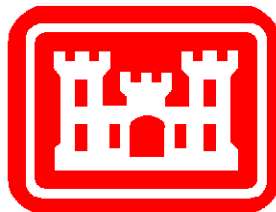


PUBLIC WORKS TECHNICAL BULLETIN 200-3-56
1 OCTOBER 2008

**EROSION ASSESSMENTS: TRAINING LOAD
OPTIMIZATION FOR ENVIRONMENTAL AND
ECONOMIC CONSIDERATIONS**



Public Works Technical Bulletins are published by the U.S. Army Corps of Engineers, 441 G Street NW, Washington, DC 20314-1000. They are intended to provide information on specific topics in areas of Facilities Engineering and Public Works. They are not intended to establish new DA policy.

PWTB 200-3-56
1 October 2008

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
441 G Street, NW
Washington, DC 20314-1000

CECW-CE

Public Works Technical Bulletin

1 October 2008

No. 200-3-56

Facilities Engineering
Environmental

EROSION ASSESSMENTS: TRAINING LOAD
OPTIMIZATION FOR ENVIRONMENTAL AND
ECONOMIC CONSIDERATIONS

1. Purpose. The purpose of this Public Works Technical Bulletin (PWTB) is to inform U.S. Army installation land managers about new methods to help enable more effective training area management and sustainment programs. This PWTB transmits the step-by-step approach used by the U.S. Army Engineer Research and Development Center's Construction Engineering Research Laboratory to quantify and rank areas of erosion at Camp Atterbury, Indiana, in 2006. The PWTB also gives lessons learned from the erosion ranking process that led to the investigation of alternative methods that would take into account training loads, environmental conditions, and land maintenance costs. If further assistance or clarification is needed on how to use the methodology, contact Heidi Howard at Heidi.R.Howard@us.army.mil.

2. Applicability. This PWTB applies to all U.S. Army facilities within the United States with active off-road military training and Integrated Training Area Management (ITAM) programs.

3. References.

a. Army Regulation (AR) 200-1, "Environmental Protection and Enhancement," 13 December 2007.

b. AR 200-2, "Environmental Effects of Army Actions," 23 December 1988.

c. AR 200-3, "Natural Resources - Land, Forest, and Wildlife Management," 20 March 2000.

4. Discussion.

a. AR 200-1, as revised in December 2007, contains policy for environmental protection and enhancement, implementation of pollution prevention, conservation of natural resources, sustainable practices, compliance with environmental laws, and restoration of previously damaged or contaminated sites. AR 200-2 contains policy for the assessment of the environmental effects of Army actions and training and requires planning for environmental impacts from their actions. AR 200-3 requires that installations be good stewards of land resources by controlling sources of wind-driven and hydrological erosion to prevent damage from management activities to the land, water resources, and equipment. Both hydrologic and wind-driven erosion play into multiple laws and regulations, such as the Clean Air Act and Clean Water Act, which affect how Army training lands are managed for erosion.

b. Accelerated erosion is an ongoing problem for many military training lands with the intensive nature of military training on limited acreage. Off-road military training decreases vegetative cover and destroys the natural soil matrix, causing high rates of soil erosion. Military training can result in resource losses that diminish the land's training capacity if sustainable land management practices are not used. Development of a comprehensive, installation-wide land management plan is needed to maintain training land carrying capacity, while staying within economic limitations. Since current techniques for installation-wide assessments of land quality and erosion are limited in scope and applicability. This PWTB provides step-by-step methods for ranking of erosional sites within a lessons learned format. In addition, a spatial optimization model was utilized to assist in developing management plans that weigh both economic and environmental consequences for management practices.

c. This PWTB also discusses lessons learned from an installation-wide erosion assessment. These lessons led to the development and case study for an optimization model that takes into account training loads, erosion, sedimentation, and economic costs for land stabilization. In response to the shortcomings found with the installation-wide erosion assessment, an investigation of the Soil and Water Assessment Tool (SWAT) developed for the U.S. Department of Agriculture

PWTB 200-3-56
1 October 2008

Agricultural Research Station (USDA-ARS) was completed to determine if and how training load requirements and economic cost constraints could be incorporated within an erosion assessment. Use of the newly developed method will result in improved decisions regarding the scheduling and placement of military training activities in the context of application of best management practices and repair of training lands.

d. Appendix A provides an overview of an installation-wide erosion assessment at Camp Atterbury. In addition, the modeling methodology and explanation of optimization functions are discussed.

e. Appendix B is an overview of the SWAT modeling methodology and an explanation of optimization functions that can be used to allow for the inclusion of economic and environmental constraints.

f. Appendix C contains model results from the study case at Camp Atterbury, IN.

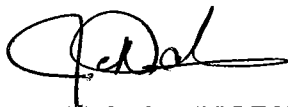
g. Appendix D lists additional references.

5. Points of Contact (POCs). Headquarters, U.S. Army Corps of Engineers (HQUSACE) is the proponent for this document. The POC at HQUSACE is Malcolm E. McLeod, CEMP-II, 202-761-0632, or e-mail: Malcolm.E.McLeod@usace.army.mil.

Questions and/or comments regarding this subject should be directed to the technical POC:

U.S. Army Engineer Research and Development Center
Construction Engineering Research Laboratory
ATTN: CEERD-CN-N (Heidi R. Howard)
2902 Farber Drive
Champaign, IL 61822-1072
Tel. (217) 398-5865
FAX: (217) 373-7251
e-mail: heidi.r.howard@usace.army.mil

FOR THE COMMANDER:



JAMES C. DALTON, P.E.
Chief, Engineering and Construction
Directorate of Civil Works

Appendix A

1. Background

a. Off-road military training is an inherently destructive activity. Vegetation is often trampled, torn, or destroyed, causing increased erosion and the formation of large gullies (Mendoza et al. 2002). If left unchecked, such training land degradation can lead to decreased training capacity and loss of wildlife habitat. In addition, the cost of sustaining and repairing training areas and trails is generally proportional to the amount of training. Balancing the demands for effective and efficient military training with the need to meet environmental regulations and economic budgets is necessary for sustainable installation operation.

b. This PWTB provides an overview of models and tools commonly used for assessing the state of erosion and sedimentation on training lands. This assessment included the following erosion models: Universal Soil Loss Equation (USLE), Revised USLE (RUSLE), and Water Erosion Prediction Project (WEPP). In addition, training land impact models for site rehabilitation were assessed and included: Site Rehabilitation Prioritization Form (SRPF) and Land Rehabilitation Potential Model (LRPM). Historic imagery and field investigations/surveys were conducted and included in the investigation. These models and tools were then used to complete an installation-wide assessment of erosion at Camp Atterbury Joint Maneuver Training Center (CAJMTC) near Edinburgh, IN. It was quickly determined that these techniques had limitations, which led to the investigation of a modeling framework that would allow for the inclusion of economics and training loads.

c. The feasibility of using a genetic algorithm model approach to address economics, training requirements, and environmental impacts was investigated. The new modeling framework was designed to produce a more complete assessment than possible with currently available techniques. The new model seeks to maximize training loads while minimizing and analyzing the associated environmental impact and economic costs. The northwest quarter of CAJMTC was used for this analysis. Only grassland training areas were analyzed within the new modeling framework.

d. This PWTB provides results and methods developed for the CAJMTC case study. This modeling approach can be used to access current and future erosion and sediment levels of training lands.

2. CAJMTC Background

a. CAJMTC, the study location, is 35 miles south of Indianapolis, IN (Figure A-1). The majority of the installation is within Bartholomew County, with smaller portions in Johnson and Brown Counties. CAJMTC is an Army National Guard (ARNG) installation, federalized in 2002 for the mobilization of ARNG and United States Army Reserve (USAR) units.

b. CAJMTC comprises more than 33,000 acres and includes more than 145 live firing ranges that include 57 direct-fire ranges, 10 mortar firing points, and more than 80 artillery firing positions. The artillery capabilities are designed to support training from both the air and ground. In addition to ARNG and USAR units, a wide range of organizations and services use CAJMTC year round, including Army, Air Guard, Navy, State Police, and Boy Scouts.

c. As an installation with a wide range of activities and training taking place year-round, it is critical to maintain CAJMTC's training areas, ranges, and road network to provide an optimal training experience. Erosion is the predominant limiter on CAJMTC and can impact training quality. Erosion affects not only the accessibility of an area but the surrounding wildlife and water quality. Most erosion sites can be controlled, but determining which sites are in need of repair and ranking critical sites can become complicated. It was determined that an installation-wide assessment was needed to identify actively eroding sites and to prioritize those sites for future rehabilitation. Generally, the first step taken in identifying eroding training sites is by use of a model.

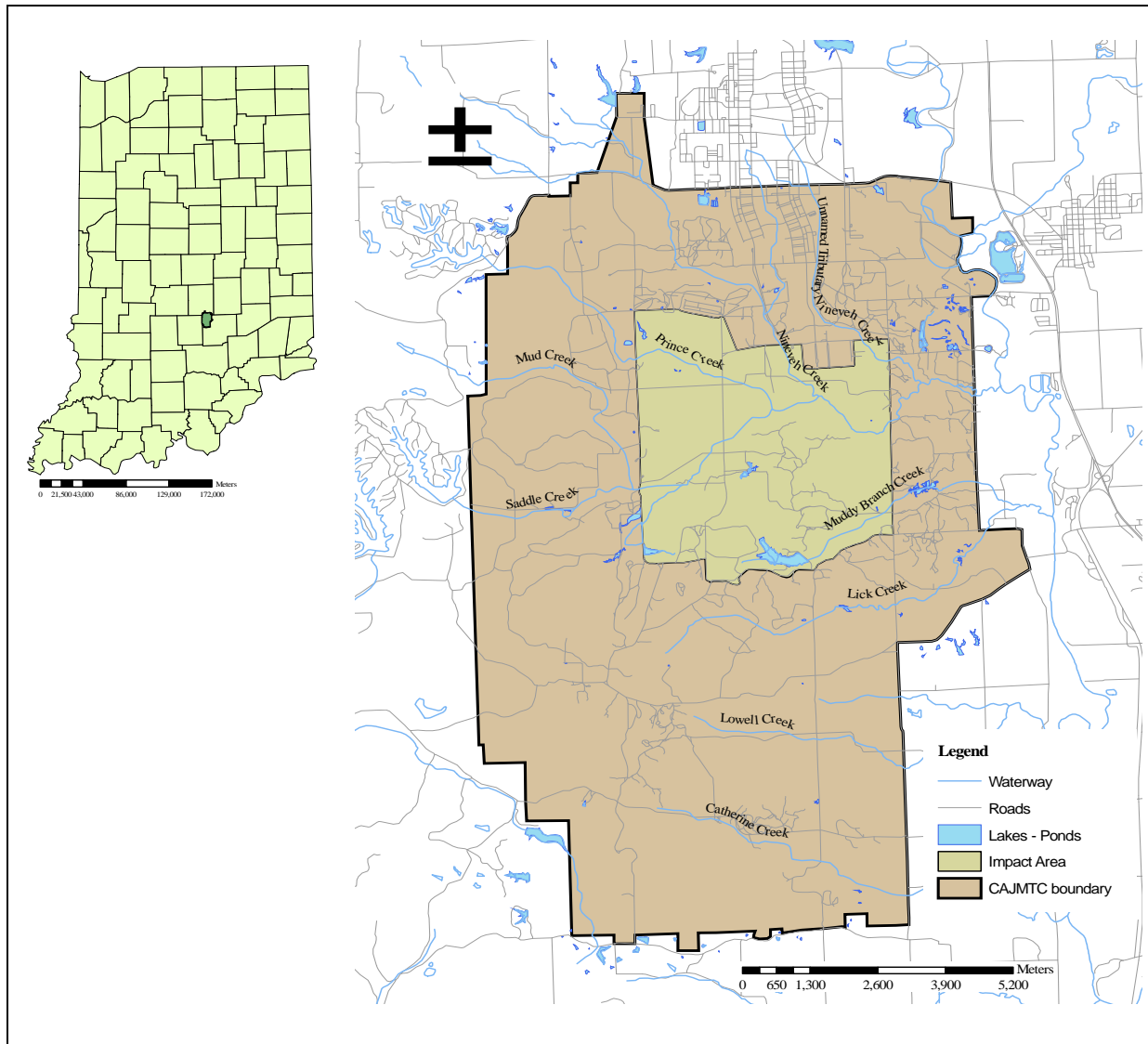


Figure A-1: Location and map of Camp Atterbury Joint Maneuver Training Center.

3. Case Study - CAJMTC Installation-Wide Assessment

a. A suite of tools was used to locate potential sites with excess erosion on CAJMTC. To accomplish this assessment, historical CAJMTC aerial photographs were used with geographic information systems (GIS) to identify and measure change over time for eroding sites. Soils were classified for their erodability using the 2004 soil survey. In addition, field surveys were conducted to validate the remote sensing data, provide groundtruthing, and collect site-specific data.

b. Aerial photographs from 1974 and 1984, along with 1999 and 2004 satellite imagery of CAJMTC, were used with GIS to find evidence of erosion. Images were processed to detect change over time and determine active vs. inactive erosion of the bare ground.

c. Historic aerial photographs can be used as bench marks for calculating areas of mass wasting and potentially for estimation of active erosion migration (MacDonald et al. 1993; Hirst et al. 2000; Micheli and Kirchner 2002; Simon et al. 2002). Using methods documented by Hirst et al. (2000), we were able to calculate change over time. The first step was to obtain a CAJMTC 2004 georectified, high resolution data set. We then obtained original historic photographs from the 1970s-1990s; high quality images only. The 1974, 1983, and 1998 aerial photographs were scanned into Tagged Image File Format (TIFF) using 300 dots per inch (dpi) resolution on the "grayscale" setting. The newly scanned images were then brought into ArcMAP and individually rectified to the 2004 image using the georeferencing toolbar of the ERDS ArcGIS software package. To rectify, at least five points were obtained. Most points were referenced using historic site locations, structures such as bridges, and other land formations that had not changed location or size over the three decades.

d. Once rectified, the images for stream bank migration were compared with each other by mapping the migration of the channel centerline over time. By using the "eroded-area polygon" technique, a measurement of bank erosion was made. The technique involves measuring the area enclosed by two successive channel centerlines mapped over a given time (MacDonald et al. 1993; Micheli and Kirchner. 2002; Simon et al. 2002). It should be noted that results are generally more accurate when streambanks are used to form the eroded-area polygon instead of channel centerlines. Unfortunately, it was difficult to decide where a streambank was located on older aerial photographs due to vegetation growth along the bank and the poor resolution, which obscured the streambank.

e. The eroded-area polygon method was used to find the area of land eroded over a given time period for each unstable section of the reach. The streambank height measurements from the field survey were then used to find an eroded volume. The streambank heights for a given site were assumed to remain constant from 1974 to 2004 because the land beyond the streambank is relatively flat along the reach.

f. Due to resolution and seasonality of the 2004 imagery, the majority of upland sites, rill, and gully erosion was visible on the 2004 satellite imagery but not the other images. It was noted during the field survey that woody debris and fallen timber were commonly mistaken for rill and gully erosion on aerial photographs of several sites. Due to canopy cover and rutting, it was more difficult to detect upland erosion than trail and roadside erosion. By comparing remote sensing images, most erosion sites were documented and recorded. The erosion site locations found during the electronic search were used as references for three field surveys during June 2005, July and August 2005, and April 2006.

4. Field Survey

a. Surveys of the identified sites focused on erosion within CAJMTC on first-order streams and upland erosion as identified during the preliminary investigation. Measurements were taken to include height, width, length, and slope of the eroded sites. Physical characteristics also noted during the survey included soil type, vegetation type and percent coverage, disturbance levels, and types of erosion. In addition, signs of recent military activity and environmental effects such as direct sediment loading to streams and presence of threatened and endangered species (TES) and associated habitat were noted. Figures A-2 through A-5 show four of the erosion sites documented during the field surveys. Note that many other types and causes of erosion were found and documented during the surveys.



Figures A-2 and A-3: Rill and gully erosion due to (top) trail degradation and (bottom) lack of vegetation.



Figures A-4 and A-5: Gully erosion due to inadequate drainage system protection.

5. Impaired Site Ranking

a. Each site identified and confirmed for active erosion during the field investigation was ranked by the degree of erosion, potential for rehabilitation, impacts to training, and impacts to the environment. These rankings were derived from linking models such as WEPP, RUSLE, SRPF, and LRPM.

b. The Sustainable Range Program (SRP) is the Army's overall approach to ensure ranges are used to promote long-term sustainability. The SRPF was developed through the Integrated Training Area Management (ITAM) Program and is intended to help prioritize land rehabilitation and maintenance of training and testing lands. The SRPF rankings are derived from a weighted system that assigns a score to each site by considering the size of the area, the percent slope, the type(s) of erosion, and the impact of the degradation on the environment and training (Figure A-6). A wide variety of forms are used from installation to installation but all include similar site characterization factors.

c. Developed by the U.S. Army Engineer Research and Development Center (ERDC) with support from the U.S. Army Construction Engineering Research Laboratory (CERL), LRPM uses several ecologically based site factors known to influence the potential for successful rehabilitation of damaged sites (Denight et al. 2005). These factors include climate, landscape, soils characteristics, stress/denudation, vegetation, and land use. Each factor is given a specific weight depending on its evaluated characteristics (Figure A-7). LRPM determines the potential for rehabilitation of sites at any location.

d. WEPP is a process-based, distributed parameter, continuous-simulation erosion prediction model. It is capable of modeling hillslope erosion processes (sheet and rill erosion), soil loss and sediment deposition from flow in small channels, and sediment deposition in impoundments. For this study the hillslope modeling was used to determine the average mass of sediment eroded from each site per year for 10 years. Soil type, slope characteristics, and vegetation coverage was adjusted to match the conditions for every erosion site. A constant climate setting was used for every erosion site modeling run and corresponds to the average yearly climate for Columbus, IN.

CAMP ATTERBURY SITE REHABILITATION PRIORITIZATION FORM (SRP)				
Training Area _____		UTM Easting _____		Date _____
		Northing _____		
<u>Size of Area Degraded (SAD)</u>				
(Length (m))	(Width (m))	(Height/Depth (m))		
_____ x _____	x _____	= _____	(cu.m)	0 - 25 _____ = 1
_____ x _____	x _____	= _____	(cu.m)	25 - 50 _____ = 2
_____ x _____	x _____	= _____	(cu.m)	50 - 75 _____ = 3
_____ x _____	x _____	= _____	(cu.m)	75 - 100 _____ = 4
_____ x _____	x _____	= _____	(cu.m)	> 100 _____ = 5
_____ x _____	x _____	= _____	(cu.m)	
Total = _____			(cu.m)	(SAD) = _____
<u>Percent Slope (PS)</u>		<u>Erosion (E)</u>		
0-3% _____ = 1		Loss Of Ground Cover _____ = 2		
4-7% _____ = 2		Loss Of Soil _____ = 3		
8-11% _____ = 3		{ Contained On Site } _____ = 1		
12-15% _____ = 4		{ OR } _____ = 1		
>15% _____ = 5		{ Discharged From Site } _____ = 4		
		{ OR } _____ = 4		
(PS) = _____		{ Discharged Off Post } _____ = 5		
		Total (E) = _____		
<u>Environmental Concerns (EC)</u>		<u>Effects on Training (ET)</u>		
No Effect _____ = 1		No Effect _____ = 1		
Vegetation Impacted _____ = 2		Impact Future Training _____ = 2		
Wildlife Habitat Impacted _____ = 3		Impact Present Training _____ = 3		
Wetland/Riparian/ Lake Impacted _____ = 4		Deterioration of Assets _____ = 4		
State Listed sp. Impacted _____ = 5		Loss of Training Area _____ = 5		
Water Quality Deterioration _____ = 6		Safety _____ = 6		
Federal Listed sp. Impacted _____ = 7				
Total (EC) = _____		Total (ET) = _____		
<u>Potential Impacts (PI)</u>		$\frac{\text{_____} \times \text{_____} \times \text{_____} \times \text{_____} \times \text{_____}}{\text{(SAD) (PS) (E) (EC) (ET)}} + \frac{\text{_____}}{\text{(PI)}}$		
Secondary Drainage _____ = 1				
Culvert/Road Drainage _____ = 2				
Primary Drainage _____ = 6				
Wetland/Riparian/Lake _____ = 12				
Total (PI) = _____				

Figure A-6: Camp Atterbury SRPF.

LRPM DATA ENTRY FORM

INSTALLATION _____ DATE _____

SITE _____

CLIMATE	LANDSCAPE	SOILS	VEGETATION
<p><u>SPRING AVERAGE RAINFALL</u></p> <input type="checkbox"/> Over 20 inches <input type="checkbox"/> 10-20 inches <input type="checkbox"/> 1-9 inches <input type="checkbox"/> Less Than 1 inch	<p><u>SLOPE GRADIENT</u></p> <input type="checkbox"/> Nearly Level (<2%) <input type="checkbox"/> Gently Sloping (2-6%) <input type="checkbox"/> Moderately Sloping (6-12%) <input type="checkbox"/> Strongly Sloping (12-18%) <input type="checkbox"/> Steep Embankment (18-25%) <input type="checkbox"/> Extremely Steep (>25%)	<p><u>USDA TEXTURE</u></p> <input type="checkbox"/> Loam <input type="checkbox"/> Silty Clay <input type="checkbox"/> Clay Loam <input type="checkbox"/> Sandy Clay Loam <input type="checkbox"/> Silty Loam <input type="checkbox"/> Sandy Clay <input type="checkbox"/> Silty Clay <input type="checkbox"/> Sandy Loam <input type="checkbox"/> Clay <input type="checkbox"/> Sand	<p><u>GROUND COVER</u> (C Value)</p> <input type="checkbox"/> 80-100% cover <input type="checkbox"/> 60-80% cover <input type="checkbox"/> 40-60% cover <input type="checkbox"/> 20-40% cover <input type="checkbox"/> <20% cover
<p><u>SUMMER AVERAGE RAINFALL</u></p> <input type="checkbox"/> Over 20 inches <input type="checkbox"/> 10-20 inches <input type="checkbox"/> 1-9 inches <input type="checkbox"/> Less Than 1 inch	<p><u>SLOPE LENGTH</u></p> <input type="checkbox"/> < 25 ft <input type="checkbox"/> 26-50 ft <input type="checkbox"/> 51-75 ft <input type="checkbox"/> 76-100 ft <input type="checkbox"/> 101-200 ft <input type="checkbox"/> 201-300 ft <input type="checkbox"/> 301-400 ft <input type="checkbox"/> 401-500 ft <input type="checkbox"/> 501-600 ft <input type="checkbox"/> 601-800 ft <input type="checkbox"/> > 800 ft	<p><u>SOIL ACIDITY</u></p> <input type="checkbox"/> pH 5.5-7.5 <input type="checkbox"/> pH 4.5-5.5 or 7.5-8.5 <input type="checkbox"/> pH <4.5 or >8.5	<p><u>PERENNIAL:ANNUAL RATIO</u></p> <input type="checkbox"/> >3 <input type="checkbox"/> 2.0-2.9 <input type="checkbox"/> 1.0-1.9 <input type="checkbox"/> < 1.0
<p><u>GROWING SEASON DURATION</u></p> <input type="checkbox"/> Over 200 days <input type="checkbox"/> 180-200 days <input type="checkbox"/> 100-179 days <input type="checkbox"/> Less than 100 days	<p><u>WIND ERODIBILITY</u></p> <input type="checkbox"/> Low to Moderate (> 8) <input type="checkbox"/> High (5-8) <input type="checkbox"/> Extreme (<5)	<p><u>NUTRIENT STATUS (NPK)</u></p> <input type="checkbox"/> Excellent <input type="checkbox"/> Moderate <input type="checkbox"/> Low <input type="checkbox"/> Insufficient	<p><u>NATIVE vs EXOTIC</u></p> <input type="checkbox"/> Dominated by native annuals <input type="checkbox"/> Dominated by exotic annuals
<p><u>PREVAILING WINDS</u></p> <input type="checkbox"/> Winds are insignificant <input type="checkbox"/> Wind may cause slight erosion <input type="checkbox"/> Winds cause significant erosion	<p><u>SOIL COMPACTION</u></p> <input type="checkbox"/> Loosely compacted <input type="checkbox"/> Densely compacted	<p><u>STRESS</u></p> <input type="checkbox"/> Minimal impacts <input type="checkbox"/> Moderate impacts <input type="checkbox"/> Severe impacts	<p><u>LAND USE</u></p> <p><u>CURRENT TRAINING LOAD (MIM)</u></p> <input type="checkbox"/> 0-50 <input type="checkbox"/> 50-1,000 <input type="checkbox"/> 1,000-2,500 <input type="checkbox"/> 2,500-5,000 <input type="checkbox"/> >5,000
<p><u>FREEZE-THAW (F-T) FACTORS</u></p> <input type="checkbox"/> F-T is NOT a consideration <input type="checkbox"/> F-T may increase erosion <input type="checkbox"/> F-T causes significant erosion	<p><u>CRUST</u></p> <input type="checkbox"/> Crust is intact <input type="checkbox"/> Crust is slightly broken <input type="checkbox"/> Crust is moderately broken <input type="checkbox"/> Crust is extremely broken <input type="checkbox"/> Crust does not exist	<p><u>NATURAL DISTURBANCE</u></p> <input type="checkbox"/> Minimal (<10% Likely) <input type="checkbox"/> Low (10%-40%) <input type="checkbox"/> Moderate (40%-70%) <input type="checkbox"/> High (> 70%)	<p><u>FUTURE TRAINING LOAD (MIM)</u></p> <input type="checkbox"/> 0-50 <input type="checkbox"/> 50-1,000 <input type="checkbox"/> 1,000-2,500 <input type="checkbox"/> 2,500-5,000 <input type="checkbox"/> >5,000
<p><u>SLOPE ASPECT</u></p> <input type="checkbox"/> Slope faces SE or SW <input type="checkbox"/> Slope faces East or West <input type="checkbox"/> Slope faces NE or NW <input type="checkbox"/> Slope faces South <input type="checkbox"/> Slope faces North	<p><u>SOIL PROFILE</u></p> <input type="checkbox"/> 'A' Horizon Intact <input type="checkbox"/> 'A' & 'B' Horizon Mixed <input type="checkbox"/> 'A' Horizon Eroded; <input type="checkbox"/> 'B' Horizon Exposed <input type="checkbox"/> 'C' Horizon Exposed	<p><u>POSITION ON SLOPE</u></p> <input type="checkbox"/> Slope is NOT critical <input type="checkbox"/> Top of Slope <input type="checkbox"/> Mid Slope <input type="checkbox"/> Bottom of Slope	

Figure A-7: LRPM.

e. The erosion sites across the installation were ranked using the SRPF, LRPM, WEPP or the SRPF, LRPM, RUSLE prioritization and erosion measurement methods. Average rankings from the three methods were then found and used to create a final average ranking of every site. The WEPP model provides a wide range of output data but, for the purpose of this erosion analysis, only the average annual soil export rate was considered. The site-specific rankings were used to determine top priority areas or locations. A number of areas encompassed a group of individual erosion sites. By combining these sites into general areas or ranges, the top ten priority locations were determined (Table A-1).

Table A-1. Top ten erosion site rankings for CAJMTC.

Rank	Sites
1	Kleiber Drop Zone
2	STAT K
3	Range 37: E-J
4	Range 37: MB1-MB4
5	Range 43
6	B6-B9: Schoolhouse Rd.
7	A3-A7: Morton Rd.
8	Nineveh Reach: I-VIII
9	A2: South of Bridge #10
10	N1-N3: Airstrip

f. Due to the topography and management structure of Range 36, it was evaluated separately from the rest of the CAJMTC erosion study since it is leased by the Air Force National Guard and located in an area of low topographic relief. To facilitate the erosion assessment, RUSLE was used instead of WEPP because the former is designed to estimate erosion from general areas of less than 1 square mile while the latter is designed to estimate erosion from a given hillslope. Therefore, RUSLE works well when using a grid system. Range 36 was divided into 100 m by 100 m grids in areas thought to be of high and moderate erosion risk (Figure A-8). The remainder of the range, which is forest, was considered as a land parcel and not divided into grids. RUSLE was used to determine the average annual erosion rate on each grid square or land parcel.

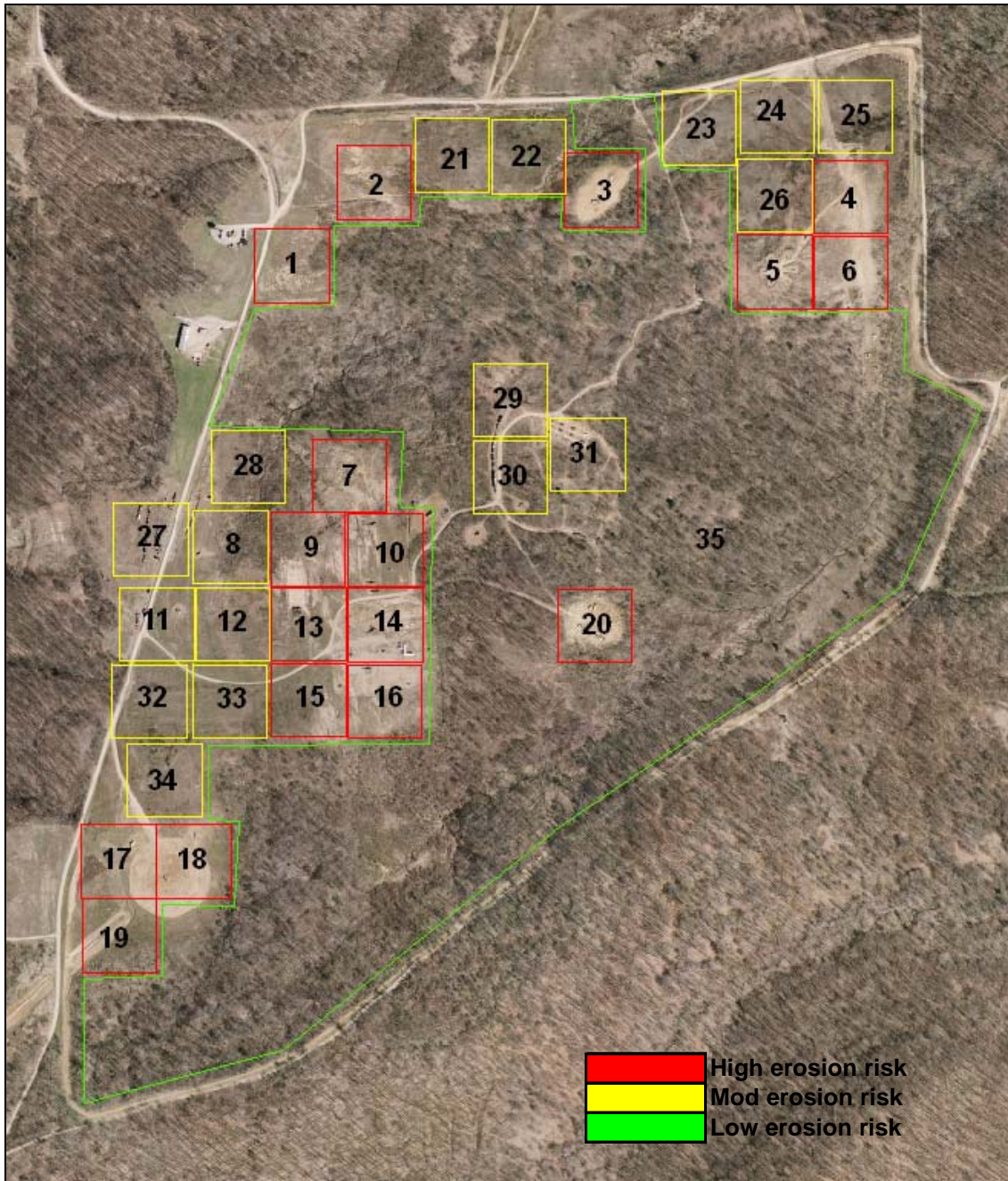


Figure A-8: CAJMTC Range 36 RUSLE erosion assessment grid.

6. Assessment Limitations

a. The assessment detailed above ranked eroding training sites/ranges at CAJMTC based primarily on environmental degradation, potential for successful rehabilitation of damaged sites, and annual soil erosion estimates. The final ranking provided CAJMTC's ITAM office with an installation-

wide snapshot of the state of active erosion affecting CAJMTC's training lands. This ranked list of sites provided useful information about where erosion was taking place. It also provided data for sites that were most in need of repair and had high potential for successful rehabilitation (see Figure B-8 in Appendix B). The assessment, however, provided no information with regard to the estimated costs of repairing these sites, and it failed to recommend preventative measures (i.e., training load scheduling and distribution across the installation to limit future training range degradation at CAJMTC).

Appendix B

1. Overview – In response to the shortcomings of the installation-wide erosion assessment detailed in Appendix A, an investigation of the Soil and Water Assessment Tool (SWAT) was completed to determine if and how training load requirements and economic cost constraints could be incorporated with an erosion assessment.

2. SWAT/Genetic Algorithm Methodologies

a. SWAT is a process-based, distributed continuous watershed model developed by the U.S. Department of Agriculture (USDA) (Neitsch et al. 2005). SWAT was chosen for this framework because it is widely used, user friendly, integrated into a GIS, and implements the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978). The objective in model development was to predict the impact of management on water, sediment, and non-point chemical yields in large, ungauged basins. In order to meet the objective, SWAT is physically based (calibration is not possible on ungauged basins), uses readily available inputs, is computationally efficient to operate on large basins, is a continuous time model (daily time steps), and is capable of simulating long periods for computing the effects of management changes. SWAT has also been integrated within the GIS software ArcView[®]. The integration allows GIS data to be used as model inputs and facilitates the spatial aspects of watershed modeling.

b. Several other watershed models were considered for this study. These included the Annualized Agricultural Non-Point Source pollution model (AnnAGNPS), the CASCade 2-D model (CASC2D), and the Water Erosion Prediction Project (WEPP). These four models, including SWAT, are physically based distributed models that can be obtained and run for free. WEPP was not used because it is not a continuous model, is not easily compatible with GIS platforms, uses hillslope land units, and does not use USLE variables to calculate erosion and sediment routing. CASC2D was not used because its sediment routing routine (CASC2D-sed) is currently under development. Model comparison is shown in Table B-1. AnnAGNPS was originally going to be used for this study; however, unresolved model crashes and the difficulty of creating an AnnAGNPS/Genetic Algorithm (GA) interface resulted in the application of the more user-friendly SWAT.

Table B-1. Watershed model tradeoffs.

Models	User-Friendly	GIS Compatible	Spatial Reference	Implements USLE in Sediment Routing	Easily Interfaced With GA
SWAT	Yes	Yes	Subwatershed	Yes	Yes
AnnAGNPS	No	Yes	Subwatershed	Yes	No
CASC2D	No	Yes	Grid	No	Yes
WEPP	Yes	No	Hillslope	No	No

c. Figure B-1 is a sample SWAT model for CAJMTC. This model includes 202 subwatersheds, each modeled as a homogenous land parcel. Average annual stream flow, overland flow, upland erosion, and sediment loading estimates are calculated for each parcel. All subwatersheds outside of the installation are excluded from the framework of the optimization model.

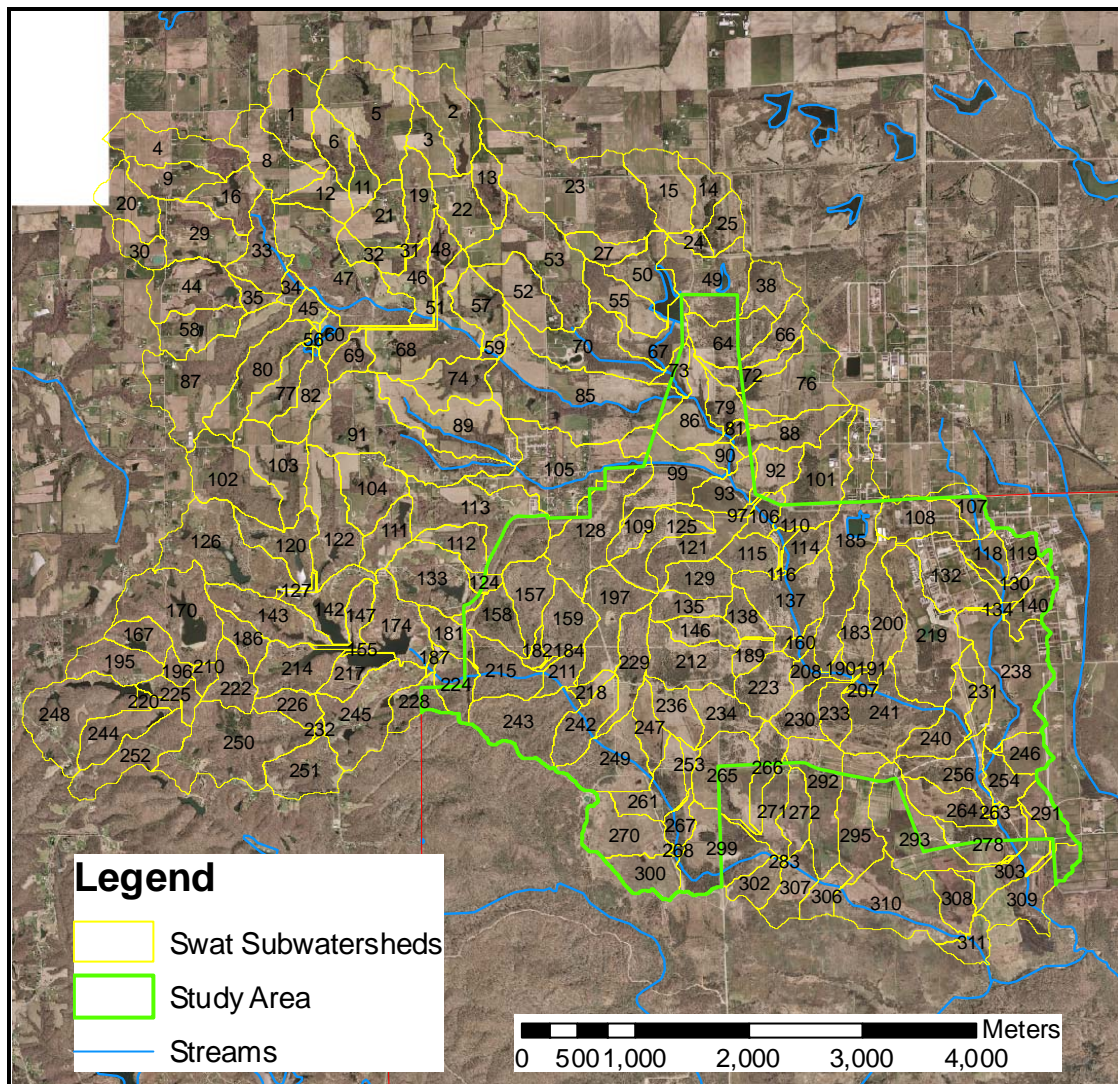


Figure B-1: SWAT subwatersheds for CAJMTC model.

d. GAs are a class of stochastic search techniques that use the mechanism of natural selection to search for the optimum solution to the objective function(s) (Goldberg 1989). Simply, GAs are a sophisticated guess and check method that takes the best qualities from the first iteration of guesses to produce the next generation of guesses until a nearly optimum solution is found. A more specific explanation of GAs is given below.

3. The GA/SWAT Interface

a. The GA/SWAT interface seeks to maximize training load while minimizing the environmental impact and economic costs. The model guesses and checks two decision variables, one of which is the training load for each subwatershed. Training load is given in units of maneuver impact miles (MIMs) per hectare. A single MIM represents the environmental impact of an M1A2 main battle tank over 1 mile of off-road maneuvering. The model converts MIMs/ha to a corresponding minimum cover factor (USAEC 1999). The cover factor is a USLE parameter that represents that amount of vegetative ground cover. If ground cover is near 100%, the cover factor is near zero. Since military training destroys vegetation, a high training load equals a high minimum cover factor.

b. The training load also affects how much money must be spent each year on training range and trail sustainment. Sustainment practices are classified as annual maintenance that does not directly reduce erosion or mitigate the environmental impact of military training. Such maintenance must be done periodically regardless of training load, but high training loads can increase how often the practices must be completed. Examples of these practices include road grading and resurfacing, the application of herbicides and pesticides, controlled burns, invasive species control, etc.

c. The second decision variable analyzed by the model is the USLE practice factor. The practice factor measures the amount of erosion reduction due to given conservation practices. Such practices are independent of training load. Examples of these practices include: seeding, mulch application, grading and shaping, terracing, riprap application, and construction of grassed waterways or sediment basins.

d. For this example, 33 subwatersheds are considered within the optimization model (Figure B-2). These subwatersheds

encompass grassland training ranges suitable for larger-scale mechanized military training. Each subwatershed is considered to be homogenous and all land management and military training is assumed to impact each training area uniformly. Within the GA methodology, a gene represents each decision variable (practice factor and training load). Since there are 33 training areas and 2 decision variables per area, there are 66 genes. Each string of 66 genes makes up a single chromosome.

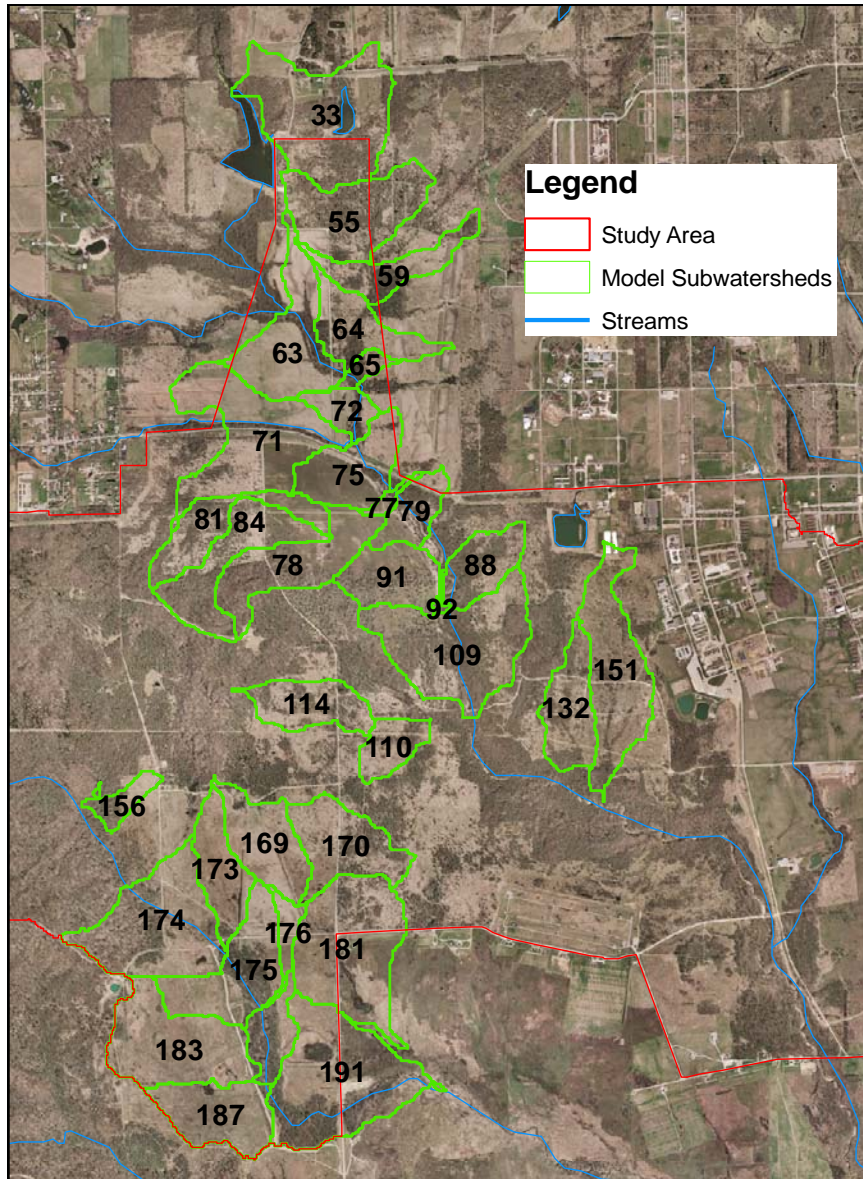


Figure B-2: GA modeled subwatersheds.

e. The GA/SWAT model works in a circular flow path. The GA begins by randomly choosing a number of different chromosomes (training load and practice factors). After converting each training load gene value to a corresponding USLE cover factor value, each chromosome is sent to SWAT individually to be run. After all five chromosomes are run, the GA uses the sediment load outputs and computed economic data to rank the fitness of each. Based on this analysis, the GA performs gene crossovers and mutations to produce new chromosomes (children). This cyclic process repeats for a number of user-specified generations or until the chromosomes merge into identical copies of each other. A flow chart of the GA methodology is presented in Figure B-3.

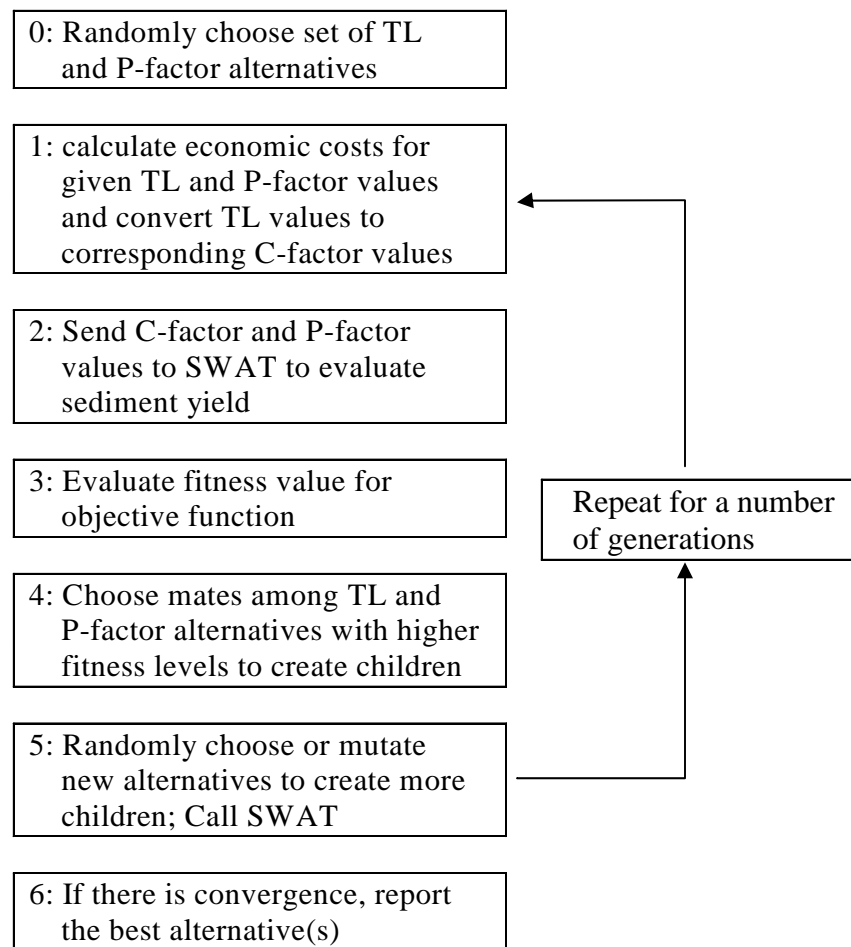


Figure B-3: Logical flow of GA/SWAT optimization.

4. Optimization Functions

a. Road and trail sustainment practices encompass periodic maintenance that must be done to maintain the vehicle capacity of a given road or trail. Such practices need to be completed to maintain a trail regardless of the amount of vehicle traffic. However, the return period for grading and resurfacing may be 10 years with little to no trail use but a half-year when the trail is used heavily. The spatial distribution of vehicle travel on roads and trails at CAJMTC is hard to define. There are multiple ways to access each training area and multiple trails within most areas. As a result, the function of training load vs. cost (Figure B-4) is generalized and based on the number of miles of roads and trails within the 33 modeled land parcels. Training load is also computed as a total of the 33 subwatersheds instead of MIMs/ha.

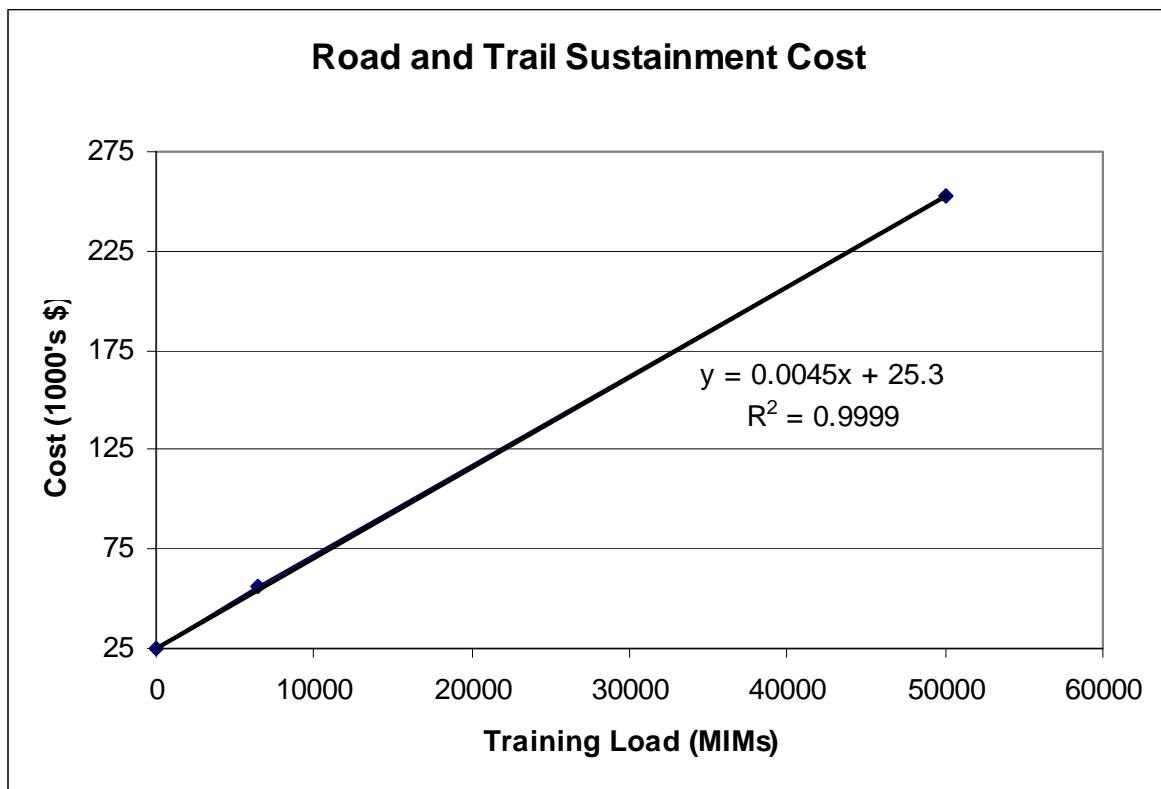


Figure B-4: Installation road and trail sustainment cost as a function of total training load.

b. Training range sustainment practices encompass periodic maintenance that must be done to maintain training capacity of a given hectare of training land. Such practices need to be completed to maintain a range regardless of the amount of training. Nonetheless, the return period for these practices on a given land parcel are also influenced by how much annual training to which the parcel is subjected. Since each parcel is assumed to be uniformly impacted by training, the function of training load vs. cost (Figure B-5) is specific to each of the 33 training parcels. The training load is given in MIMs/ha. The sustainment cost examples given in this PWTB are based on historic training load data specific to CAJMTC.

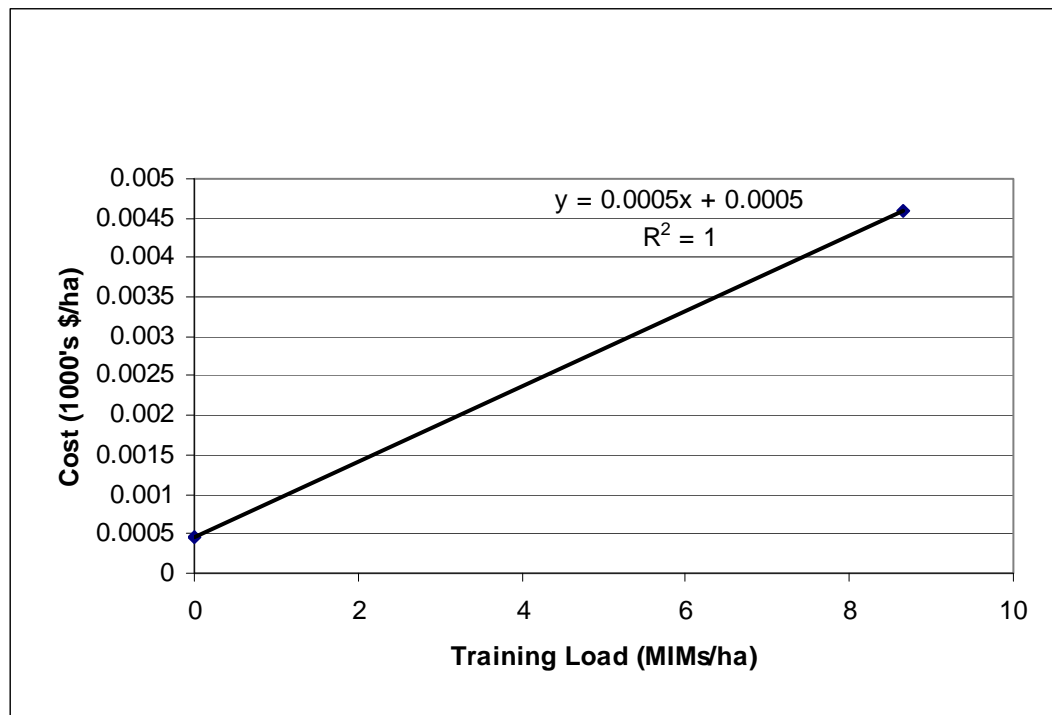


Figure B-5: Installation training range sustainment costs as a function of training load per hectare of training area.

c. Training land repair practices are those conservation practices that mitigate the erosion caused by military training. A practice factor value of 1 means no conservation practices are employed, which corresponds to no additional annual costs. A practice factor value of 1 is initially assumed for all 33 parcels. The practice factor vs. cost function was developed using a number of real-life training area conservation projects at CAJMTC. A few plausible but unused projects were also included to supplement the existing

examples. Each project was analyzed to determine the approximate average practice factor and the corresponding cost per hectare. The following function (Figure B-6) is parabolic and provides a fairly good approximation. This relationship, again, is valid only for CAJMTC. Other installations may commonly use conservation practices rarely used at CAJMTC. Developing individual relationships for other installations should be straight forward.

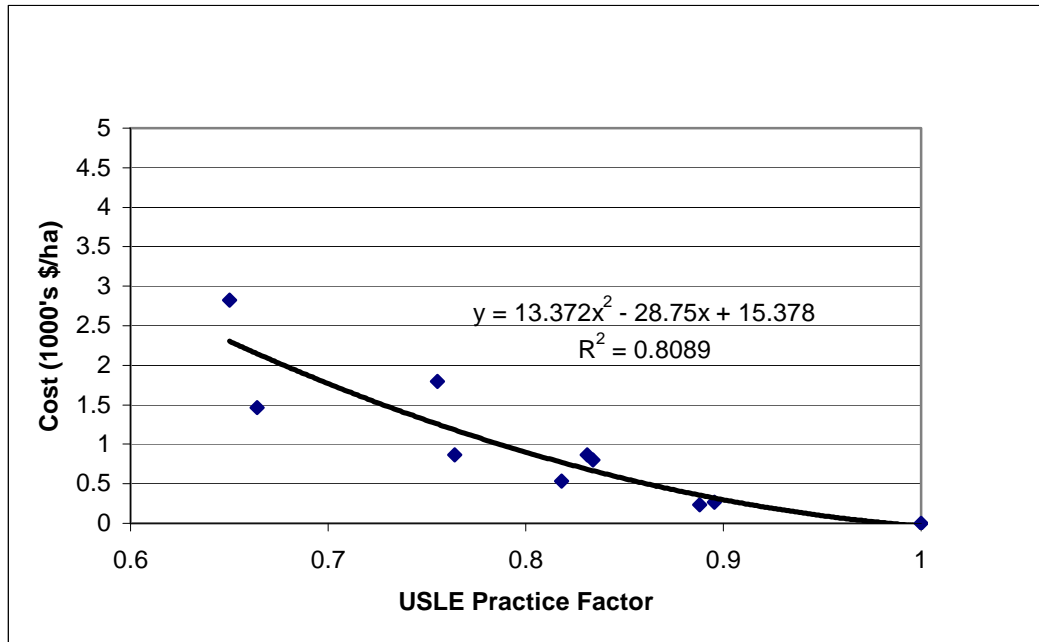


Figure B-6: Installation training range repair costs as a function of average USLE practice factor.

d. The environmental impact of military training is difficult to quantify unless onsite field studies have been performed. Weather, vegetation, soil, and seasonal variations between regions cause large differences between vegetative impact and recovery from installation to installation. Field studies from CAJMTC were used to determine the average annual vegetative impact of 1 MIM on 1 hectare of grassland training range. Vegetative impact was measured as a percent change in the amount of average annual vegetative cover. Minimum cover factor values were then calculated from the percent cover data. As a result, the relationship between training load and erosion (Figure B-7) is given as MIMs/ha vs. minimum cover factor.

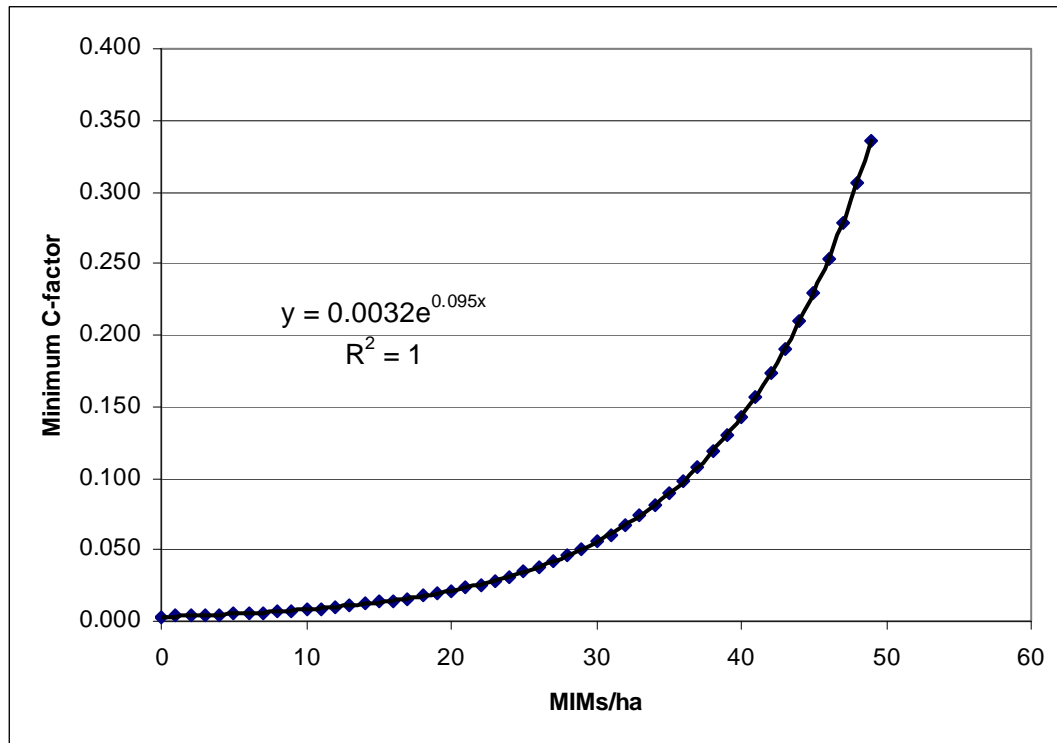


Figure B-7: USLE cover factor as a function of training load per hectare of training area for CAJMTC.

f. The model uses a weighted, multiple objective function to find the optimum training load and practice factor value for each subwatershed. The function is as follows:

$$\text{MAXIMIZE} \left[W_s \left(\frac{\text{MaxSL}}{\text{SL}} \right) + W_c \left(\frac{\text{MaxTC}}{\text{TC}} \right) + W_T \left(\frac{\text{TL}}{\text{MaxTL}} \right) \right]$$

Where *MaxSL*, *MaxTC*, and *MaxTL* are the maximum allowable total sediment load, total annual cost, and total training load; *SL*, *TC*, and *TL* are the total sediment load (tons/ha), total cost (\$), and total training load (MIMS) calculated by the model; and W_s , W_c , and W_T are weights. *MaxSL*, *MaxTC*, and *MaxTL* are needed to normalize each parameter because *SL*, *TC*, and *TL* are valued at different units. The three weights can be used to put more emphasis on a given parameter. If $W_s = W_c = W_T = 0.334$, the environmental impact, cost, and training needs will be considered equally by the model. If $W_s = W_c = 0.2$ and $W_T = 0.6$, the model will place more emphasis on maximizing total training load and less on minimizing sediment load and total cost.

Appendix C

1. Model Objective Results

a. Sixty-seven modeling runs were conducted over a 3-week period in order to sample a range of weight value combinations. For each run, W_S , W_C , and W_T were valued from 0-1, to the nearest tenth, so that the sum always equaled one. An additional run was also completed for which $W_S = W_C = W_T = 0.3$, so that each objective was considered equally. The following sections provide results from the modeling runs. Maximum average annual sediment load, total cost, and training load ($MaxSL$, $MaxTC$, $MaxTL$) were given as 1600 tons, \$150,000, and 10,000 MIMs respectively. The decision variables (training load and practice factor) were constrained between 0-20 MIMs/ha and 0.7-1.0, respectively. These are all common values for CAJMTC and for the given group of training land parcels.

b. For each modeling run, the optimum objective variable values were recorded. The minimum total average annual sediment load and total average annual cost and maximum annual training load values were recorded for the runs where $W_S = 1$, $W_C = 1$, and $W_T = 1$ respectively. These three runs are those for which only one objective was considered within the objective function and are therefore single-objective model applications. Table C-1 shows the payoff between the three single objective optimizations. Total sediment load is minimized at 1024 metric tons per year when minimal training is conducted and 1.1 million dollars is spent on training land sustainment and repair practices. Note the average annual sediment load estimated by SWAT (when natural conditions are assumed) is 1209 metric tons. Total cost is minimized at \$78,000 per year when minimal training is conducted and very little money is spent on sustainment and repair practices. The total annual sediment load is correspondingly 50% higher than the previous land management scheme. Total annual training load is maximized at nearly 15,000 MIMs (the 20 MIMs ha⁻¹ upper boundary set by the user) for the third objective function configuration. A corresponding total annual cost of \$232,000 is due to high road and trail sustainment costs while a lack of training land repair practices cause a sediment load of 1850 metric tons.

Table C-1. Objective payoff.

W_S	W_C	W_T	Total SL (metric tons)	Total Cost (1000s \$)	Total TL (MIMs)
2.0	0.0	0.0	1024	1129	6587
0.0	1.0	0.0	1514	76	5927
0.0	0.0	1.0	1875	232	14577

c. Figure C-1 shows the 3-dimensional (3-D) representation of the objective space for all 67 objective weight combinations. The model returned optimum land management plans for many different combinations of sediment load, cost, and training load. When costs are kept low, sediment load is high. An increase in training load also causes increases in erosion and cost. The economic costs of reducing sediment load below 1400 metric tons are very high, regardless of the applied training load. The empty area in the middle of Figure C-1 represents combinations of sediment load, cost, and training load that cannot be obtained through optimal sustainable range management.

d. A 3-D representation also illustrates that the equality weight scheme ($W_S = W_C = W_T$), highlighted as solid, is a very good land management choice compared with the rest of the

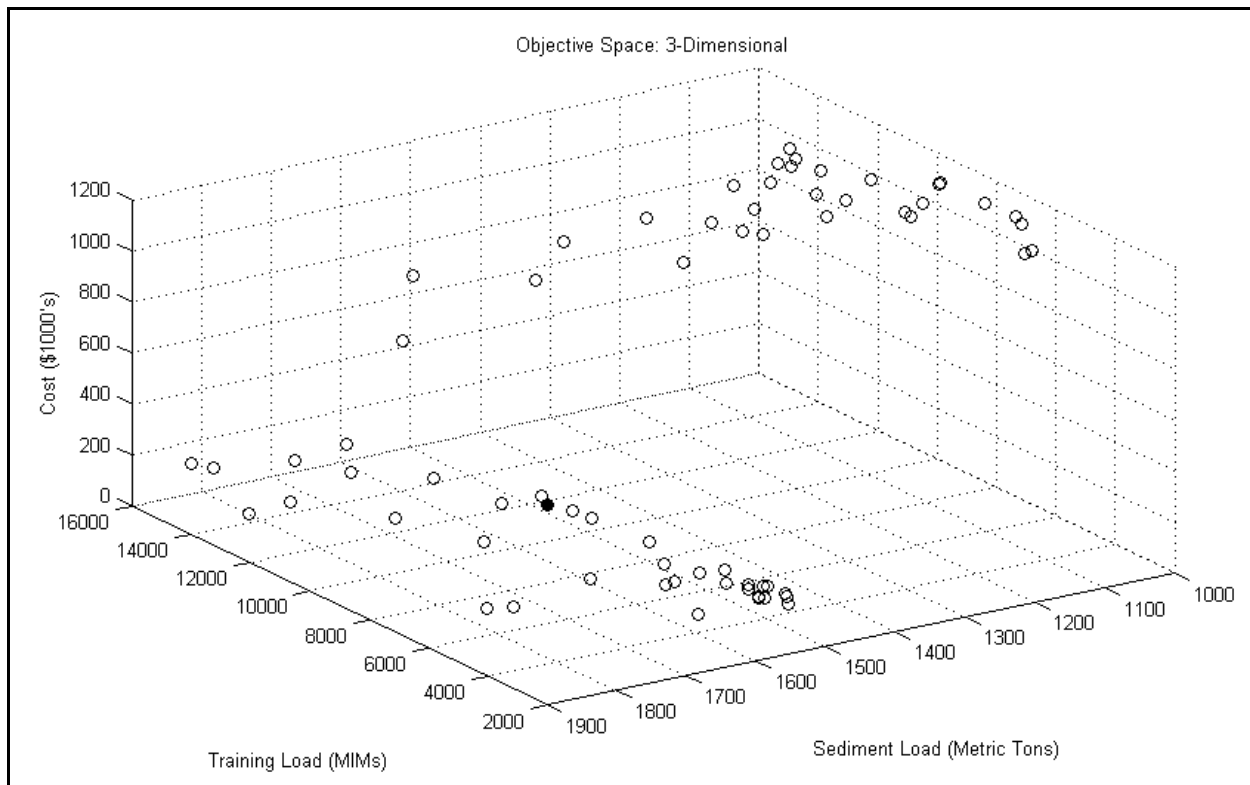


Figure C-1: 3-D objective space of total sediment load, total cost, and total training load (includes all 67 model runs).

choices. The equality management scheme produced *SL*, *TC*, and *TL* values of 1534 metric tons, \$95,000, and 10,579 MIMs respectively. As a result, the scheme is on the lower cost limb, but with a relatively high training load. From that point, reducing sediment load below 1400 tons requires a cost increase of 600 to 800 percent. In addition, increasing the total training load past 11,000 MIMs causes significant increases in sediment load (by 100 to 300 tons) and cost (by \$25,000 to \$105,000).

2. Model Decision Results

a. While the objective function results described above are a good overview of the relationships between sediment load, economic costs, and training load across the study area, spatially specific results are needed to complete the analysis. The distribution of the decision variables, training load (MIMs ha⁻¹) and USLE P-factor, across the study area for different objective weight schemes can highlight physical characteristics of the training areas. For example, training areas that are consistently assigned low training loads and/or low P-factor values may be areas that have little natural vegetative cover or are prone to high erosion rates and general environmental degradation due to the physical aspects of the area such as soil type, topography, climate, hydrology, etc. The opposite may also be true for those areas that are routinely assigned high training loads and/or P-factors near 1.0.

b. Figures C-2 through C-4 show the spatial distributions of training load, P-factor, and sediment load, respectively, for the equality scheme ($W_S = W_C = W_T$). Figure C-2 shows a large amount of training distributed throughout the study area. Figure C-3 shows limited scheduled conservation practice application needs, other than in subareas 81, 88, and 114. Figure C-4 shows that subareas 55, 59, 78, 81, 84, 88, 132, and 151 contribute elevated sediment loads for the equality scheme. In addition, Figure C-5, which shows the sediment load distribution for natural condition with no human interference, illustrates that these same subareas contribute elevated sediment load when no training load or erosion control practices are implemented. Many of the high training loads (Figure C-2) are located in the same subareas that showed elevated sediment loads when no training is applied (Figure C-5).

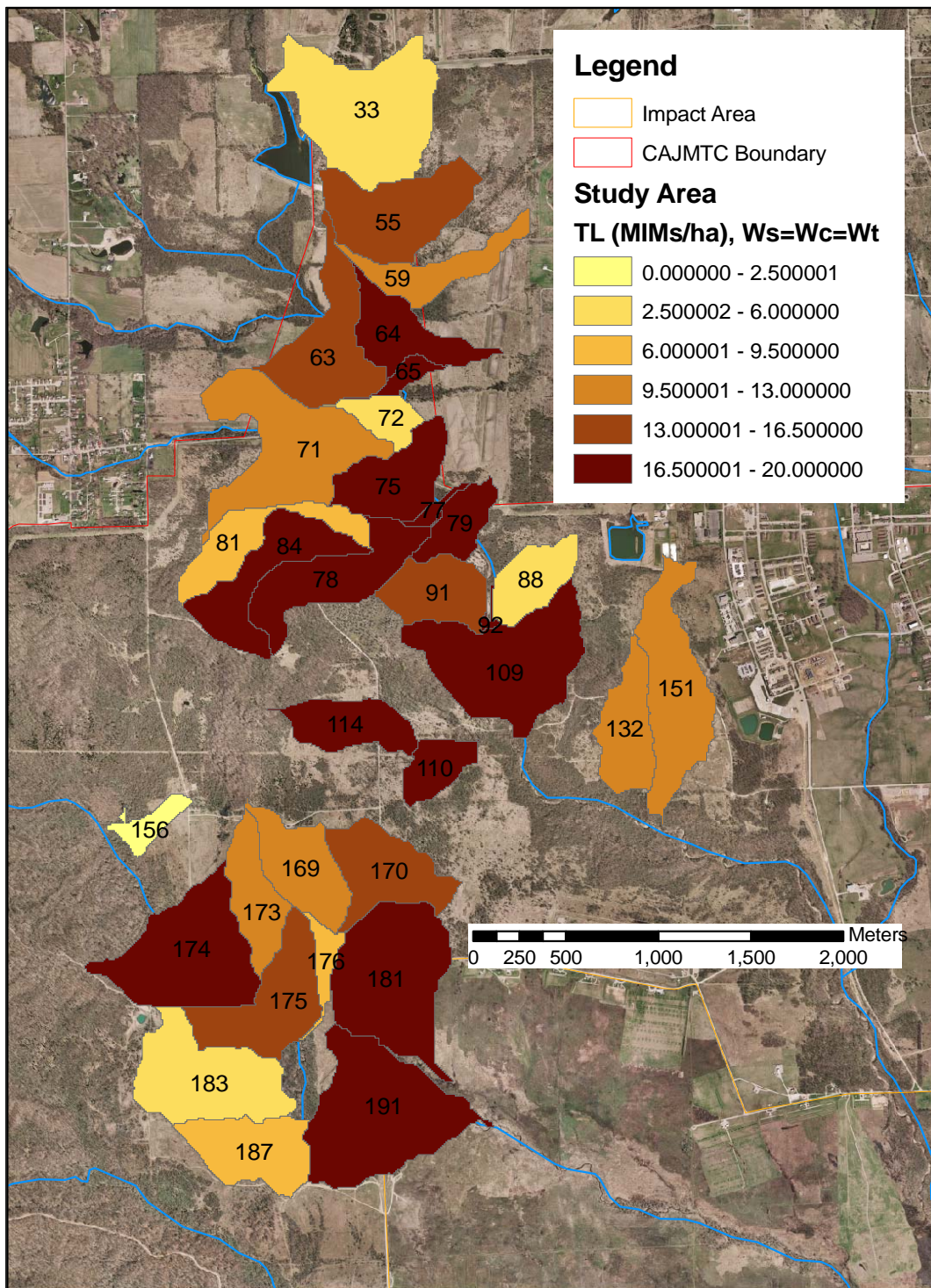


Figure C-2: Optimum off-road training load utilization for 33 ranges on CAJMTC.

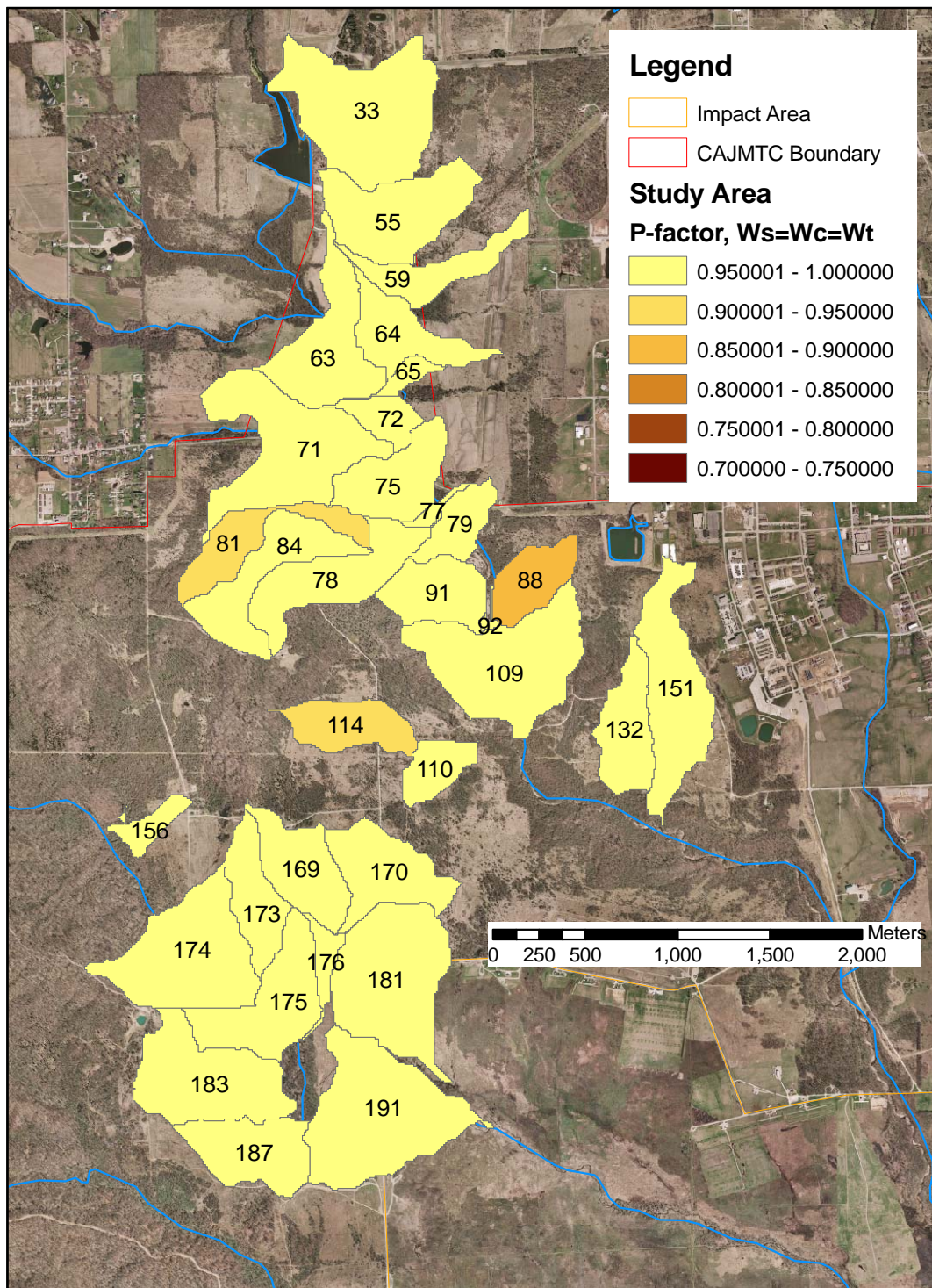


Figure C-3: Optimum practice factor (repair practice) utilization for 33 ranges on CAJMTC.

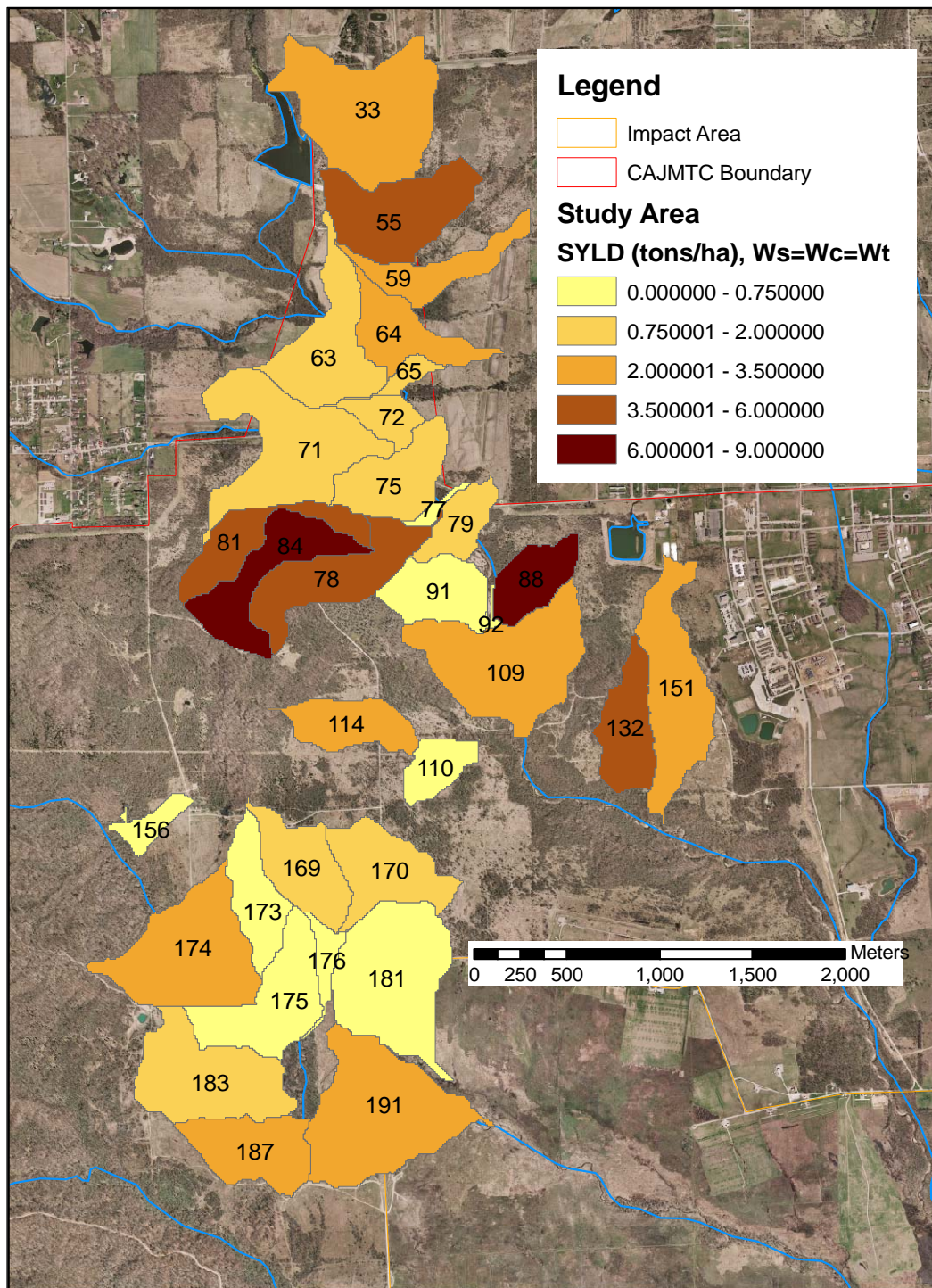


Figure C-4: Average annual sediment load for optimum land management.

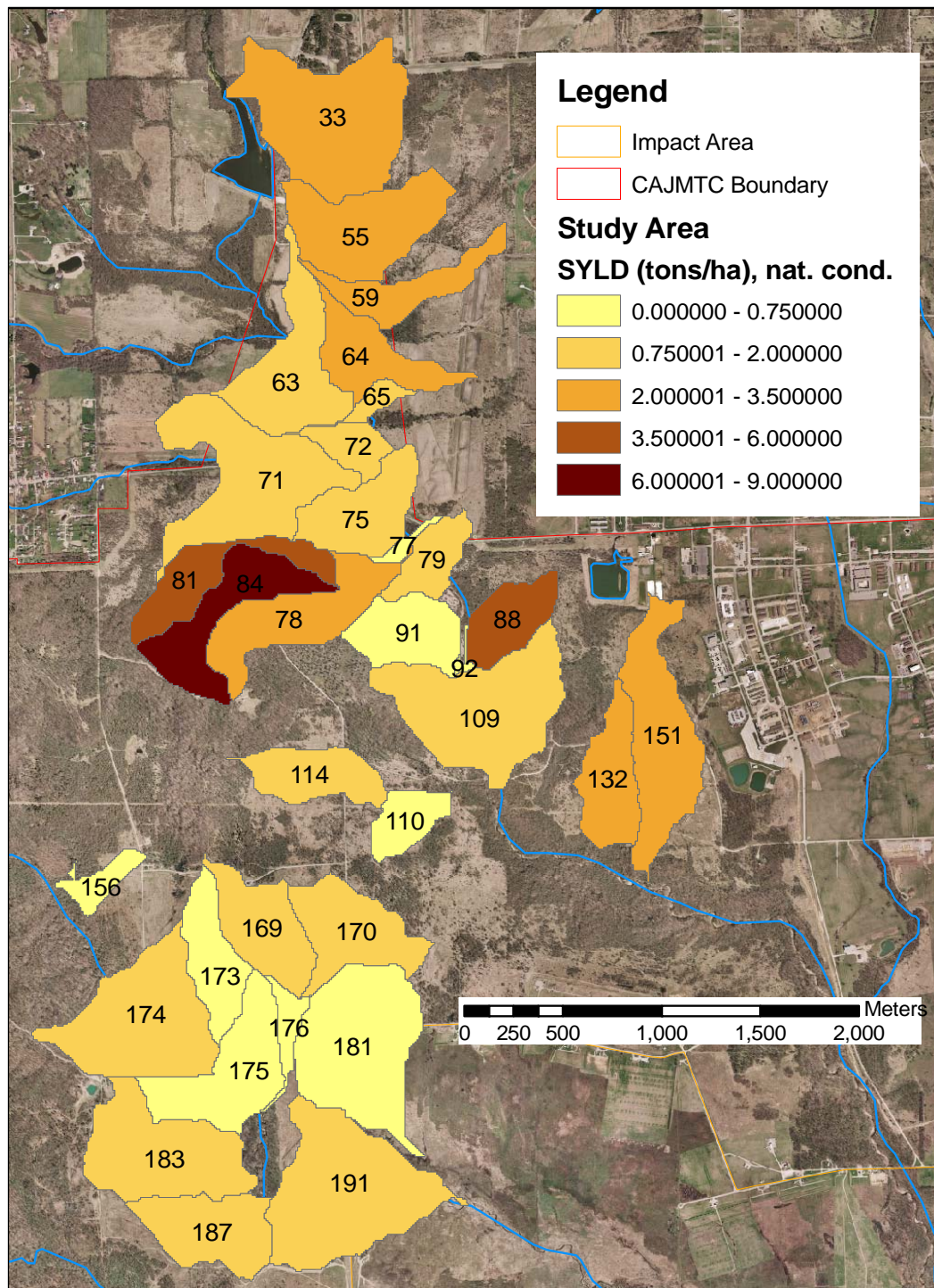


Figure C-5: Average annual sediment load for natural conditions.

c. Note that training loads and repair practices are not uniform across the training ranges. Those land parcels that are environmentally stable can generally handle more training with less annual repair than those parcels that are naturally susceptible to erosion. Such model results can be used by land managers to predict and/or avoid possible future degradation due to military training. The economic costs associated with current or planned land management can be compared to the optimum costs.

d. Heavy training loads seemed to be localized in two types of subareas for the equality objective weight scheme. The first types of subareas assigned large training loads are those that maintain relatively low sediment load outputs over a range of training loads with little to no erosion control implementations. These subareas were located in the southern half of the study area where slope is low and the Crosby-Miami soil complex features high organic matter content and very slow surface runoff. Subareas 170, 174, 175, 181, and 191 were assigned high training loads and little to no erosion control, yet the difference between the resulting sediment loads and the natural sediment loads were minor (Figure C-5). Within the context of the objective function, this plan provides increased training with minimal increases in sediment load and conservation costs. Using training areas with these kinds of physical characteristics for large-scale training seems obvious, yet such areas cannot usually handle all training requirements. As a result, an analysis of all possible training areas is needed so that the surplus training requirements can be efficiently and effectively assigned to other areas.

e. The second type of subarea contributes high sediment loads even when no localized training occurs. These subareas are located directly next to the creeks, highly sloped, and/or located on the Rensselaer-Whitaker soil complex. These soils are poorly drained and generally not recommended for heavy equipment travel due to compaction problems. Despite the fact that these soils are naturally highly erodable, the model designated these areas for large-scale military training because, within the optimization function, these areas do not contribute a large quantitative increase in sediment load between wide ranges of training loads. In other words, the sediment load off these areas is high in any case, so they might as well handle some training. Of course, within the aspect of real world applications, such a plan may

not be sustainable long-term due to the gradual destruction of the training range and corresponding safety concerns.

f. Overall this new tool adds a new dimension to military rangeland assessment and management. Sustainable training loads and the corresponding economic costs and upland erosion/sediment loads can be estimated and analyzed. The use of this tool, in addition to current assessment techniques, may enable range managers to predict and avoid rangeland degradation instead of just classifying and ranking problem areas after degradation has occurred.

Appendix D

Cited References

- Denight, M. L., D. L. Gebhart, B. A. Engel, and J. Y. Choi. 2005. Conference Presentation - Professional, Integrated Training Area Management (ITAM) Workshop, Indianapolis, IN.
- Goldberg, D. E. 1989. Genetic algorithms in search, optimization, and machine learning. Addison-Wesley Publishing Co., Inc., Reading, MA.
- Hirst, R.A., R.F. Pywell, and P.D. Putwain. 2000. Assessing Habitat Disturbance Using an Historical Perspective: The Case of Salisbury Plain Military Training Area. *J. Environmental Management* 60(2): 181-193.
- Mendoza, G. A., A. B. Anderson, G. Z. and Gertner. 2002. Integrating multi-criteria analysis and GIS for land condition assessment: Part I - evaluation and restoration of military training areas. *Journal of Geographic Information and Decision Analysis* 6(1):1-16.
- Neitsch, S. L., J. G. Arnold, J. R. Kiniry, and J. R. Williams. 2005. Soil and Water Assessment Tool theoretical documentation, version 2005. U.S. Department of Agriculture, Agricultural Research Service, Temple, TX. Available online at <http://www.brc.tamus.edu/swat/doc.html>
- United States Army Environmental Center (USAEC). 1999. Army training and testing area carrying capacity (ATTACC) handbook for installations, version 1.1. USACE: Aberdeen Proving Ground, MD. Available online at <http://srp.army.mil/public/resources/resources.aspx>.
- Wischmeier, W. H., and D. D. Smith. 1978. Predicting rainfall erosion losses: U.S. Department of Agriculture, Agriculture Handbook No. 537.

Uncited References

- Ayers, P. D. 1994. Environmental damage from tracked vehicle operation. *Journal of Terramechanics* 31(3): 173-183.

- Diersing, V. E., R. B. Shaw, S. D. Warren, and E. W. Novak. 1988. A user's guide for estimating allowable use of tracked vehicles on nonwooded military training lands. *Journal of Soil and Water Conservation* 43: 191-195.
- Gebhart, D. L., and S. B. Nemeth. 2005. Regional cost estimates for rehabilitation and maintenance practices an Army training lands. U.S. Army Corps of Engineers, Public Works Technical Bulletin 200-3-33.
- Neitsch, S. L., Arnold, J. G., Kiniry, J. R., Srinivasan, R., and Williams, J. R. 2002. Soil and water assessment tool user's manual, version 2000. U.S. Department of Agriculture, Agricultural Research Service, Temple, TX. Available online at <http://www.brc.tamus.edu/swat/doc.html>
- Shaw, R. B., and V. E. Diersing. 1989. Allowable use estimates for tracked vehicular training on Pinon Canyon Maneuver Site, Colorado, USA. *Environmental Management* 13(6): 773-782.
- Shaw, R. B., V. E. Diersing. 1990. Tracked vehicle impacts on vegetation at the Pinon Canyon Maneuver Site, Colorado. *Journal of Environmental Quality* 19: 234-243.
- Thurrow, T. L., S. D. Warren, and D. H. Carlson. 1993. Tracked vehicle effects on the hydrologic characteristics of central Texas rangeland. *Transactions of the ASAE* 36(6): 1645-1650.
- Unified Facilities Criteria (UFC). 2006. DoD facilities pricing guide. U.S. Army Corps of Engineers, UFC 3-701-06.

This publication may be reproduced