saturated hydraulic conductivity, erodibility factor, sodium adsorption ratio, and slope all moderately effect gully formation.

The effect drainage classes have on the formation of gullies showed that as drainage increases, the probability of gully formation increases. Erosion class weights vary; but it is important to note that Class 2 erosion or rill erosion increases the probability of gully formation because rills eventually form into larger gully erosion. As flood frequency increases and as frost action increases, the probability that erosion occurs decreases. Flood frequency effects erosion formation because gully erosion tends to occur in places that are covered in water a large amount of time each year, while frost action effects erosion formation because it causes a significant loss of soil strength. Group B soils have a higher effect on gully formation than soils classified in the hydrologic group C because group B soils tend to be loamier instead of having a high percentage of clay. Hydric classification had little effect on the formation of gullies because soils that are hydric tend to occur along rivers and streams, which results in an inverse relationship with the formation of gullies that is seen by the negative coefficient. As land use moves toward lower vegetation and higher exposed ground area, the probability of erosion formation increases. However, the only exception is the emergent wetlands area that most likely resulted from its inability to infiltrate more water. Runoff class coefficients vary, but this is probably due to the fact that the medium runoff class tends to occur near open water; while the other classes show that as runoff potential increases, its ability to effect formation of gullies decreases. This is not as expected, but could be caused by the fact that not very many watersheds have a high runoff potential. Finally, as particle size moves from silty to loamy, its probability of erosion formation decreases. This is probably because loams have higher percentages of sand than silts, which may affect the ability of water to dislodge or erode the soil.

Unfortunately, military training activities during the study period were unavailable. However, from the variables we can see that the compaction and removal of soil would greatly increase the potential for gully formation. The data also shows that as land use reduces the vegetation and increases bare ground exposed to the atmosphere, the higher the potential for gullies is. Another factor that may play a role is water table depth. Unfortunately, this data was available but incomplete because very few measures were actually provided in the soil survey data. Due to this, it was decided that this variable would not be highly indicative of the potential for gully formation and could be skewed with the low number of values available if it had been used.

When this equation was used on the rest of the watershed data, binary outputs were produced again showing one for gullies present and zero for gullies absent. It was found that out of the 1577 watersheds that were evaluated for the Fort Riley area, 192 watersheds had gullies present. This is most likely due to the topography and soils in the area.

Goodness of Fit Statistics

The goodness of fit statistics, shown in Table 4.5, provide several indicators of the quality of the model. These results, as discussed previously, are equivalent to R^2. The most important value to look at is the probability of Chi-square test on the on the log ratio. This is equivalent to Fisher’s F test, where we try to evaluate if the variables bring significant information by comparing the model, and it has a value lower than 0.0001, so it is significant.

Provided in the table are the total number of sample observations taken into account, and the degrees of freedom. As seen in the table, the equation has a high value for the McFadden R^2 values, showing that the full model has a high level of improvement over the model without predictors. Cox and Snell’s R^2 value does not extend to one, so it is better to look at the Nagelkerke R^2 value because it adjusts the Cox and Snell value to a range from 0 to 1. This value is fairly high, so it shows that the full model improves upon the model without predictors. The number of iterations that the algorithm has taken to produce the prediction equation is also included.

Table 4.5 Goodness of fit statistics based on gully prediction model

Statistic	Independent	Full
Observations	182	182
Sum of weights	182.000	182.000
DF	181	152
-2 Log(Likelihood)	126.048	23.813
R^2(McFadden)	0.000	0.811
R^2(Cox and Snell)	0.000	0.430
R^2(Nagelkerke)	0.000	0.860
AIC	128.048	83.813
SBC	131.252	179.933
Iterations	0	18

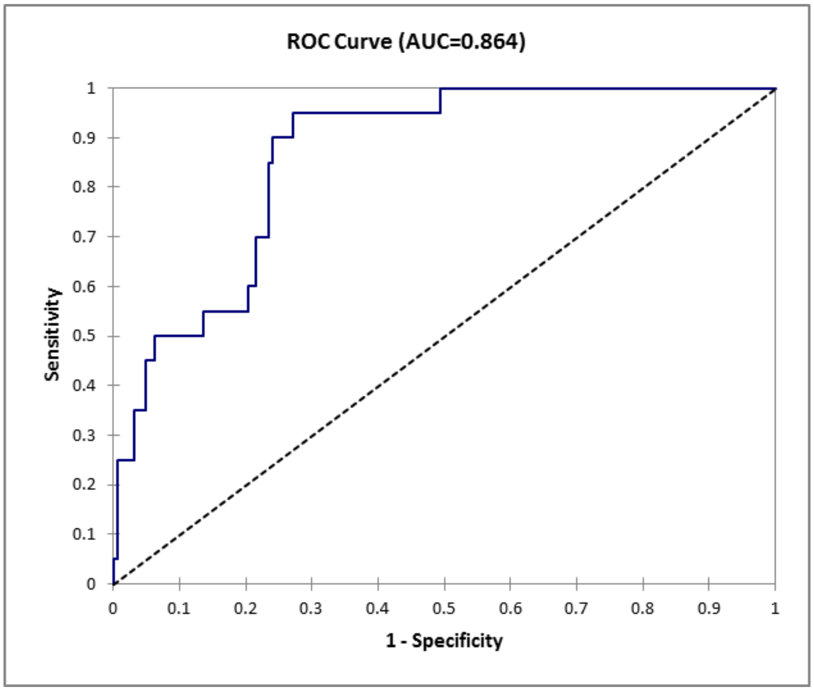
Statistic	DF	Chi-square	Pr > Chi²
-2 Log(Likelihood)	29	102.235	< 0.0001
Score	29	38.981	0.102
Wald	29	18.776	0.927

ROC Curve

The Receiver Operating Characteristics (ROC) curve was used to evaluate the performance of the model by means of the area under the curve and to compare several models together. The terms used come from signal detection theory and were originally developed by electrical engineers. However, the ROC curve is used commonly in statistics now. The proportion of well-classified positive events is called the sensitivity. The specificity is the proportion of well-classified negative events. If you vary the threshold probability from which an event is to be considered positive, the sensitivity and specificity will also vary. The area under the curve (AUC) is a synthetic index calculated for ROC curves. The AUC corresponds to the probability such that a positive event has a higher probability given to it by the model than a negative event. For an ideal model, AUC=1 and for a random model, AUC=0.5. A model is considered good when the AUC value is greater than 0.7.

The ROC Curve for our gully prediction model is shown in Figure 4.2. As seen, the curve has an area under the curve of .864, which shows that our logistic regression equation is a good model and is extremely good since the study is pertaining to natural systems.

Figure 4.2 ROC Curve based on the gully prediction model



Gully Prediction Model

The gully prediction model was developed using logistic regression on the variables that did not exhibit multicollinearity. Here, the L(x) term, shown in equation 10, is based on the input variables based on whether the variable is quantitative or qualitative.

Equation 11 Gully Prediction Model as derived using logistic regression

Gully = 1 / (1 + exp(-(L(x)))

The L(x) term is defined by the input variables as seen based on equation 11, which was based on the Logit function chosen to run the logistic regression.

Equation 12 Variable Terms used in the Gully Prediction Model

$$L(x)=L_0+L_1x_1+L_2x_2+L_3x_3+\ldots+L_{29}x_{29}$$

As seen in the equation, the qualitative variables are multiplied by a factor if the subwatershed displays the variable (Table 4.6). For instance, if a watershed was in the hydrologic group C, it would receive a value of 0.59 for the hydrologic characteristic set.

Table 4.6 Variable Terms and Values for the Gully Prediction Model

Source	Value
Intercept	-6.85
Area	1.91E-6
Aspect	1.1E-2
AWC	33.37
Bedrock	3.65E-2
Horizon	-6.96E-2
KSAT	-0.33
KW	-0.23
SAR	1.31
Slope	-0.36
Well drained	-1.10
Excessively well drained	2.92
Erosion-Null	-1.55
Erosion-Class 2	0.24
Erosion-Deposition	1.89
Flood-Rare	2.25
Flood-Occasional	1.81
Frost-High	-9.00E-2
Frost-Low	-0.12
Hydrologic Group B	1.79
Hydrologic Group C	0.59
Not Hydric	-0.11
LULC-Deciduous Forest	1.57
LULC-Cultivated Crops	3.30
LULC-Emergent Herbaceous Wetland	5.51
Runoff-Low	1.85
Runoff-High	-1.14
Runoff-Medium	-1.64
Particle Size-Fine Silty	-2.55
Particle Size-Loamy	-1.50

Validation

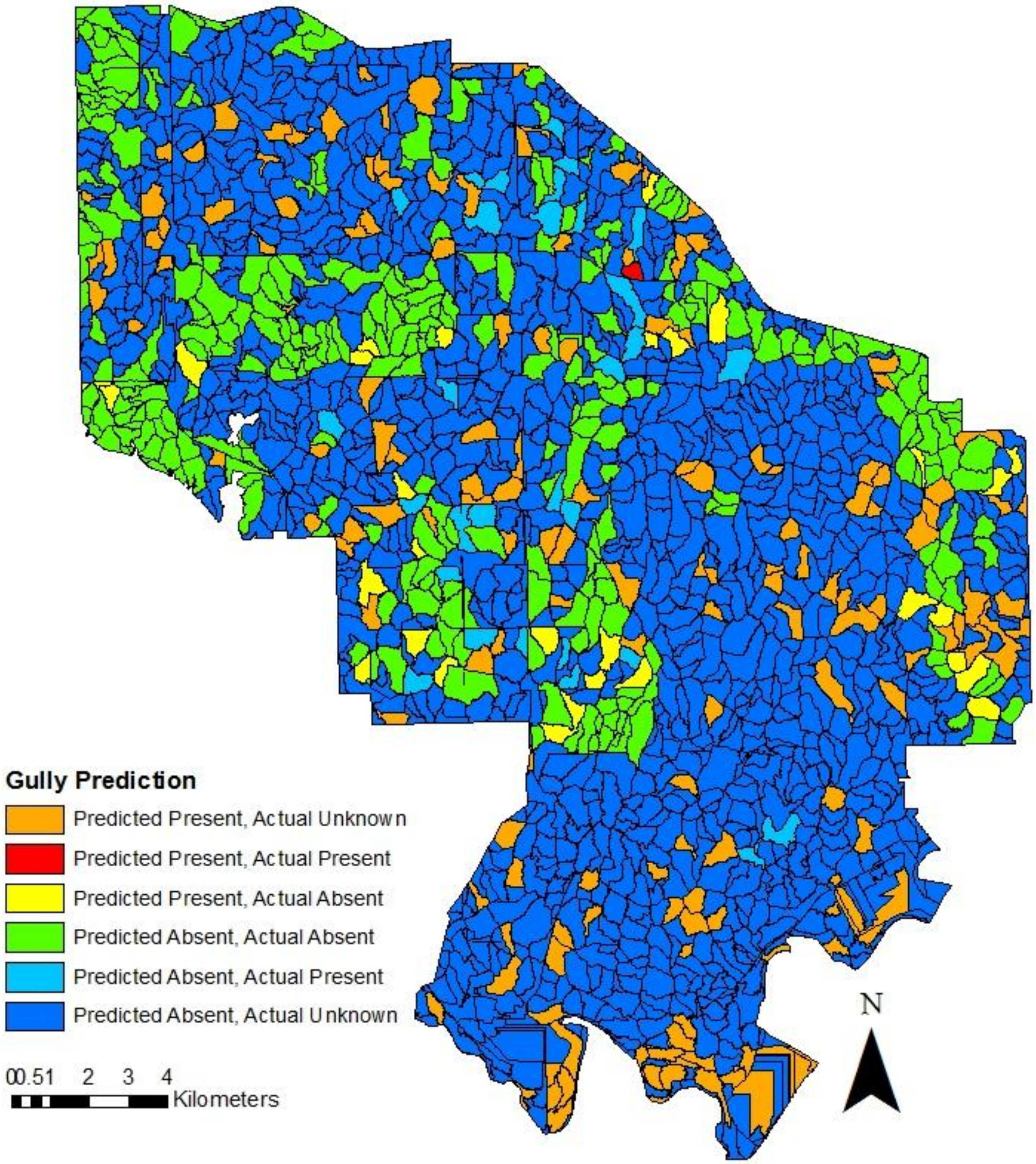
The regression was carried out using 80 out of the 262 watersheds of known gully presence or absence to produce an error matrix based on the comparison of known or actual outcomes to the predicted outcomes developed by the gully prediction model. The accuracy of the model is approximately 79% with an error of omission or false positive value of 10% and an error of commission or false negative value of 11% (Table 4.7). This has a much lower

Table 4.7 Error Matrix based on gully prediction model

	Predicted Absence	Predicted Presence
Actual Absence	62	9
Actual Presence	8	1

amount of incorrectly predicted outcomes than the previous method used. This model received a kappa statistic of -0.014, which shows that some errors are still occurring but is still better than the previous method. Future studies should focus on increasing the kappa statistic even more to produce better classifications. However, the current prediction model produces fewer false positives (Table 4.3).

Figure 4.3 Gully Presence predicted by the gully model developed



CHAPTER 5 - Summary and Conclusions

Military vehicles cause substantial environmental degradation in non-uniform patterns across the landscape, which can result in excessive soil erosion and nonpoint source pollution of waterbodies. When compared to agricultural and natural landscapes, very little research has been completed on military maneuver training lands. This study focused on gully erosion on military training lands because gully erosion not only environmental degradation through soil losses and impaired water quality, but also leads to soldier injuries and equipment damage. An improved understanding of the factors that affect gully erosion and the associated processes will assist with the reduction of safety hazards and environmental degradation associated with gully erosion.

The goal of this study was to locate and assess gully erosion occurring on Fort Riley, and develop a predictive model using a logistic regression analysis on the gully location (i.e. soils, topography, etc.) and assessment data. Gullies were located using three different methods, a LiDAR-based elevation variation model, information from Fort Riley personnel, and field reconnaissance. A total of 45 gullies were located and assessed as part of the project. A logistic regression analysis was run to evaluate several gully erosion factors related to topography, landuse/landcover, and soil characteristics in order to develop the predictive model. The logistic regression identified significant factors including available water capacity, sodium adsorption ratio, landuse/landcover classes, drainage classes, and particle sizes.

In order to improve the predictive model function and accuracy, all model inputs were tested for multicollinearity ensuring that every model input had a unique effect on the model output. A variety of watershed characteristics were eliminated prior to performing the logistic regression so that their relationship to other variables did not result in incorrect coefficient signs and values of the variables included. In general, goodness of fit statistics suggested that the gully prediction equation was accurate. The logistic regression performed on the various soil characteristics for watershed areas suggested that available water capacity was one of the most important factors that affect the formation of gullies. The areas with high available water capacities occur on areas with higher than average slopes and higher clay contents. Clay is able to store a large amount of water, but it has very low infiltration rates due to its small pore size.

This results in increased runoff and erosion. The logistic regression also suggested that landuse/landcover classes, sodium adsorption ratios, and soil characteristic data such as erosion classes and drainage classes were also important in the prediction of gully erosion. Area appeared to be relatively unimportant, but this was a result of the small range of watershed area values.

In the goodness of fit statistics analysis, it was shown that the equation produced was accurate. The ROC curve showed that sensitivity and specificity were linearly related. The area under the ROC curve corresponds to the probability such that a positive event has a higher probability given to it by the model than a negative event. The area under the curve showed that our equation was a very good model, especially for natural occurrences. Statistics that were produced show that significant information was provided by the gully prediction model.

The model's error matrix showed that the model was able to predict gully absence extremely well. It had an accuracy of approximately 79% with an error of omission or false positive value of 10% and an error of commission or false negative value of 11%. This was a much higher accuracy than the previous model used to locate gully erosion on Fort Riley. The model predicted fewer false positive values than the previous gully locating method. However, the model tended to under-predict the presence of gullies on the base. This can be explained by the relatively low amount of watersheds used in the model that have known gullies present in spite of the number of areas checked in the field (45 gullies identified). The equation produced from the logistic regression would be even more accurate with more sample data, both known gully locations and locations of confirmed gully absence.

Gully erosion was not easily found on Fort Riley. The grasses increase infiltration, but also impede the ability to see the gully erosion occurring because of the height and density of the grasses. The previous model that was used to locate gully erosion over-predicted the amount of gully erosion occurring on Fort Riley by predicting 360 possible gullies, but ground verification of the model resulted in only 30 actual gullies. The model that was developed as part of this study eliminated the issue concerning the high amount of false positives predicted in the previous model. It estimated 192 watersheds out of the 1577 watersheds for the Fort Riley area.

Gully monitoring and assessment over time will aid in the effort for developing an accurate model to predict gully presence and the factors that result in the formation of gullies. It is imperative to obtain more information to increase the sensitivity of the model. This is especially important when anthropogenic variables are a factor because very few studies have been conducted to determine the military's effect on gully erosion.

Gully erosion found on military training lands is a safety hazard that leads to increased soldier injuries and equipment damage. To prevent these hazards, gully erosion processes and the factors causing gully erosion need to be better understood. This study was the first step in gaining a better understanding of gully erosion on areas that receive substantial disturbances in non-uniform patterns across the landscape. This could be improved by studying gully erosion on different military bases that have different vegetation, soil characteristics, topography, and military training exercises. In this way, gully erosion could be more accurately modeled.

A model capable of accurately locating gully erosion needs to be developed to keep soldiers safe, decrease the amount of equipment being damaged because of gully erosion, and to help estimate costs to remediate the gully erosion problem. Once gully erosion is better understood, it could help determine the carrying capacity of a given parcel of land. This would allow for more sustainable training exercises within military bases and could also lead to decreased erosion occurring. Once erosion is remediated, sedimentation will decrease and water quality will improve. The improved water quality would allow the aquatic habitats to be restored and allow native species to replenish areas where they once thrived. The ability to develop more sustainable practices on military bases would aid in supporting present and future training requirements while preserving and enhancing ecosystem integrity.

Recommendations

It is recommended that while gullies and the factors that affect their formation are being researched, the military refrain from using tanks during wet conditions. By avoiding times when the land is especially susceptible such as after a precipitation event when soil is more easily compacted and vegetation is vulnerable, land degradation can be reduced. This would reduce the amount of bare ground exposure and rutting, resulting in less gully erosion occurring on the base.

Further monitoring and assessment of gullies will help further the knowledge of why and where gullies form. The use of the gully information database that was created will help organize the information collected over time and will facilitate future analyses. The accuracy of predicting gully erosion could be increased greatly with information of military activities performed during a study period as well as different areas' water table depths. Incorporating precipitation data would improve the prediction model and better our understanding of gully erosion in the area by providing data on erosion rates. To obtain accurate erosion rates and projected soil losses, increased monitoring and assessment of gully erosion is essential. Erosion measurements should be taken at intervals ranging from a single rainstorm to many years.

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Appendix A - Gully Sample Data

The following tables illustrate the sample data that was used in the logistic regression to develop the equation to determine the presence of gullies.

Table A.1 Sample Variable Data

ID	Gully	Area	Aspect	AWC	Bedrock	Clay	Horizon	KSAT	KW	OM	Sand	SAR	Silt	Slope	SoilH20	Wgt
6	0	433210.0	159.0	0.2	29.7	31.1	23.8	5.6	5.4	2.9	8.2	0.21	60.8	3.5	19.5	1.5
14	0	300471.0	192.5	0.2	0.0	30.6	47.4	5.7	5.4	2.9	5.9	0.07	63.5	2.6	19.5	1.5
18	0	440234.0	215.7	0.2	2.8	33.3	27.4	3.7	5.8	2.8	4.7	0.08	62.0	3.0	20.1	1.5
23	0	651621.0	202.8	0.2	11.5	31.7	22.7	4.2	5.6	3.0	6.9	0.22	61.4	3.0	19.9	1.5
27	0	369188.0	190.0	0.2	23.9	28.6	50.6	7.2	5.6	2.8	10.6	0.03	60.8	3.4	18.4	1.5
30	0	399180.0	143.8	0.2	0.5	32.2	24.5	3.9	5.7	2.9	3.6	0.02	64.2	2.6	20.0	1.5
33	0	261255.0	195.3	0.2	56.1	31.3	20.2	5.1	5.8	2.9	9.7	0.31	59.0	3.7	20.3	1.6
39	0	393054.0	198.2	0.2	21.6	29.6	28.1	6.5	5.4	3.1	9.4	0.23	60.9	3.7	19.1	1.5
59	0	236939.0	140.6	0.2	43.3	32.0	31.1	5.7	5.7	2.9	7.7	0.00	60.3	3.7	19.4	1.5
62	0	187497.0	100.9	0.2	0.0	33.3	20.0	2.0	6.0	3.0	1.0	0.00	65.7	1.2	21.0	1.6
64	0	559534.0	227.7	0.2	43.8	29.8	36.6	6.9	6.1	2.6	11.6	0.10	58.7	3.5	18.7	1.5
74	0	130339.0	134.9	0.2	11.3	30.0	32.9	6.5	5.4	3.0	9.4	0.00	60.6	3.7	19.0	1.5
78	0	351201.0	184.0	0.2	25.6	30.3	22.7	6.1	5.6	2.8	10.8	0.00	59.0	4.5	18.7	1.5
88	0	147319.0	133.9	0.2	34.0	31.8	20.3	4.2	5.9	3.0	10.5	0.18	57.7	4.3	19.8	1.5
90	0	450124.0	160.7	0.2	0.0	33.5	20.0	2.0	6.0	3.0	1.0	0.00	65.5	1.5	21.1	1.6
91	0	261400.0	163.4	0.2	66.9	30.3	21.6	6.3	5.8	3.0	10.6	0.07	59.1	3.4	19.2	1.5
92	0	257630.0	191.2	0.2	24.7	28.8	23.1	6.8	5.3	3.0	10.6	0.00	60.6	4.2	18.1	1.5
98	0	359344.0	215.3	0.2	22.8	29.0	30.6	6.8	5.3	3.0	11.1	0.08	60.0	5.7	18.4	1.5
102	0	223887.0	177.8	0.2	19.6	29.3	38.8	7.2	5.5	2.5	10.0	0.00	60.7	4.7	18.2	1.6
106	0	179887.0	179.1	0.2	30.4	32.4	20.4	4.1	5.9	2.8	8.7	0.00	58.9	2.5	19.1	1.5
125	0	201432.0	160.7	0.2	6.1	30.4	76.5	7.5	6.0	1.8	7.0	0.00	62.6	2.7	19.0	1.6

ID	Gully	Area	Aspect	AWC	Bedrock	Clay	Horizon	KSAT	KW	OM	Sand	SAR	Silt	Slope	SoilH20	Wgt
152	0	689128.0	191.9	0.2	41.8	33.7	18.1	3.4	6.1	2.7	6.1	0.06	60.2	2.8	20.1	1.5
162	0	749893.0	197.3	0.2	32.1	32.3	23.8	5.1	5.4	3.0	9.6	0.08	58.1	5.8	19.6	1.5
165	0	80899.1	174.1	0.2	0.0	33.0	83.5	5.5	6.5	1.8	8.5	0.50	58.5	3.7	21.0	1.6
166	0	102416.0	198.1	0.2	25.3	32.9	21.5	3.4	5.8	3.0	7.3	0.42	59.8	3.4	20.9	1.6
180	0	261698.0	142.8	0.2	0.0	34.5	18.6	2.7	6.0	2.7	2.4	0.00	63.1	1.2	19.7	1.4
183	0	332251.0	171.9	0.2	11.4	32.6	18.7	3.8	5.9	2.8	6.2	0.14	61.2	2.3	19.5	1.5
187	0	274582.0	147.1	0.2	26.4	29.8	28.8	5.6	5.8	2.8	9.2	0.23	61.1	3.9	19.2	1.5
190	0	74925.6	125.0	0.2	0.0	32.8	137.3	8.1	6.8	0.8	7.0	0.00	60.2	3.5	19.9	1.6
194	0	166180.0	143.4	0.2	14.1	28.8	55.5	8.8	5.3	2.1	9.6	0.00	61.6	5.7	17.2	1.6
197	0	235538.0	217.6	0.2	32.5	28.0	30.6	8.9	5.4	2.2	12.1	0.00	60.0	7.1	16.4	1.6
198	0	79869.2	223.8	0.2	15.0	27.2	26.5	8.4	4.9	2.7	10.1	0.00	62.7	5.9	16.3	1.5
207	0	265446.0	172.3	0.2	7.9	33.9	17.7	3.3	6.1	2.6	4.3	0.00	61.9	2.0	19.1	1.4
208	0	273473.0	167.7	0.2	4.9	33.0	18.5	3.0	6.0	2.9	4.6	0.19	62.4	2.2	20.2	1.5
243	0	125437.0	129.4	0.2	81.9	33.4	32.6	5.3	6.1	2.5	9.3	0.00	57.3	4.7	20.3	1.5
245	0	271240.0	118.6	0.2	104.9	31.3	26.4	5.2	6.2	2.6	12.1	0.00	56.6	3.8	19.8	1.5
246	0	396205.0	203.8	0.2	37.7	29.9	19.0	6.8	5.7	2.5	10.8	0.00	59.3	5.0	17.2	1.5
260	0	246046.0	150.0	0.2	36.8	31.4	18.9	4.8	6.0	2.9	8.7	0.15	59.9	2.5	19.6	1.5
267	0	579318.0	157.6	0.2	0.0	33.1	19.5	2.3	6.0	2.9	1.5	0.00	65.4	1.4	20.1	1.5
277	0	601266.0	188.5	0.2	22.4	28.7	21.8	8.2	5.1	2.3	9.9	0.00	61.4	6.5	16.4	1.5
281	0	275849.0	213.9	0.2	19.6	27.8	21.0	8.3	5.1	2.3	10.2	0.00	62.0	7.6	16.0	1.5
285	0	216543.0	217.9	0.2	0.0	33.5	18.0	3.0	6.0	2.8	6.4	0.48	60.0	3.4	20.4	1.5
293	0	287820.0	214.0	0.2	19.4	27.2	20.0	8.6	5.1	2.3	10.3	0.00	62.5	7.4	15.9	1.5
308	0	232134.0	168.9	0.2	0.0	34.6	18.0	2.9	6.0	2.6	3.3	0.08	62.0	2.1	19.6	1.4
324	0	137278.0	167.6	0.2	33.1	30.6	16.8	4.3	6.2	3.0	10.2	0.21	59.3	2.2	19.7	1.5
326	0	335725.0	179.1	0.2	10.7	29.8	28.4	5.6	5.0	3.3	8.9	0.15	61.3	4.1	19.4	1.5
330	0	117456.0	190.9	0.2	28.9	32.2	25.5	4.7	5.4	3.0	10.1	0.07	57.6	5.9	19.4	1.5
333	0	355023.0	155.3	0.2	0.0	34.4	18.8	2.4	6.0	2.8	2.4	0.00	63.2	2.1	20.5	1.5
336	0	199242.0	103.1	0.2	10.5	33.9	21.6	2.9	5.7	2.9	4.8	0.14	61.3	3.0	20.8	1.5
346	0	213375.0	178.2	0.2	18.5	31.0	20.1	5.0	5.7	3.0	9.5	0.17	59.5	4.3	19.2	1.5
348	0	288823.0	198.2	0.2	15.8	32.8	24.6	3.9	5.5	3.1	8.1	0.13	59.1	4.2	20.2	1.5
349	0	166023.0	221.0	0.2	3.6	34.3	21.6	2.2	5.8	3.0	2.1	0.00	63.6	2.3	21.3	1.6
351	0	162428.0	185.5	0.2	2.7	33.0	116.5	7.2	6.4	1.4	7.4	0.00	59.6	3.4	20.2	1.6

ID	Gully	Area	Aspect	AWC	Bedrock	Clay	Horizon	KSAT	KW	OM	Sand	SAR	Silt	Slope	SoilH20	Wgt
352	0	236277.0	214.1	0.2	29.0	33.2	19.0	3.7	5.9	2.8	7.8	0.16	58.9	3.5	19.7	1.5
354	0	387473.0	145.6	0.2	27.3	33.2	33.9	4.0	5.9	2.7	6.4	0.15	60.4	3.8	20.8	1.6
355	0	92915.4	131.2	0.2	20.9	35.1	23.1	2.8	5.7	2.8	5.1	0.00	59.8	2.3	20.5	1.5
357	0	429349.0	131.6	0.2	18.9	33.3	50.9	5.5	5.4	2.6	8.8	0.00	57.9	5.6	20.0	1.6
362	0	544538.0	218.7	0.2	23.7	34.6	21.1	2.5	5.8	2.8	3.6	0.03	61.8	2.6	21.0	1.5
363	0	304981.0	184.0	0.2	27.8	30.8	20.8	5.0	5.7	3.0	9.2	0.00	60.0	2.8	19.2	1.5
364	0	574868.0	217.6	0.2	4.9	33.6	20.0	2.9	5.7	2.9	6.1	0.25	60.3	3.4	21.0	1.6
372	0	403655.0	171.9	0.2	19.0	31.8	27.5	4.7	5.3	3.2	9.1	0.19	59.1	4.9	19.8	1.5
373	0	432548.0	158.9	0.2	27.9	32.4	20.2	3.6	5.8	3.0	7.5	0.24	60.2	3.4	20.8	1.6
374	0	565698.0	152.2	0.2	5.8	33.4	19.4	2.8	6.1	2.9	4.0	0.12	62.5	2.4	20.5	1.5
378	0	482196.0	171.4	0.2	0.0	33.7	20.4	2.9	5.9	2.8	2.6	0.00	63.7	1.8	20.0	1.5
381	0	375910.0	229.8	0.2	9.5	33.9	18.3	3.2	5.9	2.8	4.8	0.19	61.2	2.5	21.1	1.6
383	0	339844.0	150.2	0.2	9.4	32.8	21.8	3.9	5.7	2.9	6.8	0.26	60.5	3.3	19.7	1.5
401	0	376280.0	154.3	0.2	12.0	30.9	34.7	5.2	5.8	2.7	7.5	0.13	61.5	3.4	19.4	1.5
406	0	211471.0	151.6	0.2	31.0	32.7	28.9	4.4	5.1	3.1	7.7	0.10	59.6	5.2	20.2	1.5
408	0	769370.0	141.2	0.2	14.2	32.1	22.0	3.8	5.8	3.1	8.5	0.29	59.4	3.8	20.3	1.6
409	0	301024.0	145.6	0.2	6.6	31.6	38.1	5.2	5.5	2.8	6.7	0.00	61.7	5.0	19.9	1.6
413	0	196289.0	173.0	0.2	87.8	34.9	18.4	3.0	6.0	2.5	5.4	0.05	59.7	2.6	21.3	1.5
414	0	359882.0	238.7	0.2	7.0	33.4	17.6	3.2	6.0	2.8	6.1	0.29	60.4	2.3	20.0	1.5
415	0	353221.0	221.1	0.2	23.9	33.8	18.5	2.8	5.9	2.7	4.8	0.08	61.4	2.6	20.4	1.5
424	0	175343.0	164.6	0.2	32.8	32.6	30.5	4.7	5.0	3.1	8.6	0.00	58.9	6.2	19.8	1.5
425	0	223314.0	207.9	0.2	0.0	33.5	18.4	2.6	6.0	2.8	3.2	0.15	63.3	2.2	20.1	1.5
431	0	106709.0	210.5	0.2	8.4	31.3	23.0	4.6	5.3	3.1	8.5	0.27	60.2	4.0	20.1	1.6
432	0	377995.0	177.8	0.2	10.3	32.9	21.0	3.3	5.8	3.0	5.9	0.11	61.2	2.5	20.6	1.6
434	0	293522.0	152.0	0.2	73.8	32.4	20.0	5.8	6.0	2.8	6.9	0.00	60.7	2.5	20.0	1.5
435	0	299911.0	243.2	0.2	11.1	34.3	29.6	3.2	5.4	3.0	5.3	0.00	60.4	3.5	20.8	1.6
436	0	460228.0	165.0	0.2	37.1	35.0	24.4	3.5	4.9	3.1	7.7	0.00	57.3	6.7	20.2	1.5
439	0	290903.0	198.1	0.2	22.5	32.4	21.7	3.7	5.6	2.9	5.5	0.03	62.1	3.2	20.1	1.5
443	0	153078.0	208.5	0.2	13.8	31.5	26.3	4.7	5.2	3.3	9.3	0.17	59.2	3.7	20.2	1.6
445	0	349355.0	130.8	0.2	34.5	29.3	42.3	6.2	4.9	3.0	9.5	0.00	58.5	7.1	18.4	1.5
448	0	523266.0	183.8	0.2	42.0	33.4	25.0	4.3	5.2	3.1	9.6	0.00	57.0	5.6	19.7	1.5
449	0	196897.0	194.7	0.2	31.2	31.6	22.2	4.7	5.7	2.9	8.3	0.04	60.1	3.3	19.3	1.5

ID	Gully	Area	Aspect	AWC	Bedrock	Clay	Horizon	KSAT	KW	OM	Sand	SAR	Silt	Slope	SoilH20	Wgt
450	0	377876.0	203.0	0.2	6.7	31.8	64.1	5.7	5.8	2.2	6.6	0.00	61.5	4.1	19.5	1.6
454	0	146690.0	169.3	0.2	25.1	27.5	31.5	7.0	5.1	3.6	12.2	0.13	60.3	3.7	18.5	1.5
456	0	202654.0	216.8	0.2	0.0	33.7	18.1	2.6	6.0	2.8	4.0	0.26	62.3	2.3	20.7	1.5
460	0	209819.0	179.6	0.2	52.2	31.5	17.9	4.5	5.9	2.8	8.1	0.30	60.4	3.0	20.5	1.6
462	0	353309.0	156.8	0.2	0.0	33.9	19.3	2.3	6.0	2.8	1.7	0.00	64.4	1.6	20.4	1.5
465	0	362953.0	146.9	0.2	35.6	33.7	32.3	4.3	5.3	2.8	8.5	0.00	57.8	6.1	19.9	1.5
466	0	267666.0	193.8	0.2	49.7	31.9	20.2	4.6	5.7	2.8	7.7	0.08	60.3	3.4	19.7	1.5
472	0	241569.0	153.7	0.2	27.9	26.4	63.0	7.4	5.4	2.4	11.1	0.00	55.4	3.6	16.9	1.4
473	0	204873.0	166.9	0.2	42.1	35.9	28.4	3.3	5.1	2.9	7.7	0.00	56.5	9.1	20.4	1.5
474	0	251261.0	136.1	0.2	31.5	35.0	60.1	4.5	5.6	2.4	7.7	0.00	57.3	6.0	20.8	1.6
475	0	192011.0	125.9	0.2	8.1	30.3	47.0	6.6	5.9	2.5	7.8	0.00	61.9	5.0	18.6	1.5
480	0	294117.0	188.0	0.2	38.5	31.8	24.7	5.0	5.7	3.0	11.1	0.10	57.1	4.8	19.2	1.5
481	0	321842.0	148.1	0.2	0.0	24.1	53.9	8.0	4.3	2.9	7.9	0.00	58.6	3.5	16.4	1.4
482	0	265979.0	179.4	0.2	49.1	31.9	40.8	5.8	5.5	2.5	7.9	0.00	56.6	7.9	19.2	1.5
486	0	207079.0	109.8	0.2	19.0	32.9	17.9	3.8	6.0	2.8	7.9	0.29	59.2	2.8	19.9	1.5
488	0	469764.0	138.6	0.2	9.8	34.0	21.2	3.2	5.8	2.9	6.8	0.34	59.1	3.5	20.6	1.5
494	0	220317.0	141.5	0.2	13.8	30.9	22.0	4.1	5.7	2.8	5.8	0.05	63.4	3.5	19.4	1.5
495	0	298305.0	177.3	0.2	40.0	31.6	52.2	4.7	5.4	2.1	8.7	0.00	53.0	7.5	18.4	1.4
496	0	219107.0	200.6	0.2	19.2	32.5	21.9	4.2	5.5	2.9	6.1	0.09	61.4	3.6	19.9	1.5
497	0	454902.0	173.3	0.2	52.3	34.1	23.3	4.0	5.3	2.9	10.1	0.00	55.9	7.3	19.8	1.5
505	0	150956.0	182.2	0.2	73.7	33.5	20.6	4.6	5.7	2.8	9.9	0.00	56.5	5.7	20.0	1.5
506	0	241176.0	225.6	0.2	10.1	33.8	66.0	4.6	5.8	2.3	7.5	0.04	58.7	5.6	20.2	1.6
509	0	174482.0	222.6	0.2	86.3	31.3	19.8	5.7	6.1	2.7	9.0	0.00	59.7	4.2	19.6	1.5
517	0	395661.0	219.5	0.2	3.3	31.9	19.5	2.8	5.9	3.0	6.1	0.14	62.0	2.3	20.0	1.6
520	0	334936.0	178.9	0.2	2.5	33.7	18.1	2.6	5.9	2.8	5.5	0.27	60.8	2.4	20.9	1.6
525	0	178802.0	177.3	0.2	5.8	28.4	28.5	5.3	5.8	2.8	6.8	0.00	64.8	3.3	18.3	1.5
530	0	387271.0	200.6	0.2	8.3	32.9	16.2	3.3	6.0	2.8	6.6	0.35	60.5	2.9	20.9	1.6
532	0	246702.0	135.3	0.2	0.0	30.0	21.3	3.4	5.9	2.9	6.1	0.00	63.9	3.8	19.0	1.6
538	0	256014.0	129.8	0.2	31.3	32.1	19.9	4.1	5.9	2.9	9.5	0.11	58.4	3.1	19.5	1.5
550	0	139174.0	193.2	0.2	44.5	30.8	25.5	5.2	4.8	2.8	8.3	0.00	60.9	10.4	18.7	1.5
554	0	305303.0	182.3	0.2	17.5	32.4	23.4	4.2	5.6	3.2	9.2	0.09	58.4	3.3	20.3	1.5
557	0	86521.0	132.2	0.2	36.3	30.4	48.6	3.9	4.9	2.0	6.7	0.00	50.4	10.6	17.6	1.3

ID	Gully	Area	Aspect	AWC	Bedrock	Clay	Horizon	KSAT	KW	OM	Sand	SAR	Silt	Slope	SoilH20	Wgt
559	0	113764.0	185.1	0.2	23.3	32.9	22.4	3.4	5.7	3.0	8.3	0.50	58.8	3.9	21.0	1.6
565	0	317859.0	214.3	0.2	63.5	33.8	16.2	4.6	6.3	2.6	6.0	0.06	60.2	2.4	20.3	1.5
575	0	239858.0	128.8	0.2	81.5	33.5	16.4	4.5	6.2	2.6	6.4	0.00	60.1	2.8	20.3	1.5
600	0	569183.0	157.9	0.2	31.7	30.8	34.1	3.9	4.7	2.8	7.7	0.00	56.7	8.0	18.6	1.5
604	0	329158.0	173.4	0.2	54.2	31.3	19.0	3.5	4.3	3.1	8.8	0.00	59.8	10.4	19.2	1.6
609	0	189491.0	180.8	0.2	41.0	35.1	23.9	3.0	4.8	3.0	7.9	0.00	57.0	10.5	20.2	1.5
611	0	469201.0	166.8	0.2	52.8	34.0	20.5	4.1	5.1	2.9	8.4	0.00	57.7	7.9	19.8	1.5
616	0	267950.0	190.6	0.2	37.3	34.1	20.4	3.4	6.0	2.7	6.1	0.21	59.8	3.2	20.5	1.5
632	0	108291.0	185.6	0.2	0.0	33.9	18.3	2.4	6.0	2.9	3.5	0.09	62.6	2.1	20.9	1.5
653	0	145896.0	199.6	0.2	64.4	31.6	16.5	3.4	4.3	3.0	8.7	0.00	59.7	11.0	18.9	1.5
660	0	328477.0	199.7	0.2	0.0	33.7	19.1	2.4	6.0	2.8	1.9	0.00	64.5	1.6	20.0	1.5
685	0	173771.0	221.3	0.2	8.9	31.8	21.1	3.3	5.6	3.0	7.5	0.00	60.7	4.2	19.4	1.5
686	0	295076.0	154.8	0.2	43.0	34.6	24.8	3.6	5.0	2.9	8.2	0.00	57.2	7.1	20.1	1.6
691	0	436963.0	222.0	0.2	0.0	33.8	19.0	2.5	6.0	2.7	2.0	0.00	64.2	1.3	19.8	1.5
699	0	448119.0	175.2	0.2	38.4	31.3	20.4	4.6	4.6	3.0	8.5	0.00	60.2	9.6	19.0	1.5
704	0	357616.0	149.9	0.2	41.7	34.6	24.0	3.5	5.1	3.0	9.2	0.00	56.2	6.6	20.0	1.5
712	0	139570.0	217.7	0.2	0.0	33.4	22.3	3.7	5.7	2.8	3.6	0.00	63.0	1.8	19.2	1.4
733	0	306775.0	203.1	0.2	0.0	34.0	17.8	2.9	6.0	2.6	3.3	0.00	62.7	1.9	19.1	1.4
740	0	671277.0	169.4	0.2	67.7	31.8	17.8	3.6	4.5	3.0	9.4	0.00	58.8	10.0	18.9	1.5
744	0	183356.0	161.3	0.2	65.1	31.5	18.6	3.7	4.6	3.0	10.4	0.00	58.1	10.6	18.8	1.5
754	0	355679.0	194.6	0.2	68.1	33.4	20.8	4.4	5.4	2.9	9.2	0.00	57.5	7.9	19.9	1.5
761	0	188107.0	213.6	0.2	38.5	30.5	14.9	5.1	6.4	2.7	11.3	0.10	58.2	2.2	18.0	1.4
770	0	154677.0	252.9	0.2	2.7	24.9	20.0	6.9	5.2	2.7	9.9	0.00	65.3	5.0	15.6	1.4
778	0	206559.0	187.6	0.2	33.9	33.0	20.9	4.1	5.6	3.0	10.2	0.32	56.8	6.0	20.3	1.6
782	0	553615.0	153.8	0.2	68.2	31.4	17.2	4.5	4.9	2.9	9.6	0.02	59.0	7.1	19.0	1.5
784	0	391872.0	247.7	0.2	12.3	32.1	17.4	3.0	5.9	2.8	5.1	0.00	62.8	2.2	18.8	1.5
786	0	207073.0	225.9	0.2	0.0	30.0	15.0	3.0	6.0	3.0	7.0	0.00	63.0	3.1	19.0	1.5
788	0	297834.0	160.6	0.2	49.4	30.1	16.4	4.1	5.0	3.2	11.3	0.22	58.6	7.8	19.4	1.6
793	0	684778.0	176.1	0.2	5.4	33.6	19.5	3.0	6.0	2.8	4.0	0.04	62.5	2.4	20.2	1.5
795	0	228505.0	208.9	0.2	1.0	30.3	15.6	3.0	6.0	3.0	7.0	0.00	62.7	4.0	19.1	1.5
797	0	290228.0	209.9	0.2	21.4	33.4	21.7	3.1	5.7	2.8	6.3	0.00	60.3	2.8	19.5	1.5
803	0	171905.0	186.7	0.2	28.9	31.5	15.8	4.8	6.2	2.9	7.4	0.26	61.1	2.7	20.2	1.5

ID	Gully	Area	Aspect	AWC	Bedrock	Clay	Horizon	KSAT	KW	OM	Sand	SAR	Silt	Slope	SoilH20	Wgt
806	0	179160.0	202.5	0.2	4.6	29.6	18.0	3.0	5.8	3.0	7.1	0.00	63.3	2.5	18.1	1.5
841	0	250116.0	168.8	0.2	75.7	29.9	16.2	4.4	4.9	3.0	12.5	0.00	57.6	7.3	18.1	1.5
844	0	231845.0	159.2	0.2	3.5	30.9	17.3	3.0	5.8	3.0	7.1	0.00	62.0	2.5	19.3	1.5
846	0	531294.0	235.9	0.2	7.2	24.6	20.4	6.6	4.8	2.3	9.5	0.00	60.4	5.5	15.1	1.4
851	0	468967.0	219.5	0.2	5.8	30.8	22.4	3.4	5.5	3.0	7.3	0.00	61.8	4.0	19.3	1.5
860	0	305407.0	143.9	0.2	10.3	32.3	17.2	3.1	6.1	2.9	6.3	0.31	61.4	3.0	20.4	1.5
866	0	347466.0	142.1	0.2	7.0	31.8	19.5	3.0	5.7	3.0	7.2	0.00	61.0	4.1	19.5	1.5
867	0	172431.0	220.2	0.2	15.8	34.1	25.3	3.0	5.3	3.0	7.5	0.00	58.4	3.8	20.2	1.6
872	0	544470.0	218.9	0.2	68.7	33.3	17.5	4.4	6.1	2.7	7.1	0.00	59.6	2.7	20.1	1.5
882	0	199966.0	263.9	0.2	2.3	30.2	18.8	3.3	5.9	3.0	7.2	0.00	62.6	3.2	19.0	1.5
885	0	290121.0	171.6	0.2	72.9	29.2	16.7	5.7	5.6	3.0	15.1	0.00	55.7	5.9	17.9	1.5
886	0	410628.0	163.8	0.2	32.2	28.0	19.3	7.5	5.7	3.0	10.0	0.24	62.0	3.2	18.7	1.5
888	0	124643.0	178.9	0.2	14.8	33.9	24.6	3.0	5.4	3.0	7.5	0.00	58.7	3.5	20.1	1.6
891	0	120018.0	159.9	0.2	0.0	29.4	18.8	3.5	5.9	3.0	7.2	0.00	63.4	4.0	18.7	1.5
895	0	431783.0	177.5	0.2	10.2	32.7	21.6	3.0	5.6	3.0	7.3	0.00	60.0	3.7	19.8	1.5
899	0	119045.0	203.6	0.2	7.7	31.4	23.8	3.5	5.6	3.0	7.4	0.00	61.2	4.9	19.3	1.5
910	0	154264.0	89.7	0.2	1.4	34.1	18.5	2.8	5.9	2.8	4.5	0.25	61.4	2.8	20.4	1.5
912	0	539758.0	196.4	0.2	3.6	30.2	22.2	3.6	5.7	3.0	7.4	0.00	62.5	4.1	18.9	1.5
926	0	234559.0	229.1	0.2	52.3	32.8	22.1	3.5	4.8	3.0	9.7	0.00	57.5	7.3	19.4	1.6
928	0	244205.0	174.2	0.2	59.6	32.6	19.4	3.5	4.7	3.0	9.7	0.00	57.7	8.3	19.2	1.5
929	0	315799.0	151.4	0.2	60.0	28.9	14.8	5.1	5.3	3.0	13.1	0.20	57.9	5.8	18.4	1.5
948	0	169125.0	168.2	0.2	79.3	32.7	15.9	6.2	6.3	2.6	7.7	0.07	59.5	3.1	19.9	1.5
949	0	377713.0	155.0	0.2	31.4	33.1	17.2	4.9	6.2	2.6	5.8	0.00	61.1	2.1	19.0	1.4
954	0	526619.0	201.1	0.2	53.9	32.4	21.8	3.8	4.9	3.0	10.3	0.00	57.3	5.7	19.2	1.5
956	0	310748.0	206.2	0.2	5.4	31.4	18.5	3.0	5.8	3.0	7.2	0.00	61.4	3.7	19.4	1.5
978	0	119253.0	188.0	0.2	9.6	32.5	21.3	3.0	5.6	3.0	7.3	0.00	60.2	4.0	19.7	1.5
979	0	193785.0	222.3	0.2	8.1	32.0	20.3	3.0	5.7	3.0	7.2	0.00	60.8	2.3	19.5	1.5
981	0	290108.0	194.7	0.2	55.0	32.1	20.7	3.4	4.7	3.0	9.1	0.00	58.8	7.7	19.0	1.5
985	0	291795.0	208.4	0.2	6.8	31.3	22.1	3.4	5.6	3.0	7.4	0.00	61.3	4.5	19.3	1.5
986	0	320519.0	175.6	0.2	56.2	30.3	20.5	5.4	5.9	3.0	14.8	0.09	54.9	3.7	18.6	1.5
992	0	501583.0	186.4	0.2	4.8	28.8	23.6	4.7	5.5	2.9	8.2	0.00	63.0	3.4	18.0	1.5
994	0	342239.0	115.4	0.2	50.4	33.7	15.0	4.7	4.6	2.9	8.6	0.00	57.7	9.0	19.7	1.5

ID	Gully	Area	Aspect	AWC	Bedrock	Clay	Horizon	KSAT	KW	OM	Sand	SAR	Silt	Slope	SoilH20	Wgt
1004	0	570434.0	201.9	0.2	46.1	34.0	16.7	4.0	6.2	2.6	4.6	0.00	61.4	2.3	19.9	1.4
1007	0	474749.0	198.3	0.2	5.8	31.5	18.8	3.0	5.8	3.0	7.2	0.00	61.3	2.8	19.4	1.5
1013	0	454636.0	239.8	0.2	60.1	31.3	18.8	3.4	4.5	3.2	9.6	0.00	59.1	8.9	19.1	1.5
1020	0	187535.0	148.7	0.2	25.3	31.7	22.7	4.2	4.7	3.5	9.1	0.00	59.3	5.6	20.6	1.6
1021	0	312755.0	204.6	0.2	5.6	31.5	18.6	3.0	5.8	3.0	7.2	0.00	61.4	4.2	19.4	1.5
1024	0	444495.0	167.4	0.2	23.3	32.1	17.2	3.4	6.1	2.9	9.1	0.56	58.8	3.1	20.8	1.6
1026	0	296354.0	154.8	0.2	48.9	32.1	20.9	3.0	4.5	3.3	8.8	0.00	59.1	8.8	19.9	1.6
1029	0	233372.0	221.5	0.2	11.6	30.6	18.7	3.0	5.8	3.0	7.4	0.09	62.0	2.3	18.9	1.5
1031	0	472741.0	192.3	0.2	4.6	30.9	18.0	3.0	5.8	3.0	7.1	0.00	62.0	2.8	19.1	1.5
1038	0	220272.0	214.5	0.2	79.1	30.3	14.5	3.5	4.3	3.0	10.4	0.00	59.3	9.0	18.3	1.5
1042	0	493133.0	184.5	0.2	55.0	27.7	13.6	6.0	6.5	3.0	17.0	0.44	55.3	3.5	18.3	1.5
1051	0	430173.0	187.2	0.2	49.3	27.4	18.3	6.7	6.1	3.1	15.6	0.24	57.0	3.4	17.9	1.5
1067	0	219066.0	119.0	0.2	86.1	32.0	21.7	5.1	5.8	2.9	8.3	0.13	59.7	3.0	20.6	1.5
1071	0	307547.0	197.6	0.2	6.1	30.1	28.2	4.2	5.5	3.0	7.7	0.00	62.2	3.8	18.8	1.5
1074	0	273469.0	184.5	0.2	4.0	29.7	25.5	4.0	5.7	3.0	7.6	0.00	62.7	3.4	18.7	1.5
1076	0	378791.0	177.2	0.2	47.6	31.1	15.4	4.6	6.0	2.8	9.5	0.45	59.4	3.1	20.5	1.6
1079	0	374908.0	180.0	0.2	3.8	30.8	18.6	3.1	5.8	3.0	7.2	0.00	62.0	3.2	19.2	1.5
1084	0	208569.0	199.3	0.2	60.8	30.5	17.0	3.8	4.4	3.0	9.0	0.00	60.5	6.4	18.5	1.6
1085	0	219229.0	203.6	0.2	3.0	26.9	15.0	2.6	5.2	2.6	6.2	0.00	53.9	4.0	16.7	1.3
1086	0	263361.0	167.9	0.2	4.8	30.7	20.0	3.2	5.8	3.0	7.2	0.00	62.1	3.9	19.0	1.5
1094	0	332725.0	160.3	0.2	24.4	28.6	15.1	5.1	6.0	3.0	12.2	0.39	59.2	3.7	18.8	1.5
1096	0	235545.0	114.8	0.2	9.1	24.8	19.4	8.3	5.8	3.0	9.9	0.00	65.3	4.7	16.8	1.5
1097	0	231833.0	207.2	0.2	84.4	25.6	12.5	7.5	6.7	3.0	20.8	0.17	53.7	2.7	16.8	1.5
1108	0	146014.0	196.6	0.2	57.3	29.9	17.0	4.2	4.5	3.0	9.1	0.00	61.0	7.0	18.3	1.5
1119	0	229476.0	117.7	0.2	3.1	30.8	17.0	3.0	5.9	3.0	7.1	0.00	62.1	2.7	19.2	1.5
1122	0	164818.0	181.4	0.2	10.1	32.6	21.6	3.0	5.6	3.0	7.3	0.00	60.1	3.8	19.7	1.5
1128	0	207133.0	201.2	0.2	25.1	30.1	25.2	5.3	5.5	3.2	11.0	0.26	58.9	4.3	19.4	1.5
1130	0	234046.0	186.4	0.2	3.8	31.0	17.5	3.0	5.8	3.0	7.1	0.00	61.9	4.3	19.3	1.5
1132	0	576174.0	175.7	0.2	3.8	30.5	20.6	3.4	5.8	3.0	7.3	0.00	62.2	4.0	19.1	1.5
1136	0	501538.0	149.7	0.2	0.0	24.6	21.4	8.3	5.4	2.7	9.2	0.00	66.2	4.1	16.3	1.5
1139	0	289595.0	117.0	0.2	0.0	24.9	21.3	8.4	5.4	2.7	9.2	0.00	65.9	3.7	16.4	1.5
1141	0	175683.0	173.8	0.2	0.0	23.9	20.7	8.7	5.4	2.7	9.4	0.00	66.6	3.6	16.1	1.5

ID	Gully	Area	Aspect	AWC	Bedrock	Clay	Horizon	KSAT	KW	OM	Sand	SAR	Silt	Slope	SoilH20	Wgt
1147	0	273366.0	108.5	0.2	0.0	25.5	21.8	8.2	6.0	3.0	9.3	0.00	65.2	3.0	17.0	1.5
1148	0	177417.0	145.5	0.2	17.0	31.1	24.8	5.4	5.2	3.0	8.3	0.00	60.7	5.5	19.1	1.5
1150	0	519266.0	134.6	0.2	0.0	24.1	31.7	9.0	4.9	3.0	9.3	0.00	66.6	4.1	16.5	1.5
1155	0	978115.0	198.2	0.2	2.7	30.1	17.1	3.0	5.9	3.0	7.1	0.00	62.8	2.8	18.7	1.5
1161	0	128957.0	102.3	0.2	33.7	34.3	25.0	3.8	5.5	3.0	8.2	0.00	57.6	4.1	20.2	1.5
1166	0	275788.0	172.2	0.2	50.7	33.3	24.0	4.6	5.4	2.9	8.9	0.00	57.8	5.3	20.0	1.5
1167	0	197820.0	148.7	0.2	26.2	32.7	17.6	3.7	6.2	2.9	4.5	0.00	62.8	2.2	20.5	1.5
1176	0	413889.0	163.8	0.2	1.7	24.9	21.3	8.2	5.5	2.8	9.2	0.00	65.9	3.8	16.5	1.5
1178	0	391845.0	207.5	0.2	46.6	31.9	23.1	3.8	4.5	3.1	8.5	0.00	59.6	8.5	19.1	1.5
1190	0	186309.0	208.5	0.2	25.1	31.3	26.7	4.2	4.8	3.4	8.3	0.00	60.4	7.7	19.6	1.5
1191	0	608744.0	154.3	0.2	12.6	28.5	20.6	5.2	5.6	3.2	9.5	0.00	61.9	2.7	18.6	1.5
1197	0	200855.0	168.7	0.2	28.6	29.6	27.9	5.9	5.3	3.3	11.8	0.19	58.6	4.8	19.0	1.5
1212	0	582527.0	150.9	0.2	12.8	31.6	17.6	6.3	5.1	2.9	8.4	0.00	60.1	2.9	19.7	1.6
1226	0	171766.0	153.3	0.2	22.0	29.9	15.7	6.0	5.5	2.8	10.5	0.00	59.6	3.8	18.6	1.5
1227	0	108424.0	152.1	0.2	35.2	31.2	23.0	4.7	5.8	3.1	9.8	0.00	59.0	4.1	19.3	1.5
1229	0	192605.0	162.4	0.2	7.8	32.5	18.9	6.7	4.8	2.8	8.3	0.00	59.3	4.2	20.1	1.6
1230	0	252573.0	173.4	0.2	8.8	30.7	27.3	5.1	5.2	3.3	9.0	0.26	60.3	4.8	19.8	1.5
1231	0	391101.0	190.4	0.2	25.7	30.6	20.3	4.7	5.9	3.1	8.5	0.00	60.9	3.5	19.4	1.5
1233	0	436892.0	185.9	0.2	3.4	24.2	20.6	8.3	5.0	2.6	9.2	0.00	66.6	3.6	15.9	1.5
1244	0	726637.0	152.9	0.2	31.0	30.8	29.0	5.6	5.2	3.1	8.9	0.14	60.3	4.8	19.5	1.5
141	1	235745.0	148.7	0.2	28.7	33.7	22.9	3.4	5.8	2.9	7.2	0.09	59.1	3.3	20.0	1.5
176	1	215326.0	140.8	0.2	27.8	33.8	17.2	3.3	6.1	2.7	5.0	0.22	61.2	2.3	20.7	1.5
199	1	147587.0	224.3	0.2	0.0	34.7	18.3	2.8	6.0	2.6	2.7	0.00	62.6	2.0	19.4	1.4
220	1	274556.0	171.8	0.2	16.8	31.4	19.8	4.4	5.9	2.9	9.0	0.31	59.5	2.5	19.4	1.5
238	1	233605.0	229.2	0.2	11.2	37.0	16.1	1.8	6.0	2.5	1.7	0.00	61.3	2.8	22.7	1.6
261	1	246162.0	164.9	0.2	39.1	31.5	21.0	5.7	5.6	2.9	9.8	0.17	58.7	3.1	19.6	1.5
268	1	522496.0	160.9	0.2	16.3	32.9	16.9	3.8	6.1	2.7	6.5	0.07	60.7	1.9	19.0	1.4
317	1	369894.0	179.3	0.2	30.0	29.5	17.6	5.0	6.0	3.1	13.5	0.56	57.0	3.4	19.7	1.6
318	1	191359.0	120.7	0.2	93.5	34.1	17.1	3.9	6.2	2.6	6.9	0.15	59.1	3.9	21.3	1.5
340	1	602696.0	154.1	0.2	92.8	34.1	16.9	4.5	6.2	2.6	6.9	0.07	59.0	2.9	20.8	1.5
479	1	604502.0	190.1	0.2	30.0	34.3	21.1	3.5	5.8	2.7	6.5	0.00	59.2	2.9	19.6	1.5
498	1	377586.0	123.6	0.2	75.6	30.7	19.5	5.4	5.9	2.8	10.6	0.08	58.7	3.0	19.5	1.5

ID	Gully	Area	Aspect	AWC	Bedrock	Clay	Horizon	KSAT	KW	OM	Sand	SAR	Silt	Slope	SoilH20	Wgt
541	1	364358.0	198.2	0.2	18.1	31.7	20.9	4.3	5.9	3.0	10.0	0.34	58.4	4.3	19.8	1.5
673	1	367933.0	231.4	0.2	8.3	31.9	20.5	3.2	5.6	3.0	7.4	0.00	60.7	3.7	19.5	1.5
825	1	275761.0	179.1	0.2	16.9	31.5	17.5	3.5	6.1	3.0	6.6	0.15	61.9	2.6	20.3	1.6
829	1	266969.0	226.0	0.2	3.2	30.8	17.1	3.0	5.9	3.0	7.1	0.00	62.1	2.8	19.2	1.5
850	1	391210.0	228.1	0.2	50.4	28.9	17.5	5.4	6.2	3.0	14.0	0.00	57.1	3.3	17.9	1.5
863	1	288902.0	202.2	0.2	0.0	34.5	18.1	3.0	6.0	2.6	3.3	0.00	62.2	2.3	19.2	1.4
898	1	464850.0	188.0	0.2	24.6	32.7	20.7	3.8	5.7	2.9	7.5	0.00	59.8	3.7	19.5	1.5
969	1	263469.0	207.4	0.2	9.0	32.4	20.9	3.0	5.6	3.0	7.3	0.00	60.4	4.1	19.7	1.5
1058	1	416317.0	223.4	0.2	0.0	28.4	15.6	3.0	6.0	3.0	7.0	0.00	64.6	2.2	17.8	1.5
1087	1	224969.0	207.1	0.2	67.3	26.7	14.0	7.0	6.3	3.0	17.4	0.21	55.9	3.5	17.6	1.5
1095	1	169503.0	191.3	0.2	98.1	32.3	22.8	5.5	5.7	2.8	7.6	0.00	60.1	2.4	20.6	1.5
1098	1	181135.0	146.6	0.2	0.0	29.3	15.0	3.0	6.0	3.0	8.0	0.33	62.7	2.5	18.9	1.6
1127	1	375489.0	189.6	0.2	39.4	32.2	25.1	4.7	5.6	3.0	11.4	0.00	56.5	5.1	19.1	1.5
1129	1	224225.0	122.6	0.2	33.2	29.5	18.0	4.9	6.0	3.1	11.5	0.48	59.0	3.3	19.6	1.6
1135	1	385474.0	214.2	0.2	6.5	31.5	20.4	3.2	5.7	3.0	7.3	0.00	61.2	4.2	19.4	1.5
1321	1	546595.0	165.8	0.2	19.9	28.0	39.3	7.2	5.2	2.7	8.8	0.00	63.2	6.6	18.1	1.5
1330	1	208320.0	162.8	0.2	20.3	29.4	22.6	5.3	5.1	3.4	9.5	0.00	61.1	4.4	19.5	1.6

Table A.2 Sample Variable Data (Continued)

ID	Gully	Drainage	Erosion	Flood	Frost	HydrGrp	Hydric	LULC	Runoff	PartSize
6	0	3	2	3	4	5	3	71	6	5
14	0	3	1	3	2	3	2	71	3	5
18	0	3	2	3	2	5	2	71	2	5
23	0	3	2	3	2	5	2	71	2	5
27	0	3	2	3	2	3	2	71	3	5
30	0	3	2	3	2	5	2	71	4	5
33	0	3	2	3	4	5	3	71	6	5
39	0	3	2	3	4	5	3	71	6	5
59	0	3	3	3	2	5	3	71	6	5
62	0	3	2	3	2	5	2	71	4	5
64	0	3	2	3	4	5	2	71	6	5
74	0	3	3	3	4	3	3	71	2	5
78	0	3	2	3	4	4	3	71	2	5
88	0	3	2	3	4	5	3	71	6	6
90	0	3	2	3	2	5	2	71	4	5
91	0	3	2	3	4	5	3	71	6	6
92	0	5	2	3	4	3	3	71	6	5
98	0	5	2	3	4	3	3	41	6	5
102	0	5	2	3	4	3	3	71	3	5
106	0	3	2	3	2	5	2	71	6	5
125	0	5	4	5	2	3	2	71	3	5
152	0	3	3	3	2	5	2	71	2	5
162	0	5	2	3	3	4	3	71	6	5
165	0	3	2	3	2	3	2	71	3	5
166	0	3	2	3	4	5	3	71	6	5
180	0	3	3	3	2	5	2	71	2	5
183	0	3	2	3	2	5	2	71	2	6
187	0	3	2	3	2	5	3	71	6	5
190	0	5	4	5	2	3	2	41	3	5

ID	Gully	Drainage	Erosion	Flood	Frost	HydrGrp	Hydric	LULC	Runoff	PartSize
194	0	6	2	3	4	3	3	71	3	5
197	0	6	2	3	4	5	3	71	2	5
198	0	6	2	3	4	5	3	71	2	5
207	0	3	3	3	2	5	2	71	2	5
208	0	3	2	3	2	5	2	71	4	5
243	0	3	3	3	4	5	3	71	6	5
245	0	3	3	3	4	5	3	71	6	5
246	0	3	2	3	4	5	3	71	2	5
260	0	3	2	3	2	5	2	71	6	5
267	0	3	2	3	2	5	2	71	3	5
277	0	6	2	3	4	5	3	71	2	5
281	0	6	2	3	4	5	3	71	2	5
285	0	3	2	3	2	5	3	71	6	5
293	0	6	2	3	4	5	3	71	2	5
308	0	3	3	3	2	5	2	71	2	5
324	0	3	2	3	4	5	2	71	6	5
326	0	5	2	3	2	3	3	71	6	5
330	0	5	2	3	3	4	3	71	6	5
333	0	3	2	3	2	5	2	71	2	5
336	0	3	2	3	2	5	2	71	6	5
346	0	3	2	3	4	5	3	71	6	5
348	0	5	2	3	3	5	3	71	6	5
349	0	3	2	3	2	5	2	71	4	5
351	0	5	4	5	2	3	2	41	3	5
352	0	3	2	3	2	5	2	71	6	5
354	0	3	2	3	2	5	3	71	6	5
355	0	3	2	3	2	5	2	71	2	5
357	0	5	2	3	3	4	3	71	6	5
362	0	3	2	3	2	5	2	71	4	5
363	0	3	2	3	4	5	2	71	6	5
364	0	3	2	3	2	5	3	71	6	5
372	0	3	2	3	3	4	3	71	6	5

ID	Gully	Drainage	Erosion	Flood	Frost	HydrGrp	Hydric	LULC	Runoff	PartSize
373	0	3	2	3	2	5	3	71	6	5
374	0	3	2	3	2	5	2	71	4	5
378	0	3	2	3	2	5	2	71	2	5
381	0	3	3	3	2	5	2	71	2	6
383	0	3	3	3	2	5	3	71	2	5
401	0	3	2	3	2	5	2	71	6	5
406	0	5	2	3	3	4	3	71	6	5
408	0	3	2	3	2	5	3	71	6	5
409	0	5	2	3	2	4	3	71	6	5
413	0	3	3	3	4	5	3	71	6	5
414	0	3	2	3	2	5	2	71	2	5
415	0	3	3	3	2	5	2	71	2	6
424	0	5	2	3	3	4	3	71	6	5
425	0	3	2	3	2	5	2	71	2	5
431	0	5	2	3	3	4	3	71	6	5
432	0	3	2	3	2	5	2	71	6	5
434	0	3	3	3	4	5	2	71	6	5
435	0	5	2	3	3	4	3	71	6	5
436	0	5	2	3	3	4	3	71	6	5
439	0	3	2	3	2	5	2	71	6	5
443	0	5	2	3	3	4	3	71	6	5
445	0	5	1	3	2	3	3	41	3	5
448	0	5	2	3	3	4	3	71	6	6
449	0	3	2	3	2	5	3	71	6	5
450	0	5	2	5	2	3	2	71	3	5
454	0	3	2	3	2	3	3	41	6	5
456	0	3	2	3	2	5	2	71	4	5
460	0	3	2	3	4	5	3	71	6	5
462	0	3	2	3	2	5	2	71	4	5
465	0	5	2	3	3	4	3	71	6	5
466	0	3	3	3	4	5	3	71	6	5
472	0	3	1	3	2	3	2	82	3	5

ID	Gully	Drainage	Erosion	Flood	Frost	HydrGrp	Hydric	LULC	Runoff	PartSize
473	0	5	2	3	3	4	3	71	6	5
474	0	5	2	3	3	4	3	71	6	5
475	0	3	2	3	2	3	2	71	6	5
480	0	3	2	3	3	5	3	71	6	5
481	0	3	1	4	2	3	3	41	3	5
482	0	5	2	3	3	4	3	41	6	5
486	0	3	2	3	2	5	2	71	6	5
488	0	3	2	3	2	5	3	71	6	6
494	0	3	2	3	4	5	2	71	2	6
495	0	5	2	3	3	4	3	71	6	5
496	0	5	2	3	2	5	3	71	6	5
497	0	5	2	3	3	4	3	71	6	5
505	0	5	2	3	3	4	3	71	6	5
506	0	5	2	3	3	4	2	95	6	5
509	0	3	3	3	4	5	3	71	6	6
517	0	3	2	3	4	4	2	71	2	5
520	0	3	2	3	2	5	2	71	2	5
525	0	3	2	3	4	4	2	71	2	5
530	0	3	2	3	2	5	2	71	6	5
532	0	3	2	3	4	4	2	71	2	5
538	0	3	2	3	2	5	2	71	6	6
550	0	5	2	3	4	4	3	41	6	5
554	0	3	2	3	3	5	2	71	6	5
557	0	5	2	3	3	4	3	41	6	5
559	0	3	2	3	4	5	3	71	6	5
565	0	3	3	3	4	5	2	71	6	5
575	0	3	3	3	4	5	2	71	6	5
600	0	5	2	3	4	4	3	41	6	5
604	0	5	1	3	4	4	3	71	6	6
609	0	5	2	3	3	4	3	71	6	5
611	0	5	2	3	3	4	3	71	6	5
616	0	3	3	3	2	5	3	71	6	6

ID	Gully	Drainage	Erosion	Flood	Frost	HydrGrp	Hydric	LULC	Runoff	PartSize
632	0	3	2	3	2	5	2	71	2	5
653	0	5	1	3	4	4	3	41	6	5
660	0	3	2	3	2	5	2	71	2	5
685	0	3	2	3	3	4	2	71	6	5
686	0	5	2	3	3	4	3	71	6	5
691	0	3	3	3	2	5	2	71	2	5
699	0	5	2	3	4	4	3	71	6	6
704	0	5	2	3	3	4	3	71	6	5
712	0	3	3	3	2	5	2	71	2	5
733	0	3	3	3	2	5	2	71	2	5
740	0	5	1	3	4	4	3	71	6	5
744	0	5	1	3	4	4	3	71	6	5
754	0	5	2	3	4	4	3	71	6	5
761	0	3	3	3	2	5	2	71	2	5
770	0	5	1	3	4	3	3	71	4	7
778	0	3	2	3	4	4	3	71	6	5
782	0	5	1	3	4	4	3	71	6	5
784	0	3	2	3	4	5	2	71	2	5
786	0	3	2	3	3	4	2	71	2	5
788	0	5	1	3	4	4	3	71	6	5
793	0	3	2	3	2	5	2	71	2	5
795	0	3	3	3	3	4	2	71	6	5
797	0	3	2	3	3	4	2	71	2	6
803	0	3	2	3	4	5	2	71	6	5
806	0	3	2	3	4	4	2	71	2	5
841	0	5	1	3	4	4	3	71	6	5
844	0	3	2	3	3	4	2	71	2	5
846	0	5	1	3	4	3	3	71	4	5
851	0	3	3	3	3	4	2	71	6	5
860	0	3	2	3	2	5	2	71	6	5
866	0	3	3	3	3	4	2	71	6	5
867	0	5	2	3	3	4	3	71	6	6

ID	Gully	Drainage	Erosion	Flood	Frost	HydrGrp	Hydric	LULC	Runoff	PartSize
872	0	3	3	3	4	5	2	71	6	5
882	0	3	3	3	3	4	2	71	6	5
885	0	5	2	3	4	4	3	71	6	5
886	0	3	2	3	4	5	3	41	6	5
888	0	5	2	3	3	4	3	71	6	5
891	0	3	3	3	3	4	2	71	6	5
895	0	3	2	3	3	4	2	71	6	5
899	0	3	3	3	3	4	2	71	6	5
910	0	3	2	3	2	5	2	71	2	5
912	0	3	2	3	3	4	2	71	6	7
926	0	5	2	3	3	4	3	71	6	5
928	0	5	2	3	4	4	3	71	6	5
929	0	5	2	3	4	4	3	71	6	5
948	0	3	3	3	4	5	2	71	6	5
949	0	3	3	3	2	5	2	71	2	6
954	0	5	2	3	4	4	3	71	6	5
956	0	3	2	3	3	4	2	71	6	5
978	0	3	2	3	3	4	2	71	6	5
979	0	3	2	3	3	4	2	71	6	5
981	0	5	1	3	4	4	3	71	6	6
985	0	3	2	3	3	4	2	71	6	5
986	0	3	2	3	3	4	3	71	6	5
992	0	5	2	3	3	4	3	71	6	5
994	0	5	2	3	4	4	3	71	6	5
1004	0	3	3	3	2	5	2	71	2	5
1007	0	3	2	3	3	4	2	71	6	5
1013	0	5	1	3	4	4	3	71	6	5
1020	0	5	2	3	4	4	2	71	6	5
1021	0	3	2	3	3	4	2	71	6	5
1024	0	3	2	3	4	5	3	71	6	5
1026	0	5	1	3	4	4	3	71	6	6
1029	0	3	2	3	4	4	2	71	2	6

ID	Gully	Drainage	Erosion	Flood	Frost	HydrGrp	Hydric	LULC	Runoff	PartSize
1031	0	3	2	3	3	4	2	71	6	6
1038	0	5	1	3	4	4	3	71	6	5
1042	0	3	2	3	4	5	2	71	6	6
1051	0	3	2	3	4	5	3	71	6	6
1067	0	3	3	3	4	5	3	71	6	6
1071	0	3	2	3	3	4	2	71	6	5
1074	0	3	2	3	3	4	2	71	6	5
1076	0	3	2	3	4	5	3	71	6	7
1079	0	3	3	3	3	4	2	71	6	7
1084	0	5	1	3	4	4	3	71	6	5
1085	0	3	2	3	3	4	2	71	6	5
1086	0	3	2	3	3	4	2	71	6	5
1094	0	3	2	3	4	5	3	71	6	5
1096	0	3	2	3	4	4	2	71	6	5
1097	0	3	2	3	4	5	2	71	6	5
1108	0	5	1	3	4	4	3	71	6	5
1119	0	3	2	3	3	4	2	71	6	5
1122	0	3	2	3	3	4	2	71	6	5
1128	0	3	2	3	4	5	3	71	6	5
1130	0	3	3	3	3	4	2	71	6	5
1132	0	3	3	3	3	4	2	71	6	5
1136	0	5	2	3	2	3	3	71	4	5
1139	0	5	2	3	2	3	3	71	4	7
1141	0	5	2	3	2	3	3	71	4	5
1147	0	3	2	3	4	4	2	71	2	5
1148	0	5	2	3	3	4	3	71	6	6
1150	0	5	2	3	2	3	3	41	3	5
1155	0	3	2	3	3	4	2	71	2	5
1161	0	5	2	3	3	4	3	71	6	5
1166	0	5	2	3	3	4	3	71	6	5
1167	0	3	2	3	2	5	2	71	4	5
1176	0	3	2	3	2	3	3	71	2	5

ID	Gully	Drainage	Erosion	Flood	Frost	HydrGrp	Hydric	LULC	Runoff	PartSize
1178	0	5	1	3	4	4	3	71	6	5
1190	0	5	2	3	2	4	3	41	6	5
1191	0	3	2	3	4	4	2	71	2	5
1197	0	3	2	3	4	5	3	71	6	5
1212	0	3	2	3	4	4	2	41	2	5
1226	0	3	2	3	4	4	2	41	6	5
1227	0	3	2	3	2	5	2	71	6	7
1229	0	5	3	3	4	4	2	41	6	5
1230	0	3	2	3	2	5	3	71	6	5
1231	0	3	2	3	2	5	2	71	6	6
1233	0	5	2	3	2	3	3	71	4	5
1244	0	3	2	3	4	4	3	71	6	5
141	1	3	2	3	2	5	3	71	6	5
176	1	3	3	3	2	5	2	71	6	5
199	1	3	3	3	2	5	2	71	2	5
220	1	3	2	3	2	5	2	71	6	5
238	1	3	3	3	2	5	2	71	2	5
261	1	3	2	3	4	5	3	71	6	5
268	1	3	3	3	2	5	2	71	2	5
317	1	3	2	3	4	5	3	71	6	5
318	1	3	3	3	4	5	3	71	6	5
340	1	3	3	3	4	5	3	71	6	5
479	1	3	3	3	2	5	2	71	2	5
498	1	3	3	3	4	5	3	71	6	5
541	1	3	2	3	4	5	3	71	6	5
673	1	3	2	3	3	4	2	71	6	5
825	1	3	2	3	2	5	2	71	4	5
829	1	3	2	3	3	4	2	71	6	5
850	1	3	2	3	4	4	2	71	6	5
863	1	3	3	3	2	5	2	71	2	5
898	1	3	2	3	3	4	2	71	6	5
969	1	3	2	3	3	4	2	71	6	5

ID	Gully	Drainage	Erosion	Flood	Frost	HydrGrp	Hydric	LULC	Runoff	PartSize
1058	1	3	2	3	4	4	2	71	2	5
1087	1	3	2	3	4	5	2	71	6	5
1095	1	3	3	3	4	5	3	71	6	5
1098	1	3	2	3	4	4	2	71	2	5
1127	1	5	2	3	3	4	3	71	6	5
1129	1	3	2	3	4	5	3	71	6	5
1135	1	3	2	3	3	4	2	71	6	5
1321	1	5	2	3	4	3	3	41	3	5
1330	1	5	2	3	4	4	2	71	6	5

Appendix B - Watershed Data Maps

The following include maps of variable data separated by watershed data.

Figure B.1 Slope map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007)

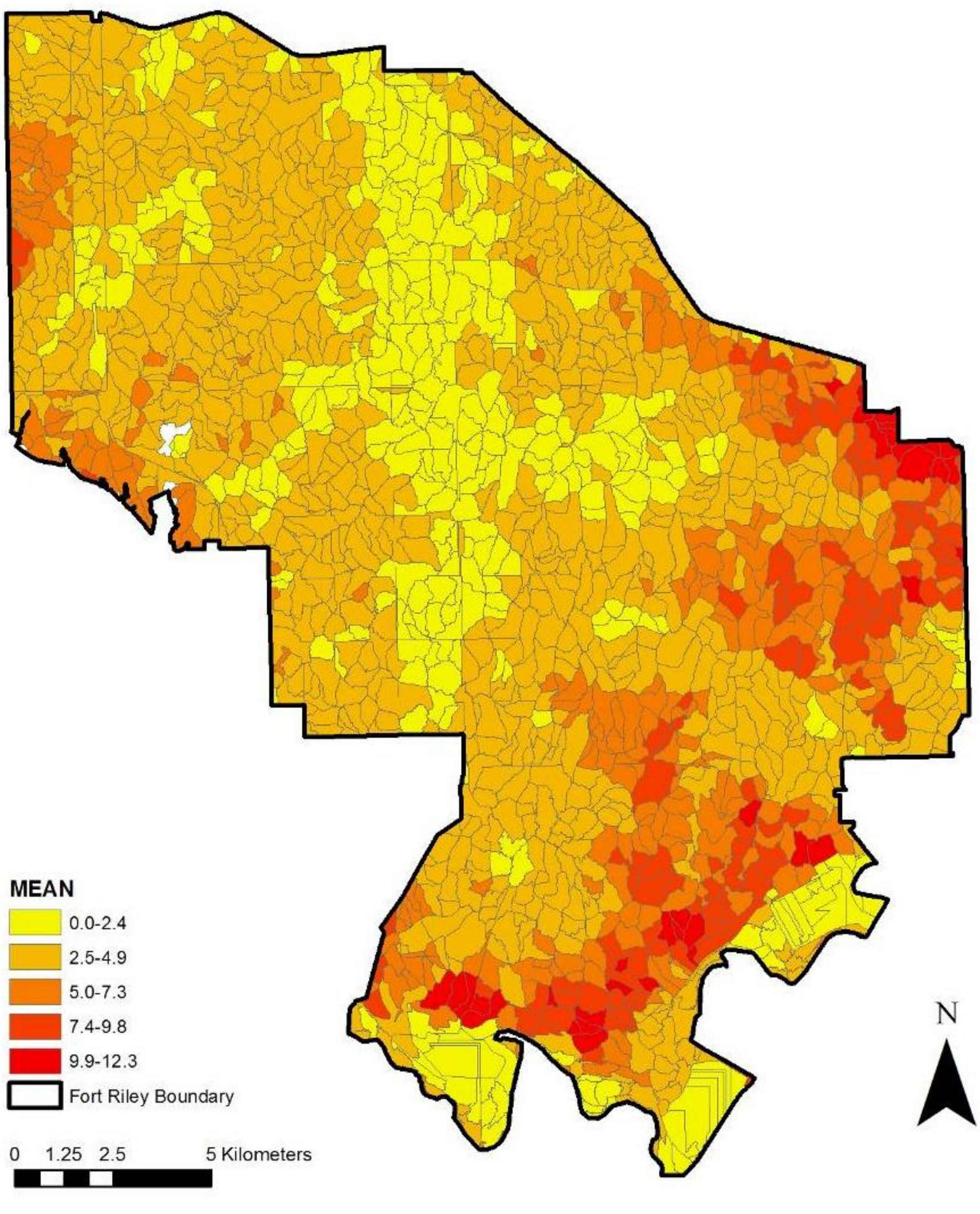


Figure B.2 Aspect map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007)

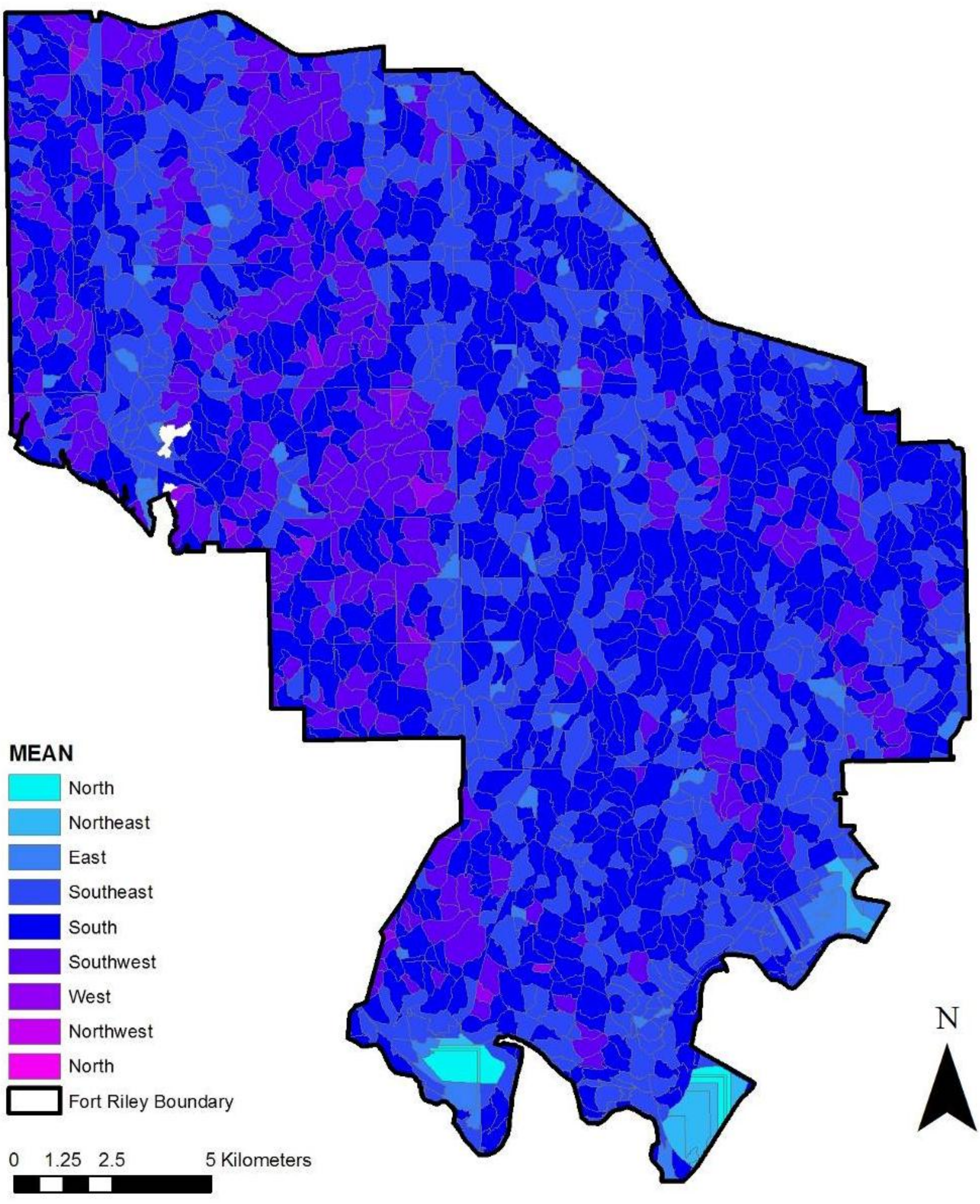


Figure B.3 National Land Cover map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and U.S. EPA 2001)

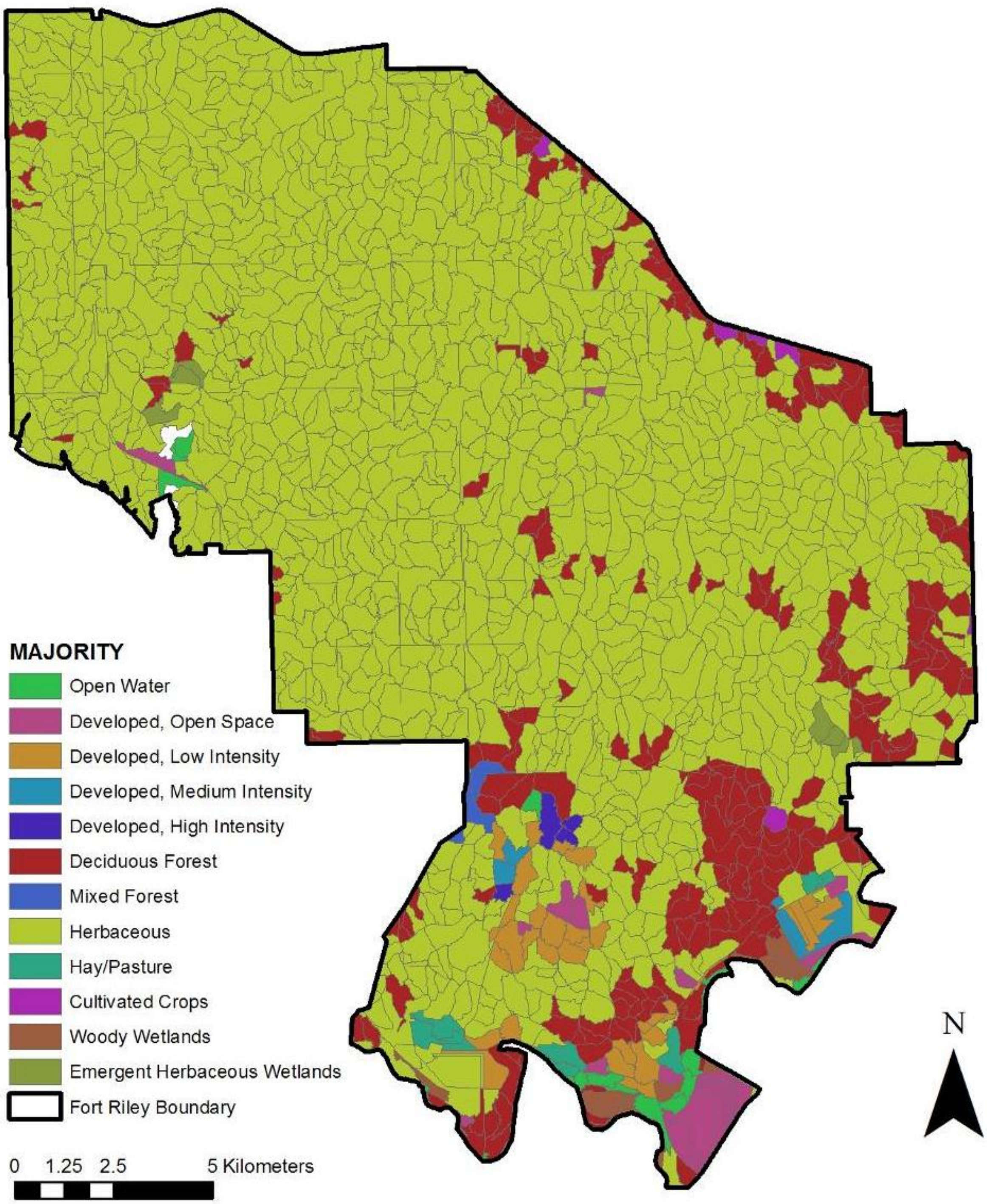


Figure B.4 Runoff Potential map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

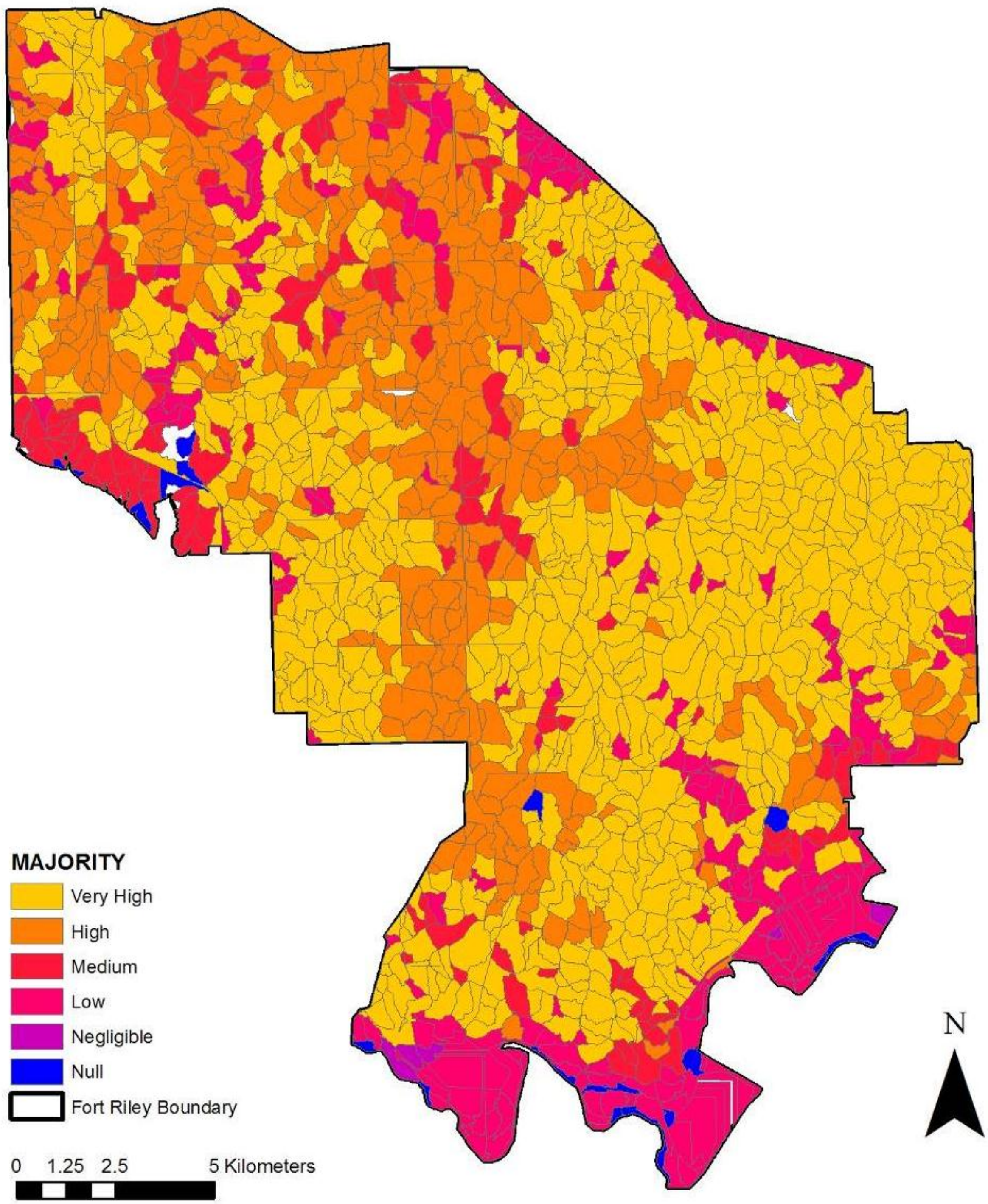


Figure B.5 Erosion Class map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

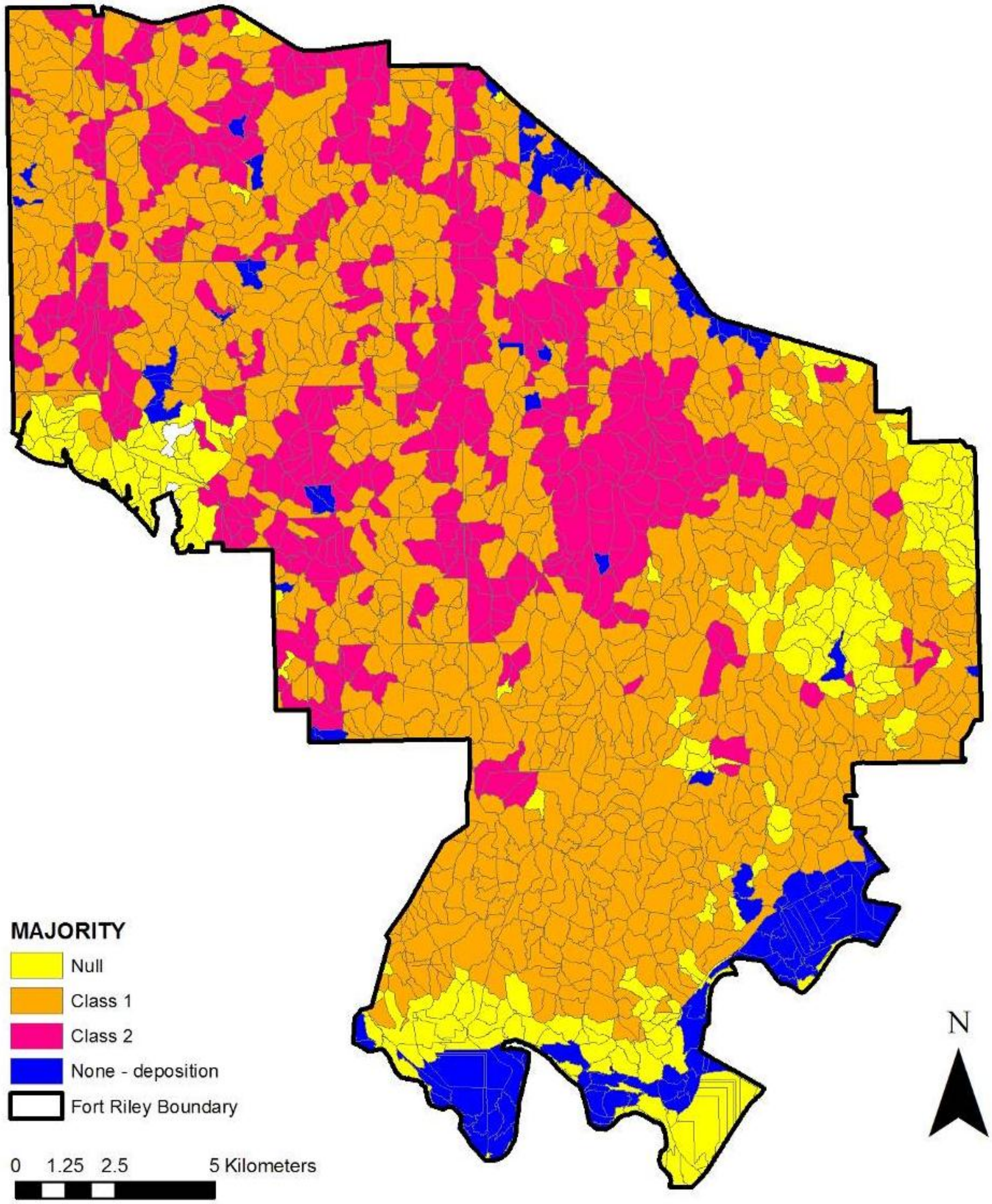


Figure B.6 Drainage Class map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

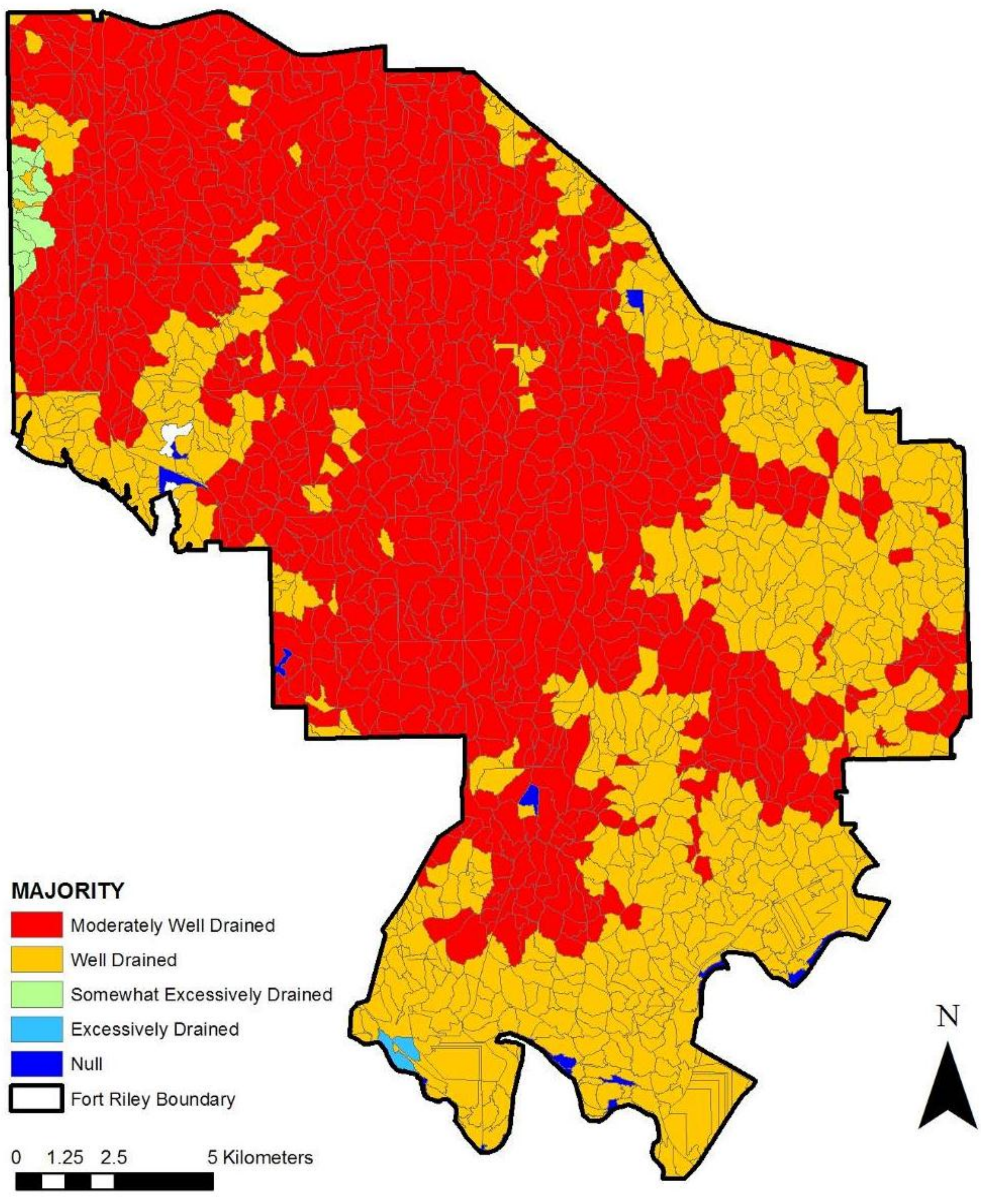


Figure B.7 Frost Action map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

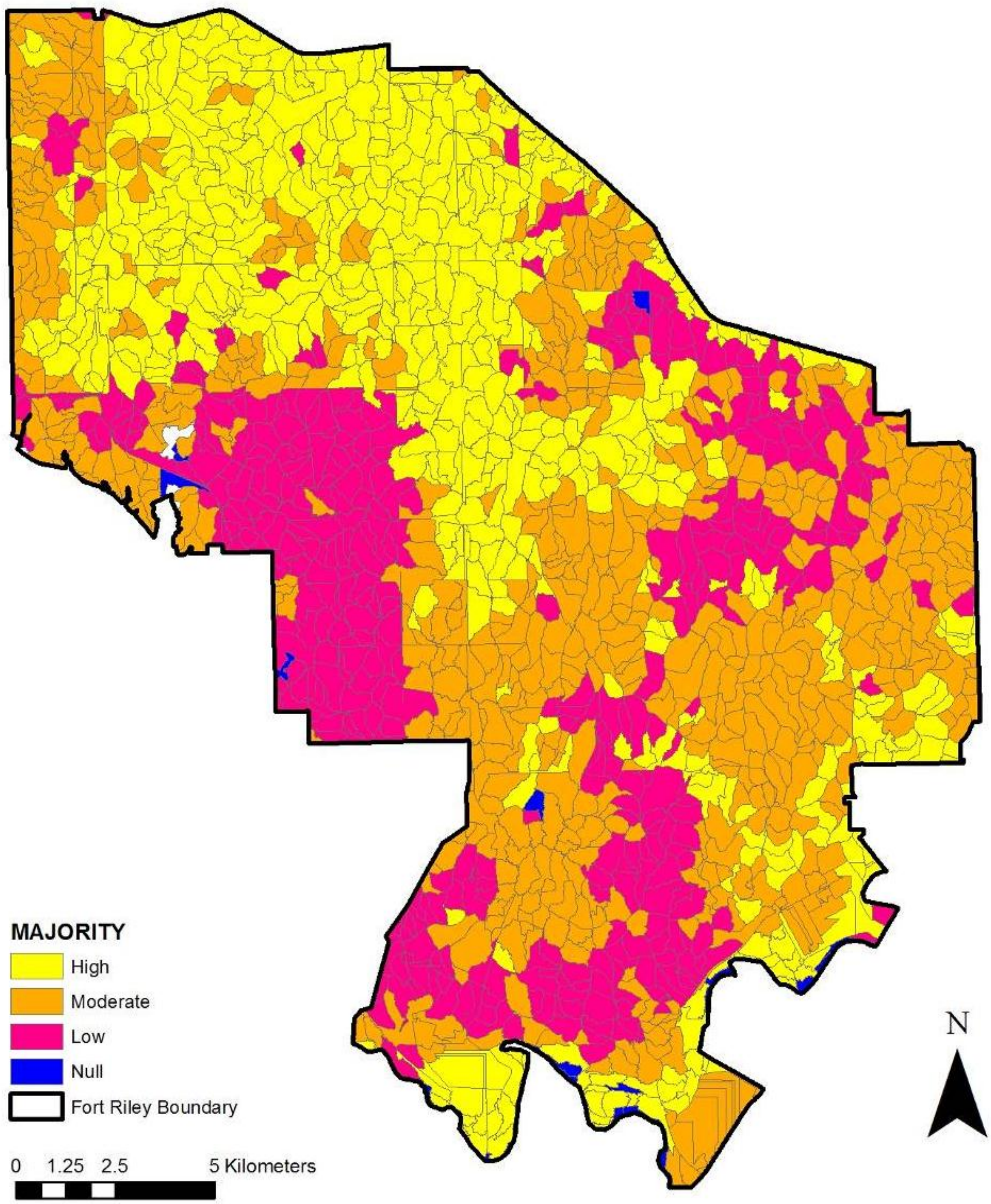


Figure B.8 Hydrography Group map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

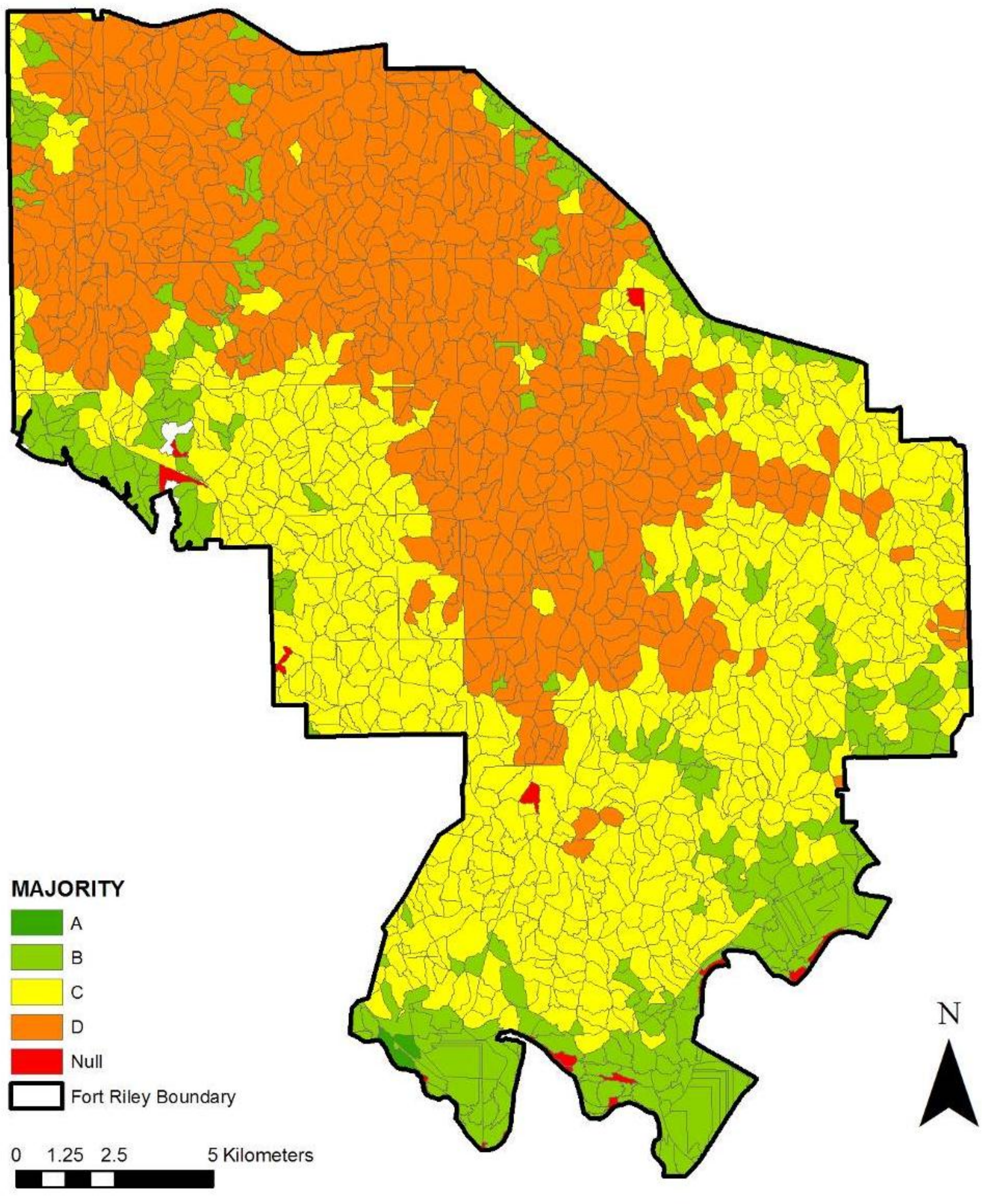


Figure B.9 Particle Size map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

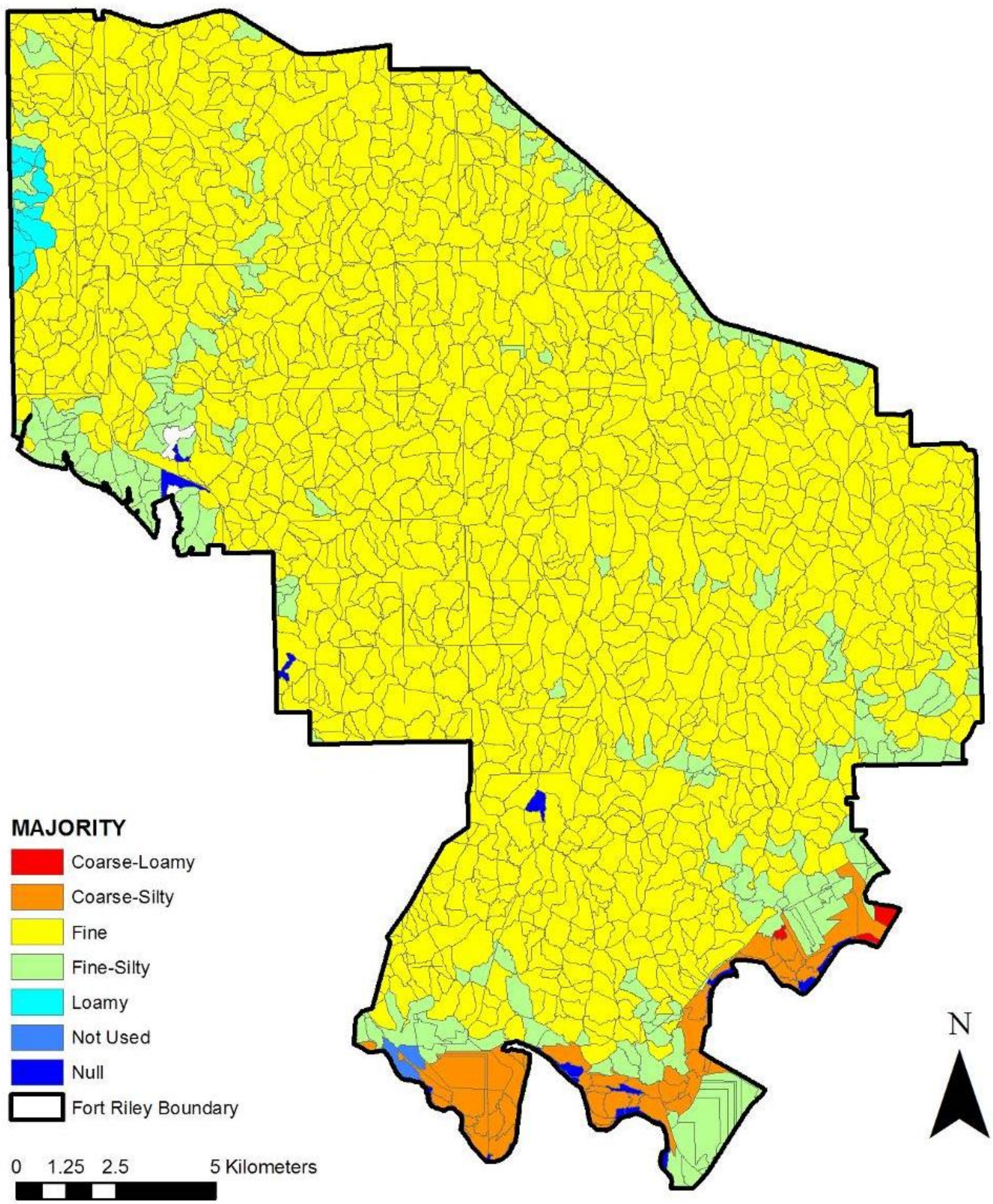


Figure B.10 Bed Rock Depth map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

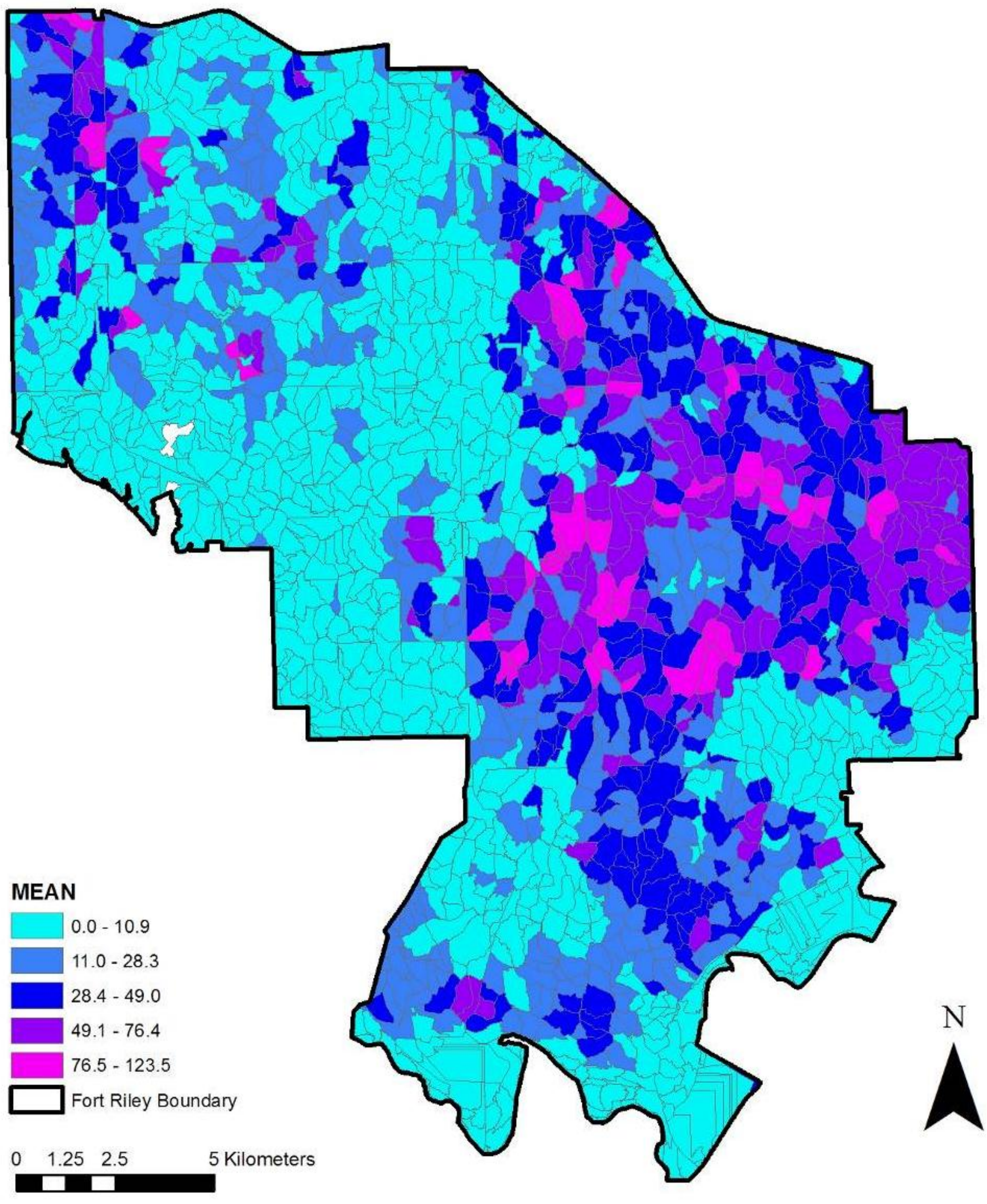


Figure B.11 Flood Frequency map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

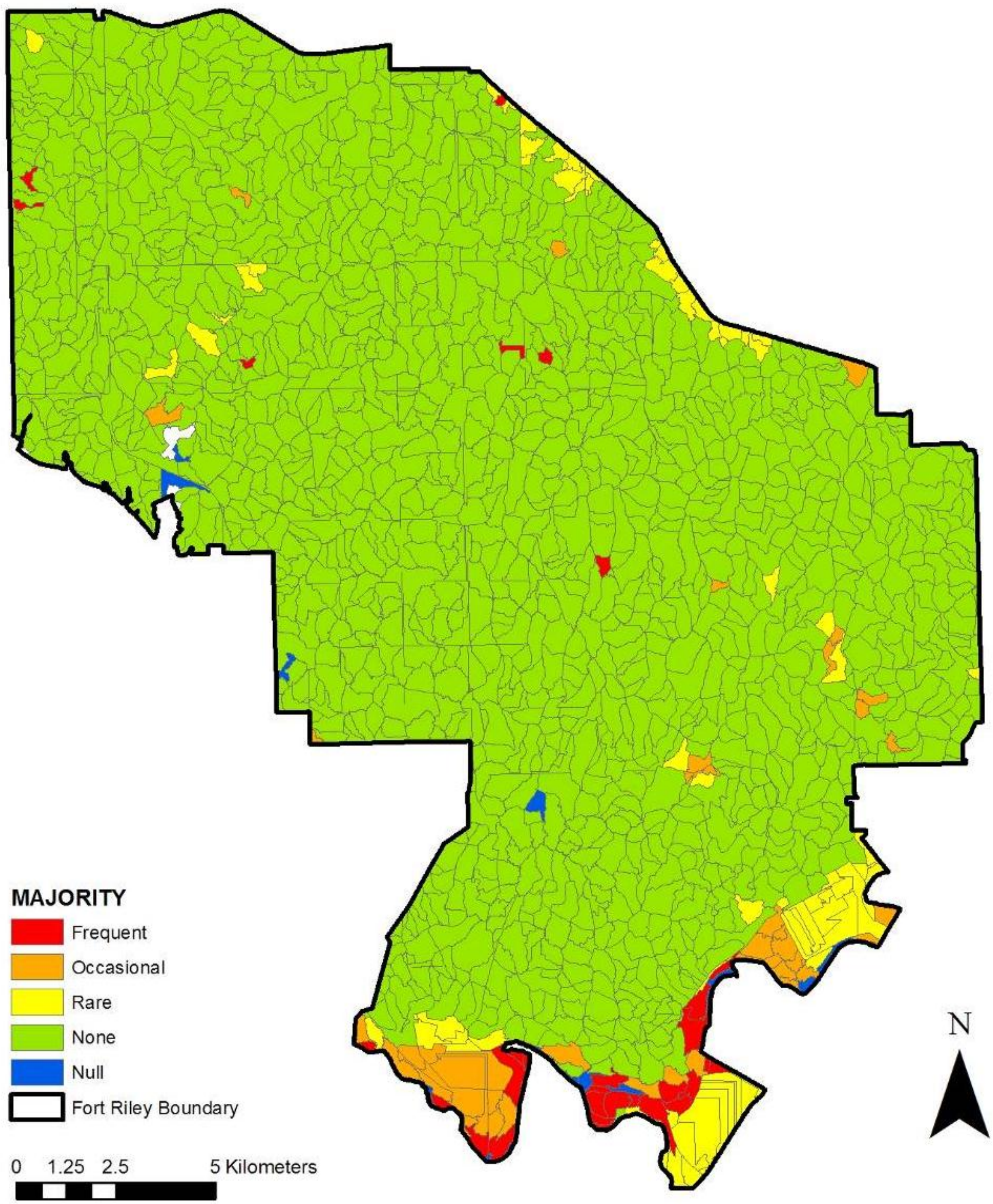


Figure B.12 Hydric Classification map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

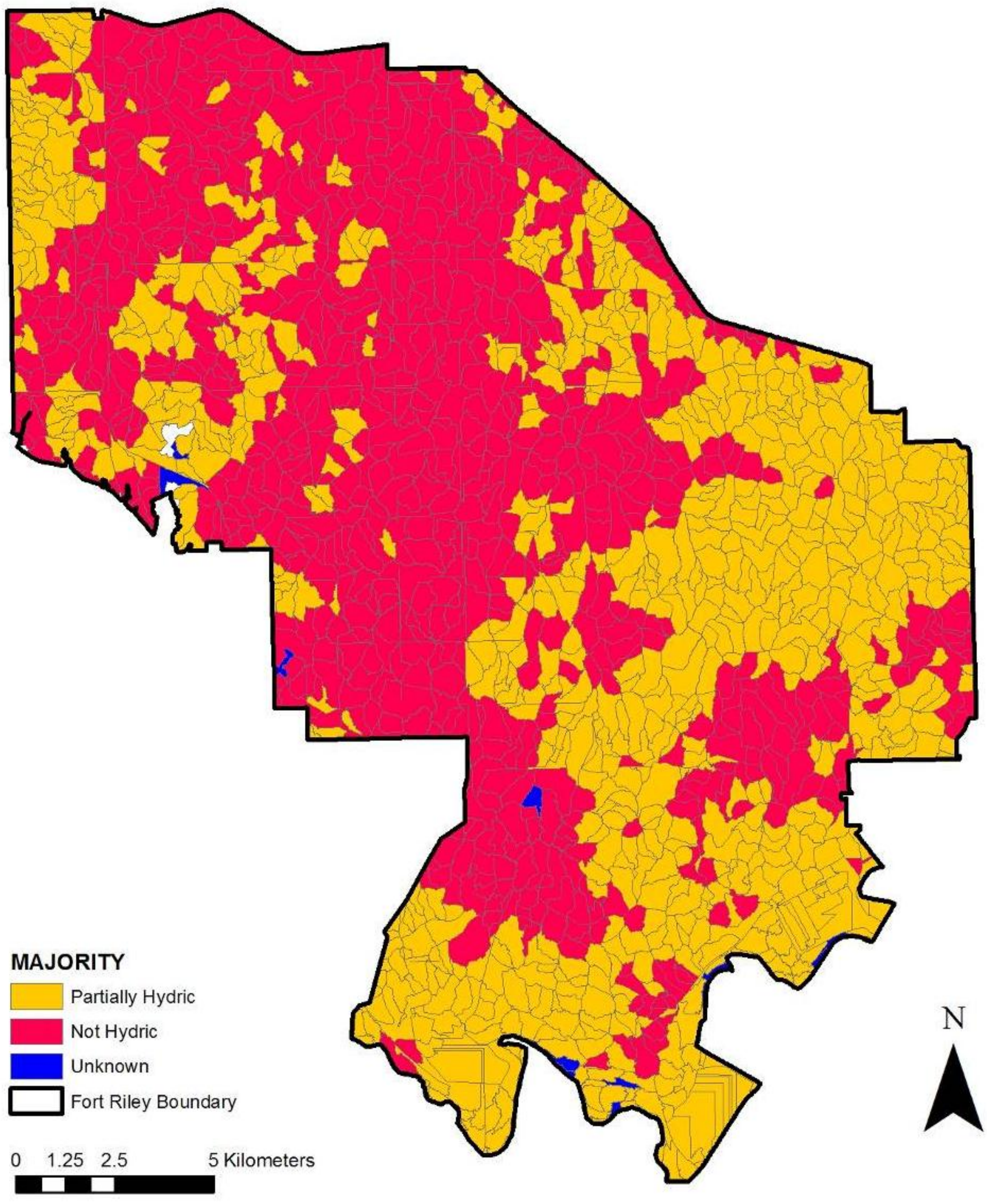


Figure B.13 Soil Horizon Depth map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

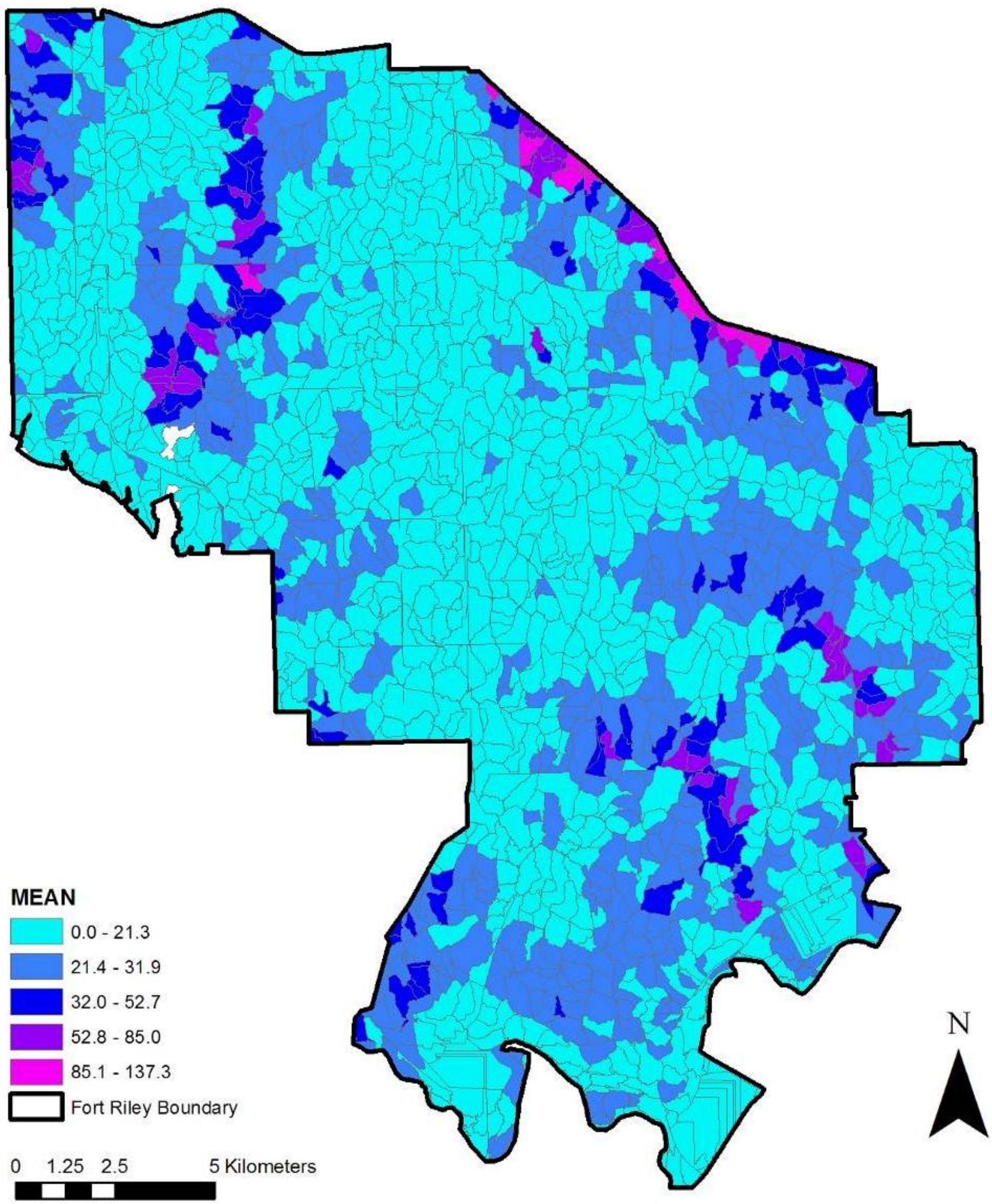


Figure B.14 Sand Composition by Percentage map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

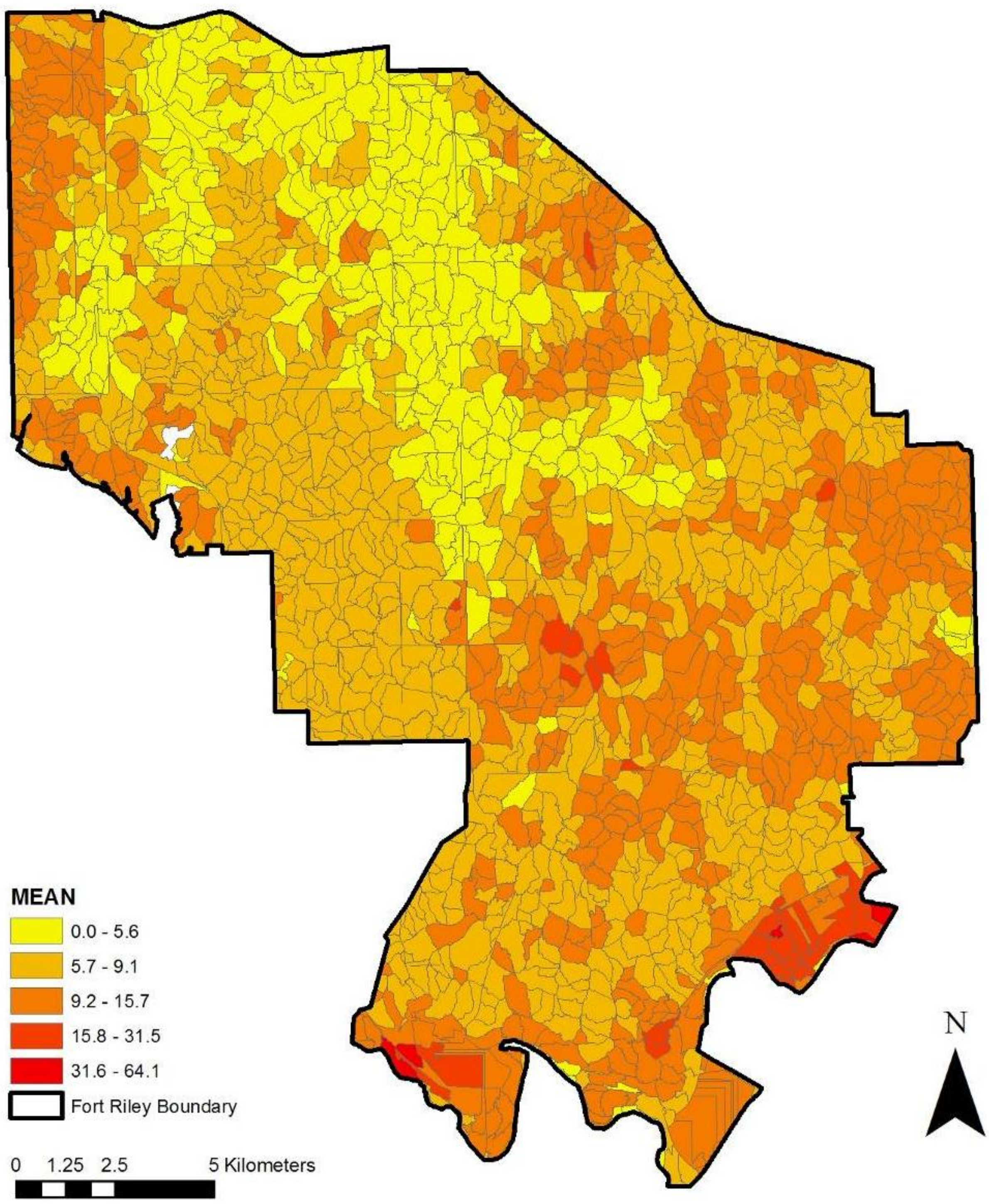


Figure B.15 Silt Composition by Percentage map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

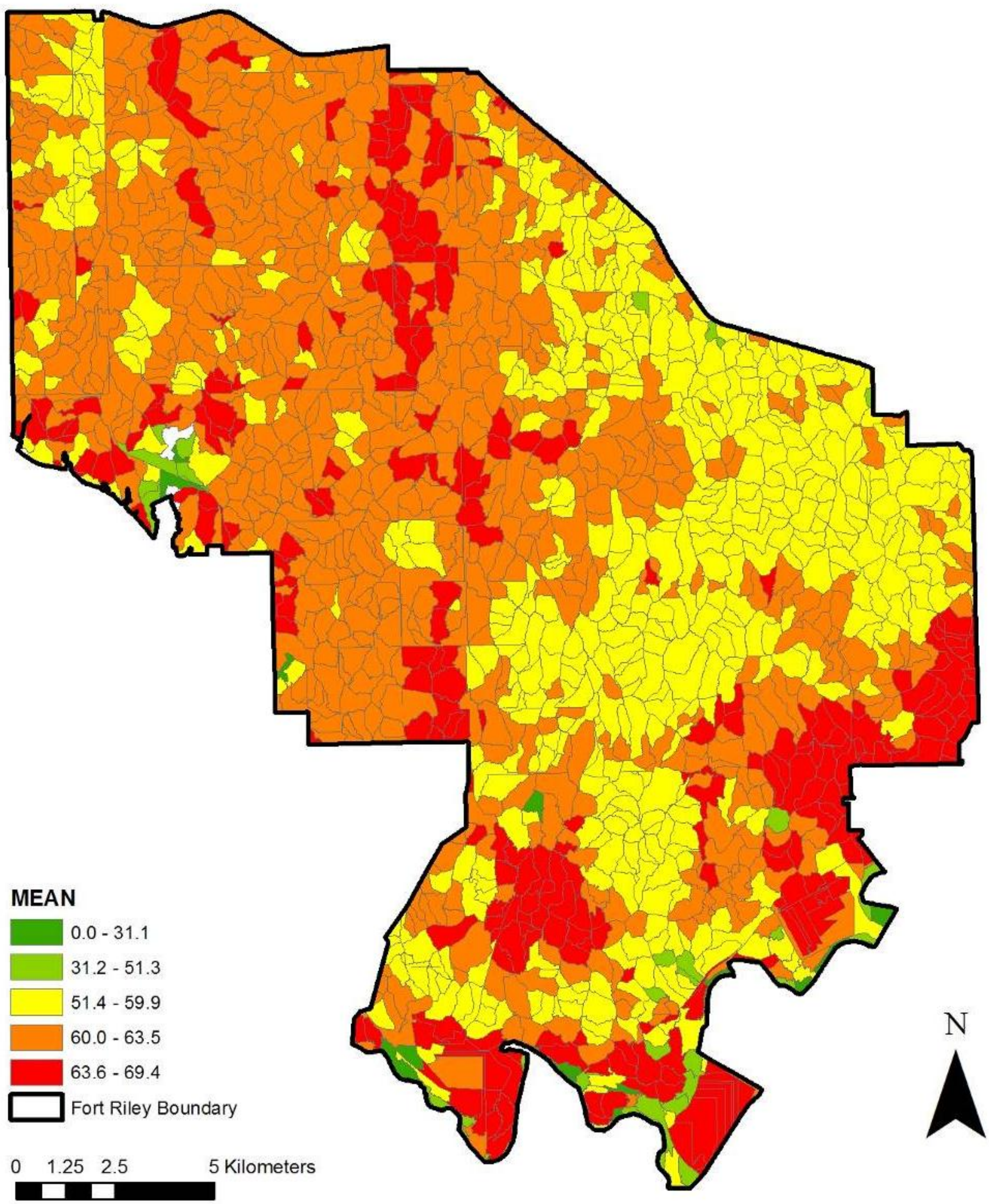


Figure B.16 Clay Composition by Percentage map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

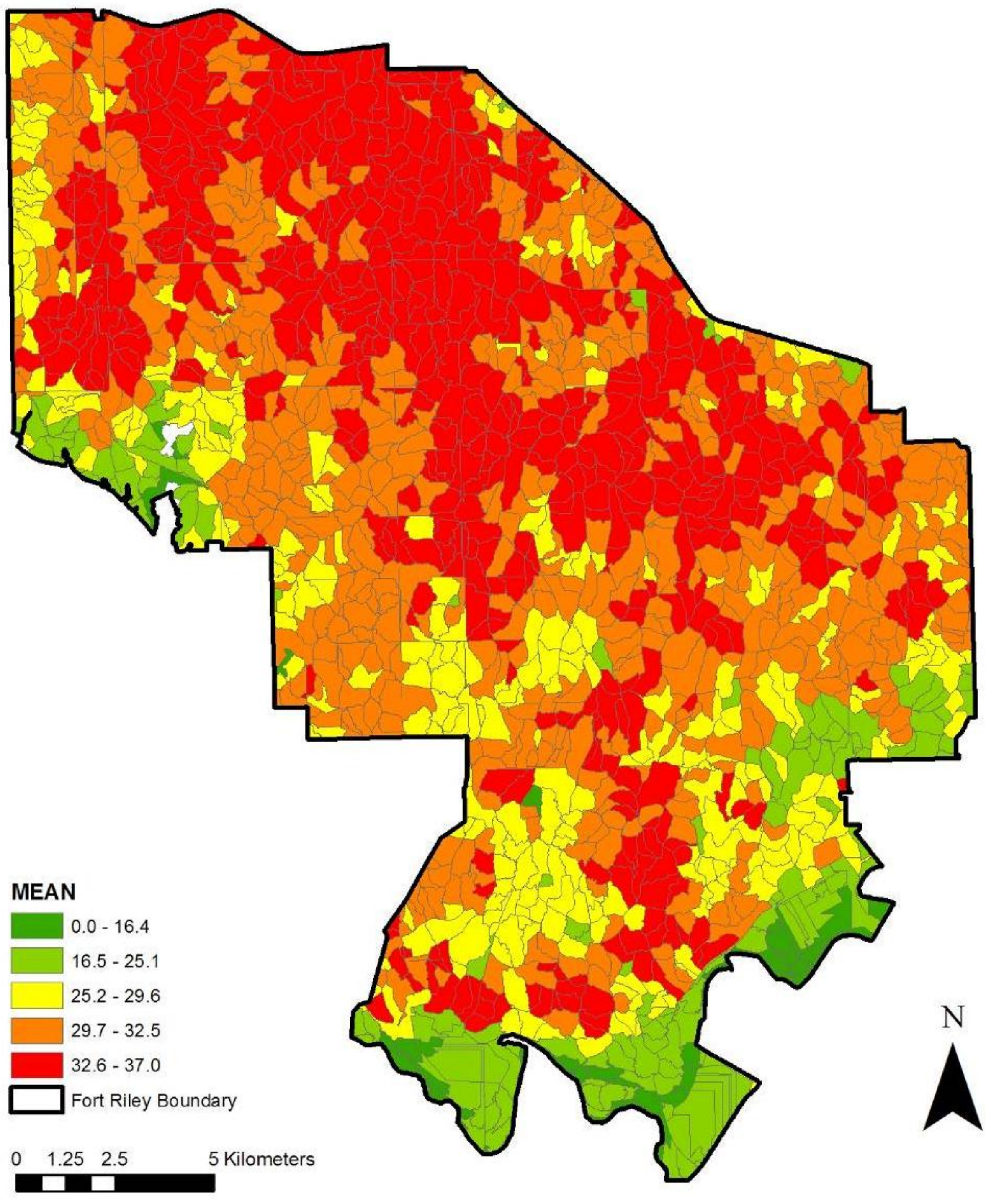


Figure B.17 Organic Matter Composition map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO)

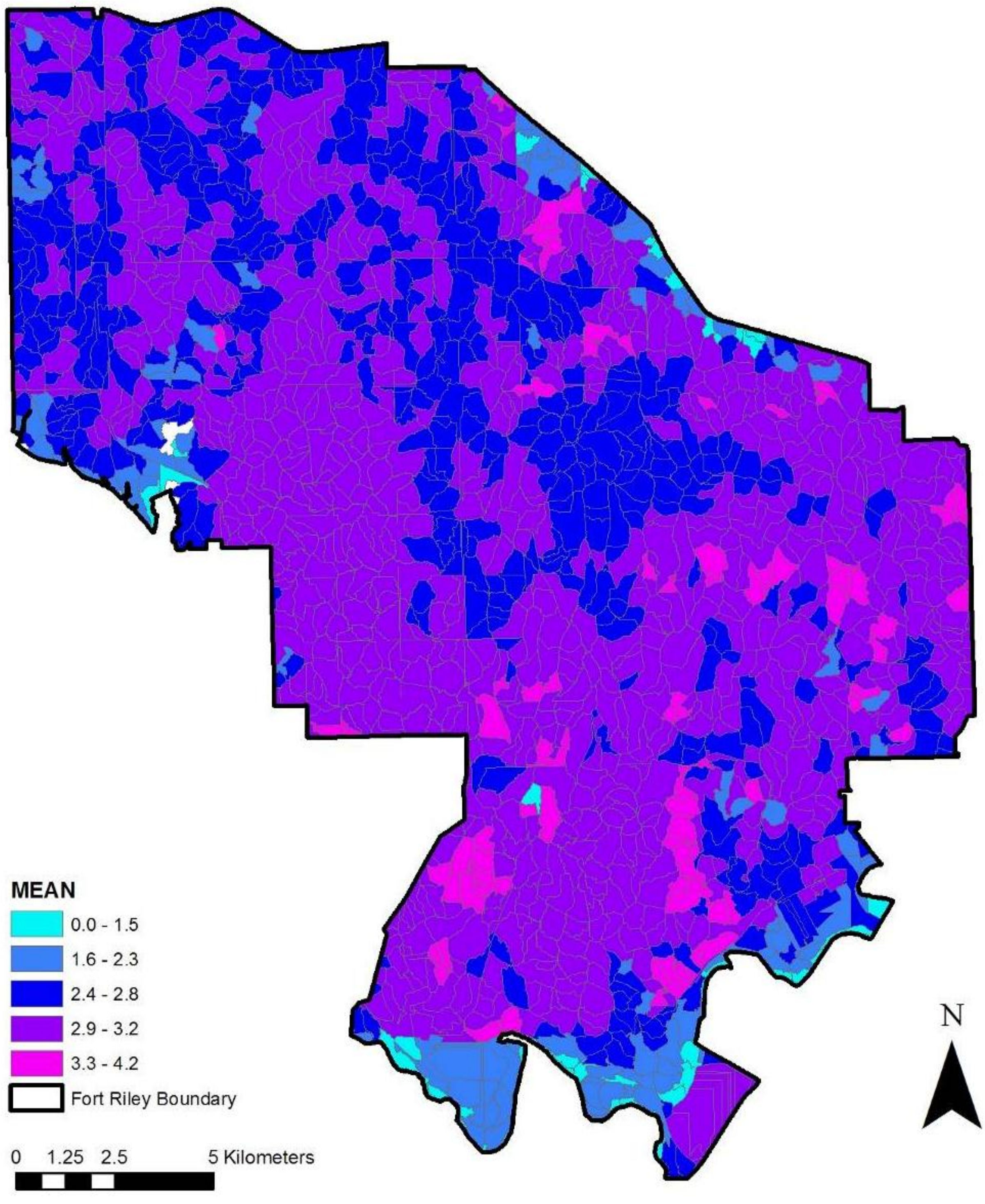


Figure B.18 Oven dry weight map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO)

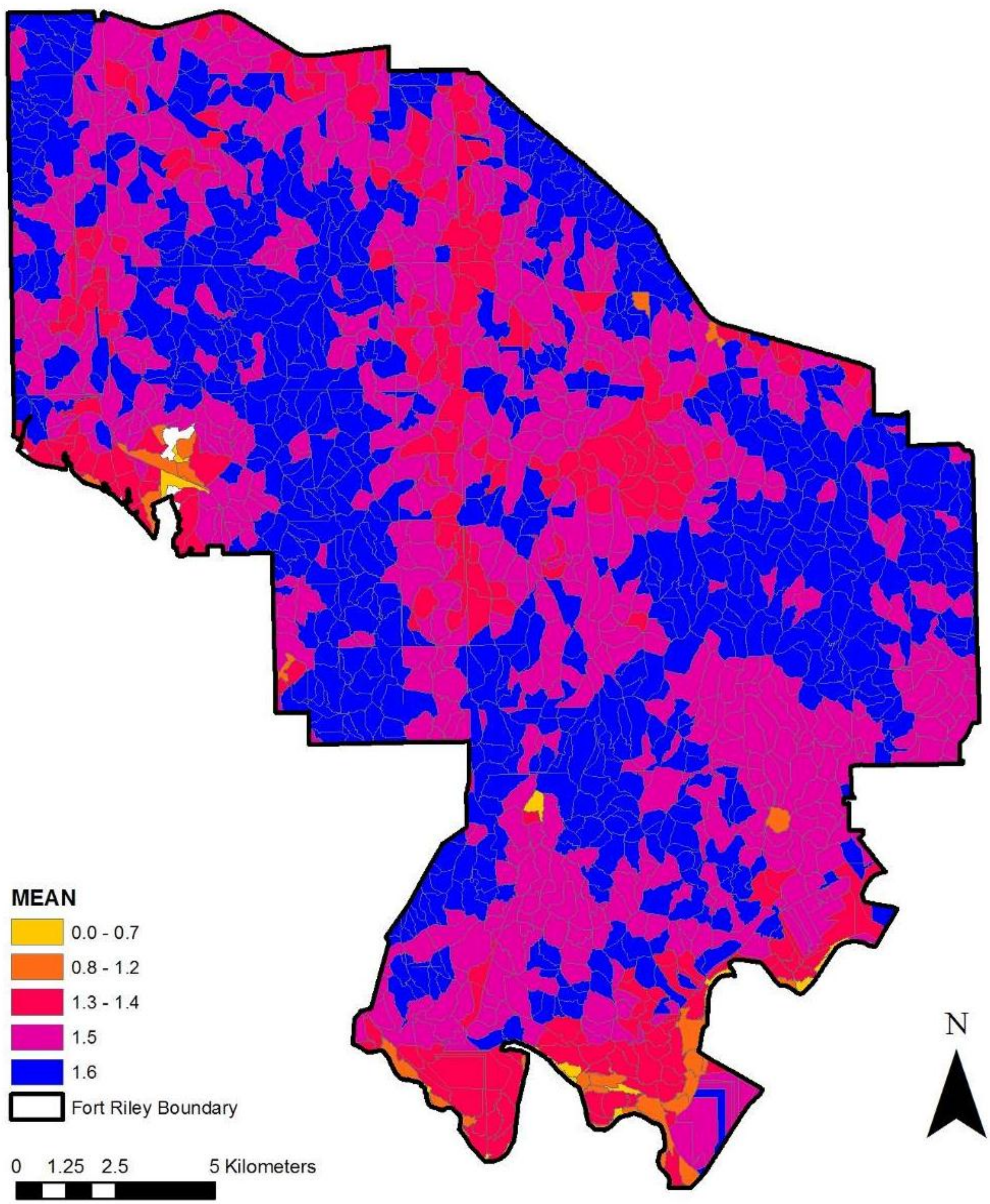


Figure B.19 Saturated Hydraulic Conductivity map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

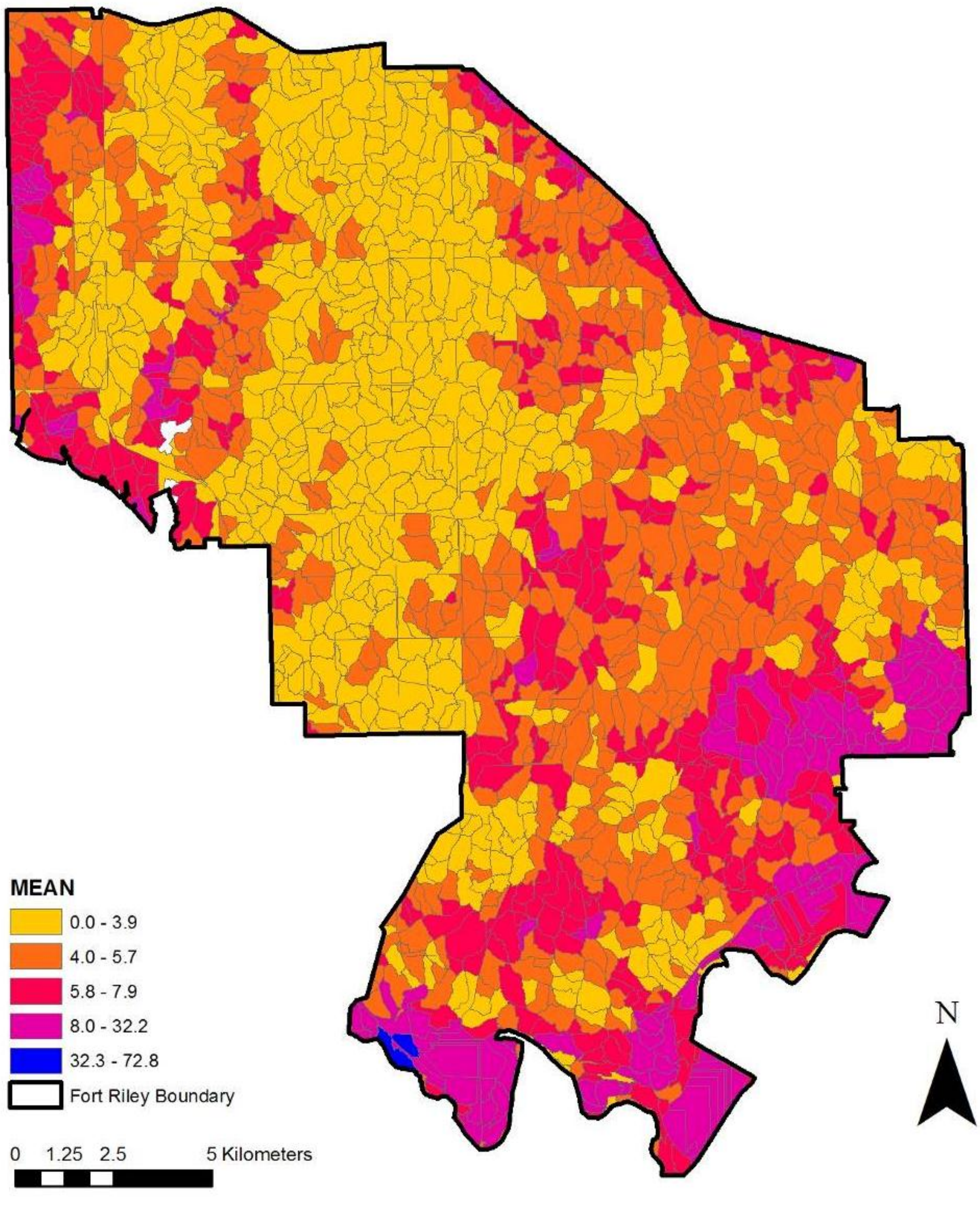


Figure B.20 Available Water Content map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

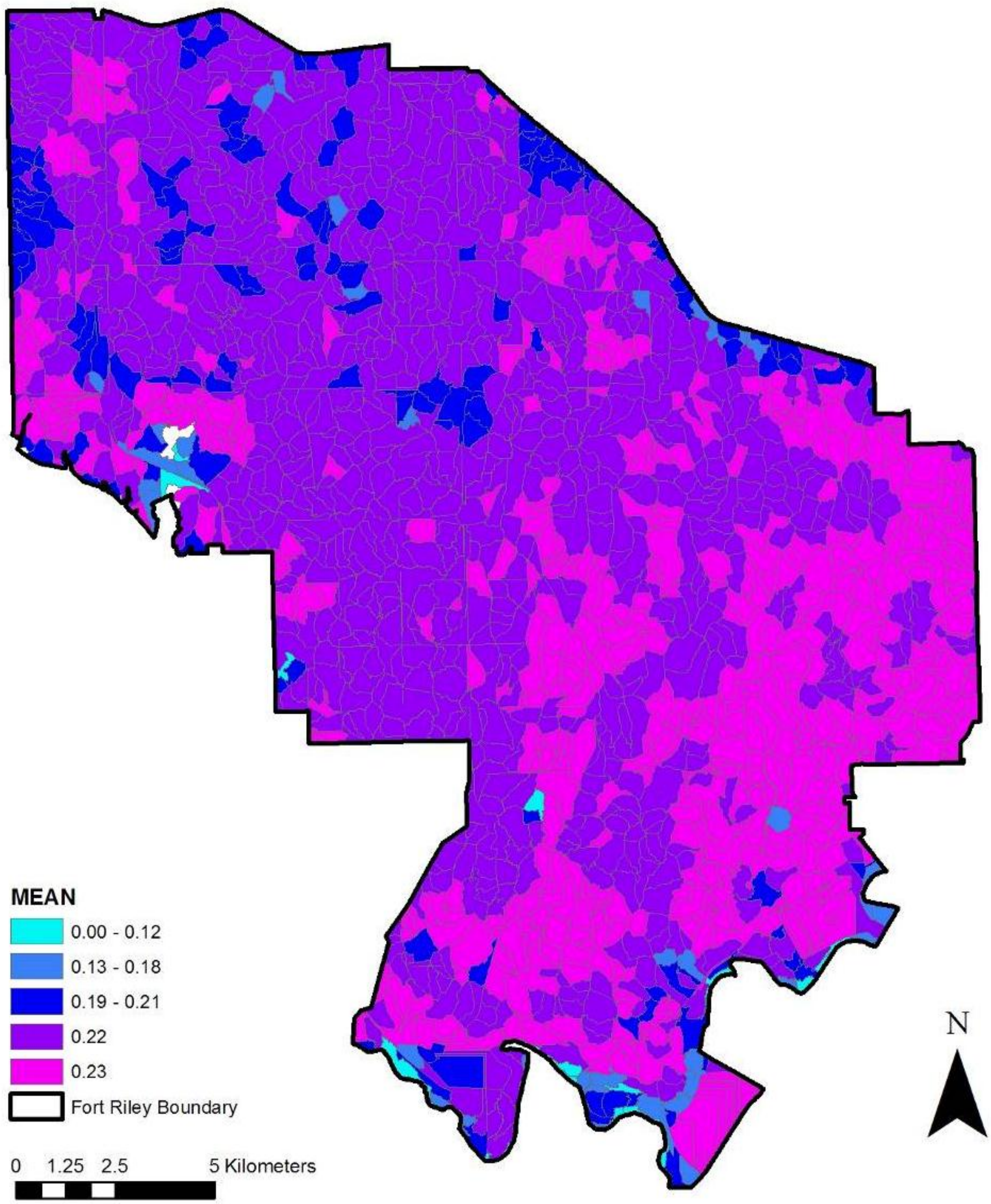


Figure B.21 Soil Water Present at 15 bar map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

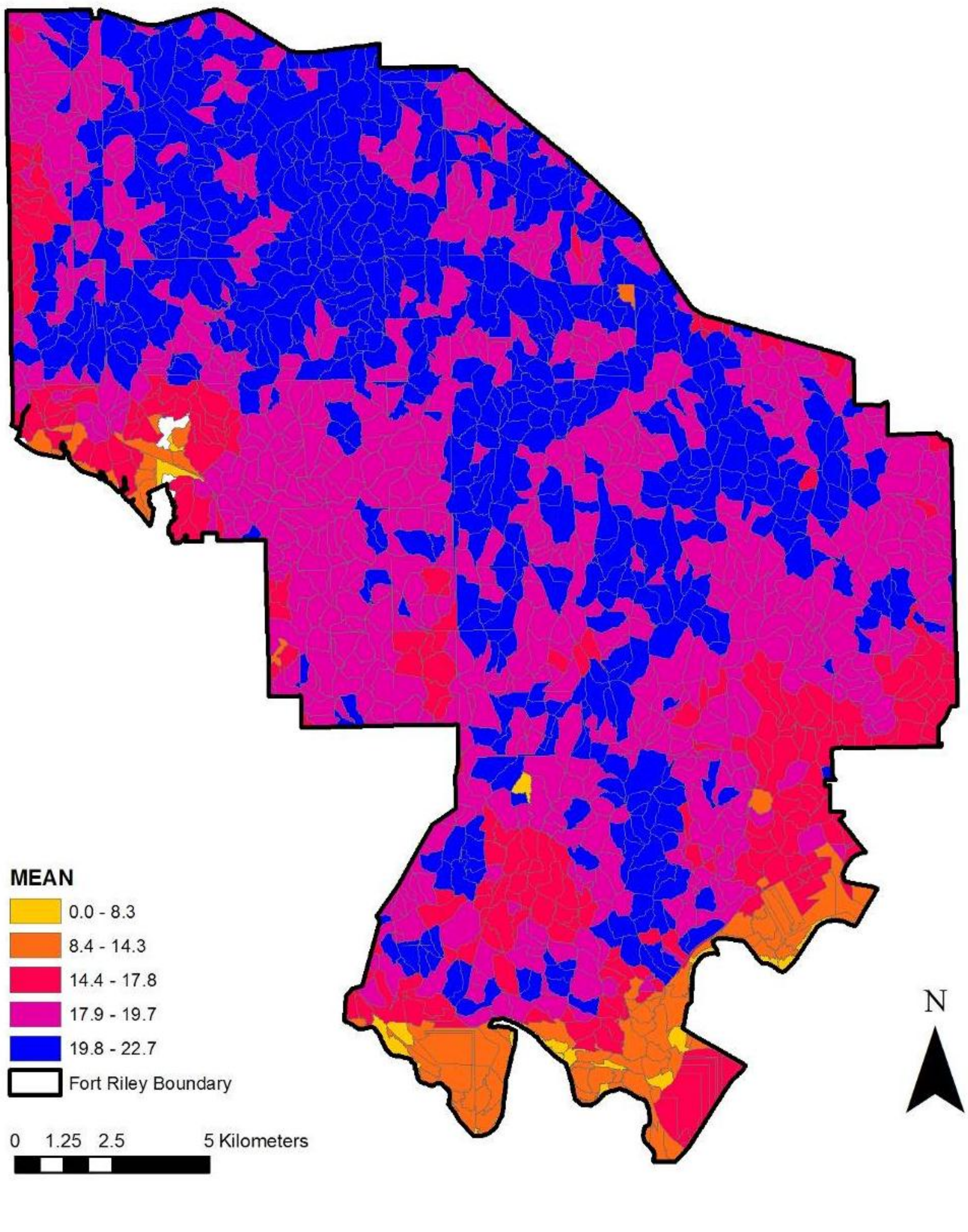


Figure B.22 Soil Erodibility Factor map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)

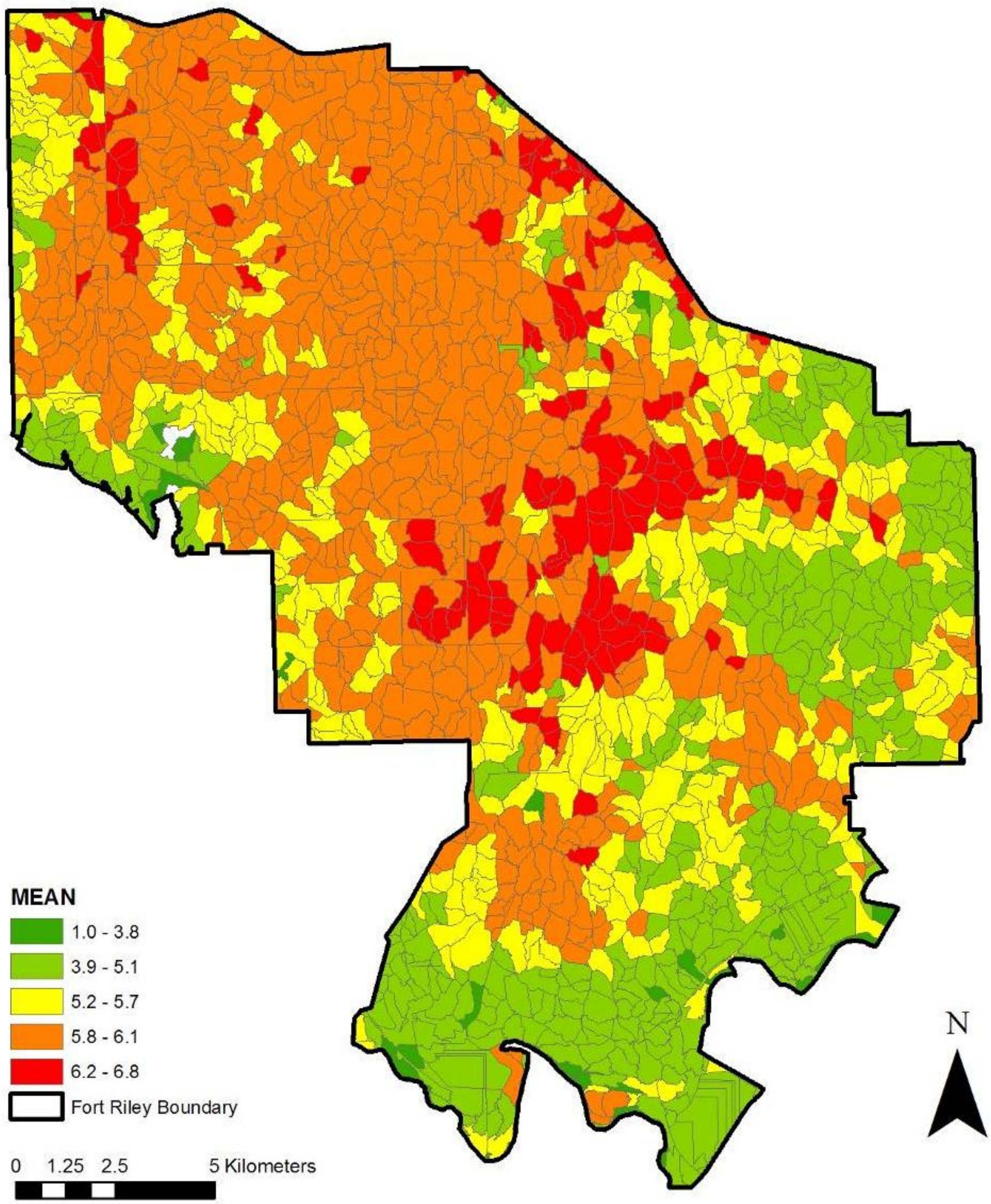
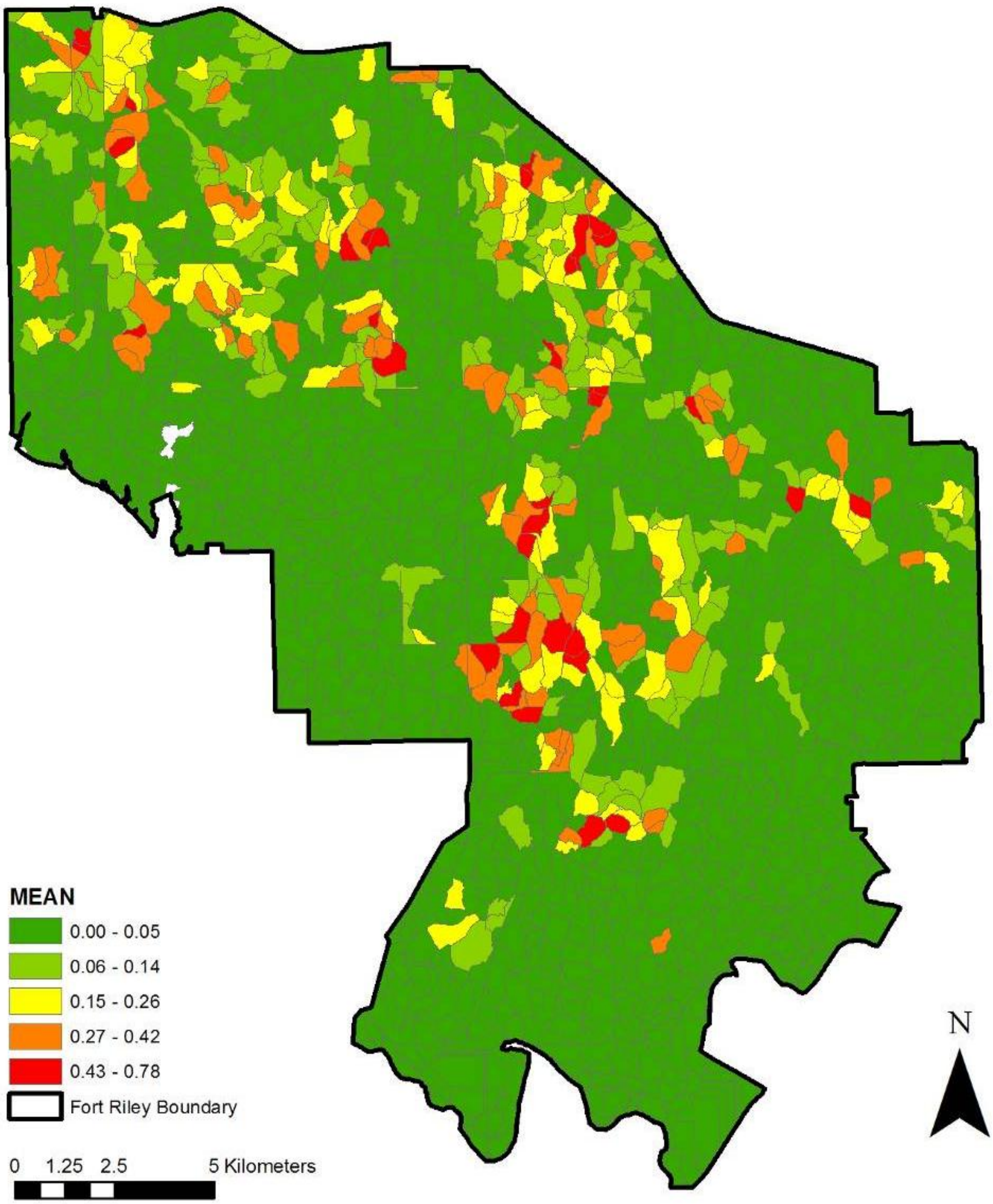


Figure B.23 Sodium Adsorption Ratio map of Fort Riley based on a 3 meter spatial resolution digital elevation model (Data Source: Fort Riley Integrated Training Management Program 2007 and SSURGO 2002)



Appendix C - XLStat Logistic Regression Results

Table C.1 Summary Statistics

Variable	Categories	Frequencies	%
Gully	0	162	89.01
	1	20	10.99

Variables	Observations	Obs. With missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Area	182	0	182	86521.00	978115.00	316119.67	147710.97
Aspect	182	0	182	100.86	252.94	175.81	32.32
AWC	182	0	182	0.19	0.23	0.22	0.01
Bedrock	182	0	182	0.00	104.90	25.47	23.40
Horizon	182	0	182	12.50	76.52	23.92	10.25
KSAT	182	0	182	2.00	8.96	4.51	1.59
KW	182	0	182	4.27	6.67	5.59	0.46
SAR	182	0	182	0.00	0.56	0.08	0.13
Slope	182	0	182	1.24	11.04	4.24	1.95

Variable	Categories	Frequencies	%
Drainage	3	121	66.48
	5	57	31.32
	6	4	2.20
Erosion	2	141	77.47
	1	15	8.24
	3	25	13.74
	4	1	0.55
Flood	3	179	98.35
	5	2	1.10
	4	1	0.55
Frost	4	73	40.11
	2	60	32.97
	3	49	26.92
HydrGrp	5	85	46.70
	3	17	9.34
	4	80	43.96
Hydric	3	97	53.30
	2	85	46.70
LULC	71	169	92.86
	41	11	6.04
	82	1	0.55
	95	1	0.55
Runoff	6	125	68.68
	3	10	5.50
	2	33	18.13
	4	14	7.69
PartSize	5	157	86.26
	6	20	10.99
	7	5	2.75

Table C.2 Validation Statistics

Variable	Categories	Frequencies	%
Gully	0	71	88.75
	1	9	11.25

Variable	Observations	Obs. With missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Area	80	0	80	74925.60	749893.00	299948.37	147998.45
Aspect	80	0	80	89.68	263.88	184.10	32.02
AWC	80	0	80	0.17	0.23	0.22	0.01
Bedrock	80	0	80	0.00	92.81	26.29	25.59
Horizon	80	0	80	15.00	137.33	24.90	18.98
KSAT	80	0	80	1.84	8.68	4.40	1.65
KW	80	0	80	4.33	6.78	5.67	0.49
SAR	80	0	80	0.00	0.50	0.07	0.11
Slope	80	0	80	1.34	10.53	4.01	2.16

Variable	Categories	Frequencies	%
Drainage	3	57	71.25
	5	21	26.25
	6	2	2.50
Erosion	2	51	63.75
	1	5	6.25
	3	22	27.50
	4	2	2.50
Flood	3	78	97.50
	5	2	2.50
	4	0	0.00
Frost	4	27	33.75
	2	32	40.00
	3	21	26.25
HydrGrp	5	39	48.75
	3	10	12.50
	4	31	38.75
Hydric	3	33	41.25
	2	47	58.75
LULC	71	73	91.25
	41	7	8.75
	82	0	0.00
	95	0	0.00
Runoff	6	49	61.25
	3	5	6.25
	2	23	28.75
	4	3	3.75
PartSize	5	74	92.50
	6	5	6.25
	7	1	1.25

Table C.3 Type III Analysis

Source	DF	Chi-square (Wald)	Pr > Wald	Chi-square (LR)	Pr > LR
Area	1	1.414	0.234	72.858	< 0.0001
Aspect	1	1.694	0.193	73.498	< 0.0001
AWC	1	0.243	0.622	72.109	< 0.0001
Bedrock	1	3.564	0.059	76.922	< 0.0001
Horizon	1	1.273	0.259	70.502	< 0.0001
KSAT	1	1.172	0.279	73.598	< 0.0001
KW	1	0.033	0.857	70.979	< 0.0001
SAR	1	0.227	0.633	71.537	< 0.0001
Slope	1	1.113	0.291	72.322	< 0.0001
Drainage	2	2.280	0.320	70.740	< 0.0001
Erosion	3	0.988	0.804	71.676	< 0.0001
Flood	2	0.706	0.703	70.551	< 0.0001
Frost	2	0.019	0.990	70.878	< 0.0001
HydrGrp	2	0.797	0.671	70.308	< 0.0001
Hydric	1	0.018	0.892	71.010	< 0.0001
LULC	3	3.528	0.317	71.449	< 0.0001
Runoff	3	2.729	0.435	75.264	< 0.0001
PartSize	2	3.841	0.147	80.505	< 0.0001

Table C.4 Model Parameters

Source	Value	Standard error	Wald Chi-Square	Pr > Chi²	Wald Lower bound (95%)	Wald Upper bound (95%)	Odds ratio	Odds ratio Lower bound (95%)	Odds ratio Upper bound (95%)
Intercept	-6.85	15.94	0.18	0.67	-38.09	24.39			
Area	0.00	0.00	1.41	0.23	0.00	0.00	1.00	1.00	1.00
Aspect	0.01	0.01	1.69	0.19	-0.01	0.03	1.01	0.99	1.03
AWC	33.37	67.76	0.24	0.62	-99.44	166.18	310787939867119.00	0.00	1.48E+72
Bedrock	0.04	0.02	3.56	0.06	0.00	0.07	1.04	1.00	1.08
Horizon	-0.07	0.06	1.27	0.26	-0.19	0.05	0.93	0.83	1.05
KSAT	-0.33	0.31	1.17	0.28	-0.93	0.27	0.72	0.39	1.31
KW	-0.23	1.25	0.03	0.86	-2.68	2.22	0.80	0.07	9.25
SAR	1.31	2.74	0.23	0.63	-4.07	6.69	3.70	0.02	802.11
Slope	-0.36	0.34	1.11	0.29	-1.02	0.31	0.70	0.36	1.36
Drainage-3	0.00	0.00							
Drainage-5	-1.10	1.22	0.81	0.37	-3.49	1.29	0.33	0.03	3.65
Drainage-6	2.92	2.89	1.03	0.31	-2.74	8.58	18.63	0.06	5349.46
Erosion-2	0.00	0.00							
Erosion-1	-1.55	1.84	0.71	0.40	-5.16	2.06	0.21	0.01	7.88
Erosion-3	0.24	0.74	0.11	0.75	-1.21	1.70	1.27	0.30	5.45
Erosion-4	1.89	3.47	0.30	0.59	-4.91	8.68	6.59	0.01	5886.23
Flood-3	0.00	0.00							
Flood-5	2.25	3.20	0.49	0.48	-4.02	8.51	9.48	0.02	4981.27
Flood-4	1.81	3.60	0.25	0.61	-5.25	8.88	6.14	0.01	7173.46
Frost-4	0.00	0.00							
Frost-2	-0.09	0.81	0.01	0.91	-1.68	1.50	0.91	0.19	4.46
Frost-3	-0.12	1.02	0.01	0.91	-2.12	1.89	0.89	0.12	6.63
HydrGrp-5	0.00	0.00							
HydrGrp-3	1.79	2.18	0.67	0.41	-2.49	6.06	5.97	0.08	428.85
HydrGrp-4	0.59	1.09	0.30	0.59	-1.54	2.72	1.81	0.21	15.23
Hydric-3	0.00	0.00							
Hydric-2	-0.11	0.84	0.02	0.89	-1.76	1.53	0.89	0.17	4.64
LULC-71	0.00	0.00							
LULC-41	1.57	1.34	1.37	0.24	-1.06	4.19	4.79	0.35	66.12
LULC-82	3.30	3.64	0.82	0.36	-3.83	10.43	27.15	0.02	33854.76
LULC-95	5.51	3.98	1.91	0.17	-2.30	13.31	245.94	0.10	601236.75
Runoff-6	0.00	0.00							
Runoff-3	1.85	2.19	0.71	0.40	-2.44	6.15	6.38	0.09	468.06
Runoff-2	-1.14	0.95	1.45	0.23	-2.99	0.72	0.32	0.05	2.04
Runoff-4	-1.64	1.61	1.04	0.31	-4.79	1.51	0.19	0.01	4.54
PartSize-5	0.00	0.00							
PartSize-6	-2.55	1.39	3.38	0.07	-5.27	0.17	0.08	0.01	1.19
PartSize-7	-1.50	1.98	0.57	0.45	-5.38	2.39	0.22	0.00	10.86