PUBLIC WORKS TECHNICAL BULLETIN 200-1-123
31 MARCH 2013

IDENTIFICATION OF SUPERFLUOUS ROADS IN TERMS OF SUSTAINABLE MILITARY LAND CARRYING CAPACITY AND ENVIRONMENT

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

CECW-CE

Public Works Technical Bulletin 31 March 2013

No. 200-1-123

FACILITIES ENGINEERING
ENVIRONMENTAL

IDENTIFICATION OF SUPERFLUOUS ROADS IN TERMS OF SUSTAINABLE MILITARY LAND CARRYING CAPACITY AND ENVIRONMENT

1. Purpose.

a. This report introduces a methodology developed at Fort Riley that can be used to identify superfluous roads for closure based on both sustainable military training and environmental factors. This methodology can quickly ascertain which roads can be closed to provide the most cost efficiency without hindering the mission, while simultaneously providing benefits for environmental protection and also providing land managers with a comprehensive analysis and assessment of alternatives.

b. All PWTBs are available electronically in Adobe® Acrobat® portable document format [PDF]) through the World Wide Web (WWW) at the National Institute of Building Sciences' Whole Building Design Guide (WBDG) Web page, which is accessible through this Universal Resource Locator (URL):

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability. This PWTB applies to all U.S. Army facilities engineering activities.

3. References.

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

b. EO 13514, “Federal Leadership in Environmental, Energy and Economic Performance,” 5 October 2009. .

4. Discussion.

a. The US Army takes care of the land management on more than 5,500 sites covering approximately 30 million acres. These lands are used for various military training programs. Consequently, land managers are often faced with the challenge of how to optimize road networks on these lands. The management challenge is to maintain roads and trails while reducing negative impacts on the environment.

b. Appendix A contains background information.

c. Appendix B contains study area, datasets, and methods information.

d. Appendix C contains summary information.

e. Appendix D contains steps for creating a road priority map for identification of superfluous roads.

f. Appendix E contains general references.

g. Appendix F contains abbreviations and acronyms along with their spellouts.

5. Points of Contact.

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Appendix A

INTRODUCTION

In the United States, the Army manages the lands at more than 5,500 sites, covering approximately 30 million acres of land (DEPARC 2007). These lands are used for various military training programs including field maneuvers, combat vehicle operations, mortar and artillery fire, small-arms fire, etc. (Anderson et al. 2005). These lands have roads that often are not constructed roads, but are bare lands on which roads and trails have formed due to repeated uses that also increase soil erosion of surrounding areas (Gatewood 2002; Grace 2002).

Roads on these lands present conflicting but inter-related challenges as land managers try to maintain both sustainable military land carrying capacity and proper land condition (USACE 2006). On one hand, the roads and trails provide access to the areas where various training activities are planned to enhance the effectiveness and readiness of the military mission. On the other hand, these training activities (especially those using dirt roads and trails) inevitably cause degradation of natural resources and land condition, which can have negative impacts on the environment and landscape. Those negative impacts include increasing sedimentation of adjacent waterways, soil erosion, habitat destruction, landscape fragmentation, degradation of water supply, and noise production (USACE 2006). Moreover, military vehicles that disturb the soil also stunt or kill vegetation.

The resulting degraded land conditions can then limit military land carrying capacity (Ayers, Anderson, and Wu 2005). Halting training activities will reduce the disturbance and decrease the negative impacts of the roads and trails on the environment (Egan 1999; Elliot, Hall, and Graves 1999). However, road closure needs to be carefully planned so as not to interfere with training necessary to the installation’s military mission. With closer management and analysis, fewer roads ultimately can accomplish the same or nearly the same training effectiveness while reducing the land disturbance, therefore eliminating excess or superfluous roads.

There is also an associated cost factor to consider. The cost of maintenance increases as the density of the roads increases because roads need ongoing maintenance to maintain sustainable military carrying capacity. However, installations often lack funding to maintain all of the roads.

Selective road closure can solve many of these problems. The roads that do not strongly support the mission and, at the same time, need a large amount of funding, manpower, and time should be closed. Advantages of closing superfluous roads (USACE 2006) are:

- reducing maintenance costs,
- limiting roadway width expansion due to impassability (i.e., impassible pothole develops and roadway expands adjacent to the pothole and thereby impacting a larger area),
- mitigating negative impact of vehicular traffic to adjacent natural areas,
- decreasing soil erosion,
- improving water quality for nearby streams and water bodies,
- slowing landscape fragmentation, and
- increasing habitat quality for resident species.

The factors outlined above combine to show a strong need to develop a methodology for determining an optimal road network density. To accomplish that, this study focuses on identifying superfluous roads. The study’s methodology used a geographic information system (GIS) and remote sensing technologies, along with landscape analysis and models based on factors that impact environment and military land carrying capacity.

The study’s results prioritized roads and trails by using factors of utilization and maintenance; it then derived priority estimates of all roads (roads, trails, and paths) for closure. The results provided useful guidelines that will facilitate land management decisions based on alternative scenarios. This effort provided a method to quickly ascertain which roads are most cost-effective for closure without hindering the mission. It also provided benefits for environmental protection and a comprehensive analysis and assessment of alternatives for land managers.

Appendix B

STUDY AREA, DATASETS, AND METHODS

Study area and datasets

This study was done at Fort Riley, Kansas. Fort Riley consists of 101,700 acres (41,154 ha) and is located in northeastern Kansas in the Bluestem Prairie section of the Tall Grass Prairie biotic province (Bailey 1976; Figure B-1). In the study area, most of the required datasets were available (Gertner et al. 2002, 2006; Wang et al. 2007; Wang et al. 2008a, 2008b, and 2009). Those existing datasets included digital elevation models (DEMs), soil maps, road maps, records of military training intensity, vegetation maps, vehicle use disturbance maps, soil erosion maps, and various remotely sensed images. Though developed at Fort Riley, the methods described here can be employed at all installations with required datasets.

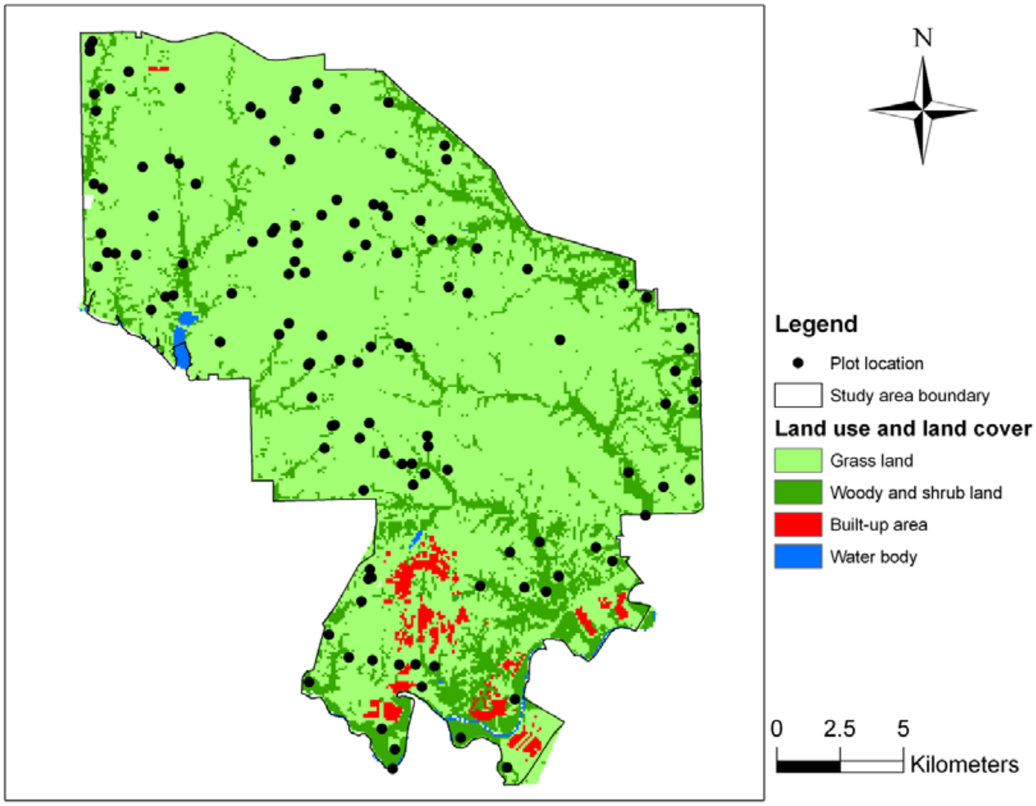

Figure B-1. Study area at Fort Riley: land use, land cover types, and permanent sample plots.

A variety of military training activities have taken place at Fort Riley for many years. The land condition trend analysis (LCTA),[1] plot inventory and field methods were used for collecting the ground sample data required for monitoring the landscape and environmental dynamics (Tazik et al. 1992). A total of 154 permanent plots were installed and remeasured annually during summers in 1989–2001 (Figure B-1). Moreover, Landsat Thematic Mapper (LTM) images covering this area were acquired annually from 1989–2001. Other satellite images such as India Remote Sensing (IRS) images, Lidar, and historical aerial photos were also available.

Methods

A methodology to identify superfluous roads for closure was developed by integrating GIS and remote sensing technologies with landscape analyses and modeling methods. First, the factors that affect both military land carrying capacity and environment were analyzed. In turn, those factors determined utilization and maintenance priorities of roads and trails. The factors included maintenance cost of roads and trails, road access area, military training intensity, soil erosion, water quality, landscape fragmentation, and noise production. The factors were quantified and derived by using GIS, remote sensing, and landscape modeling methods and then were converted into normalized values. A spatial multi-criteria decision analysis and pair-wise comparison method was then developed to integrate these factors and derive a priority map of roads and trails.

All the roads within Fort Riley were classified into one of five military road classes defined by Ayers, Anderson, and Wu (2005):

- Class 1: primary road (hard surfaces for all-weather use; e.g., freeway, state highway)
- Class 2: secondary road (hard surface for all-weather use, but lower quality than the primary roads)
- Class 3: light-duty road (hard or improved surface; e.g., residential street, rural road, or gravel road)
- Class 4: trail (unimproved surface for fair- or dry-weather use)

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[1] This is now known as range and training land assessment (RTLA).

- Class 5: path (mere tire tracks)

The first step in classifying the roads was obtaining a road map for Fort Riley’s pre-existing roads. The pre-existing road coverage file was evaluated for accuracy and then, the road segments were reclassified into the five classifications just stated. The pre-existing road map then was overlapped on high-resolution satellite and aerial photographs to interpret, identify, and digitize any other roads, trails, and paths that did not exist on the original road map. These newly identified roads were generally of the Class 4 or Class 5 road types: trails and paths. The newly identified/classified roads were combined with the pre-existing roads, which led to a complete road map for Fort Riley.

Land managers and experts at Fort Riley and eight other, similar installations were contacted to provide cost information for maintaining their installations’ roads, trails, and paths. Additionally, general regional data was collected from literature, database, and historical records. Generally, the Class 1-3 roads have various levels of improved surfaces; thus, none of them were assumed to be candidates for closure.

In this study, costs were calculated to maintain all roads, trails, and paths. For example, the cost to restone a trail was $19,200 per mile for 1,400 tons of #53 stone and trails are restoned every 2–3 yr, depending on use. The trails also were graded and rolled 2-3 times per year, and that cost was calculated at $325 per hour per piece of equipment including costs for operators, fuel, and parts. It often takes an individual operator about 16 hr to restone 1 mile of trail. In addition, dust suppressants are applied to trails at a cost of $.08 per square foot. Corresponding costs for other road classes were calculated based on their differences from trails.

For all areas that the roads provided access to, a calculation was conducted by using a path-allocation function in GIS. A search was made for the shortest path from a given point to the nearest road, and a slope map derived from a digital elevation model was used as a barrier factor. (The higher the slope, the more difficult it would be for a vehicle to pass through.) A road identification that had the shortest path to each cell within the study area was first obtained. The cells that had the same road identifications were counted and timed by the spatial resolution, which led to determining the road access areas. The access areas provided information on the relative importance of the roads for military training plans.

The datasets for Fort Riley training intensity data from 1989–2001 were obtained. The training intensity was quantified by total training days (TTD) per year, and this number varied over space and time. The TTD calculation came from multiplying the number of days each soldier occupies a training area by the number of soldiers in that training area. TTD was spatially characterized by a choropleth map technique; that is, digitizing training areas, converting the polygons into raster layers, and then assigning them a TTD value within each polygon. A map showing the spatial variation of TTD for each year was produced.

Maps of soil erosion for Fort Riley were available from Wang et al. (2007). The values of soil erosion were predicted by using a Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997; Wischmeier and Smith 1978). In this equation, soil loss is a product of five input factors:

- R = rainfall-runoff erosivity
- K = soil erodibility
- L = slope length
- S = slope steepness
- C = cover management

Several methods can be used to produce these five factors. In the study by Wang et al. (2007), a constant R value (rainfall runoff) was derived by interpolating data from the R isoerodent map compiled by the US Department of Agriculture (USDA). The map of K (soil erodibility) was obtained from soil survey data (USDA Soil Conservation Service 1975). The topographic factor LS (as the product of slope length and steepness) was calculated by using a DEM that was based on empirical equations developed by Foster, Meyer, and Onsted (1977) and McCool, Brown, and Foster (1987). To derive the map of C (cover factor), an image-aided co-simulation was developed by Wang et al. (2007). In this algorithm, the value of soil erosion at a location was considered to be a realization of a random process, obtained by randomly drawing a value from a conditional distribution as determined by a neighboring sample and image data. To show the significant erosion that was prevented from bare soils on the roads and trails, soil erosion potentials with and without the cover factor were computed and compared. The road map was then overlaid on the obtained soil erosion maps, which led to the erosion potentials of the roads with and without the residuals (USACE 2006).

A dataset of water quality was obtained from the Monitoring and Assessing Water Quality (MAWQ) website (see Appendix E). The water quality values were available only for the streams and water bodies within the study area. For other areas, the water quality values were derived by using the values from steams and water bodies within the same watershed and the distances of locations from those streams and water bodies. The Fort Riley watershed consists of three watershed sub-basins including the Upper Kansas (hydrologic unit code [HUC] 8 #1027010), Lower Republican (HUC 8 #10250017), and the Lower Big Blue (HUC 8 #10270205). All the rivers, streams, and water bodies within Fort Riley were extracted.

Landscape fragmentation due to training activities for Fort Riley was quantified by using spatial metrics of perimeter, shape, fractal dimension, and contagion at patch level. The perimeter measures the edge of each patch, fractal dimension quantifies the shape complexity for each patch, and contagion index refers to the tendency of patch types to be spatially aggregated; that is, to occur in large, aggregated, or “contagious” distributions as measured using probability.

The LTM and IRS images were employed to divide the landscape into segments by using IDRISI’s[2] image segmentation method from the IDRISI website (see Appendix E). Image segmentation is a process by which pixels are classified into homogeneous polygons based on spectral similarity. Across space and overall input bands, a moving window assesses this similarity, and segments are defined according to a stated similarity threshold. This method first creates a variance image by using a user-defined filter – moving window. The more homogeneous the pixels are, the lower the variance values. The pixels at the boundaries of homogeneous regions naturally have higher variance values than those within homogeneous polygons. Based on the variance values, pixels are grouped into segments. The image segments are then merged to form new segments if their differences are smaller than the given threshold value. The smaller the threshold is, the more homogeneous the segments are. The obtained segmentation maps were then applied to calculate the spatial metrics of the landscape at patch level.

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[2] IDRISI is a computer program developed by Clark Labs, designed to process and analyze raster information.

Military training activities also produce noise. Based on the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) website (see Appendix E) that gives noise levels of common Army equipment, the highest noise level was used in this study. In reality, the impacts of noise will vary depending on the distance from a location to be considered to the roads and training areas. When a road is closed, the impacts of noise is mitigated or stopped. Thus, the impact and reduction of noise production from vehicles on roads can be quantified based on the distances of the roads to the locations. Based on Westervelt and White (2009), the effect of distance on mitigation of noise for 3-D spreading can be mimicked by using a distance decay function:

$$NL(u) = NL(u_0) + 10 \times \log(d(u_0)^2 / d(u)^2) - 0.005212 \times d(u) \qquad (1)$$

where:

$NL(u_0)$ is the noise level (dB) at the location u_0,
$NL(u)$ is the noise level (dB) at a location u, and
$d(u_0)$ and $d(u)$ are the distances of the locations u_0 and u from the sound source.

All the data layers in Equation 1 were created by using ArcGIS (referring to ESRI website), ERDAS Imagine (referring to ERDAS website), and IDRISI (see IDRISI in Appendix E). The data layers or variables had different units and scales. Their values were then transformed to comparable units using a linear scale transformation based on maximum and minimum values. The transformed values ranged from 0 to 1 and were compatible. The data layers were finally integrated by using a spatial multi-criteria decision analysis to derive the priority estimates of all the roads for closure (Longley et al. 2005; Malczewski1 1999), expressed as:

$$\mathrm{Pr}\,iority(u) = \sum_{i=1}^{m} w_i f_i(u) \qquad (2)$$

where:

m is the number of the factors considered,
$f_i(u)$ is the value of factor i at a location u, and
w_i is the weight of factor i.

The priority of a road for maintenance is based on its importance in terms of both sustainable military land carrying capacity and environment. In general, this means the higher the priority for a road to be maintained, the lower the priority for the road to be closed. For example, the larger the military training area provided by a road, the more important the use of that road. By contrast, the higher the negative impact (such as soil erosion from the road), the less important is the use of that road. The roads with higher values of negative impacts on environmental quality and maintenance costs, yet lower values of military training intensity, should have higher priority values for being closed. Thus, the values of military training intensity are inversed.

Furthermore, with spatial multi-criteria decision analysis, the weight assessment of the factors or variables was made by using a pair-wise comparison method. This method includes developing a pair-wise comparison matrix and computing variable weights. If m is the number of the variables, there are total $m(m-1)/2$ comparisons. For example, the military mission may be moderately preferred over the environment but strongly preferred over road maintenance cost. Several military land managers and experts were interviewed to obtain the weights of the above factors. The final weight for each factor was obtained by weighting the values of preferences and averaging them. All the data layers were then weighted to obtain a map that provided the priority estimates for the roads to be closed. The priority map was finally applied together with the road access area map to determine the order of individual roads to be closed. Within a homogeneous area of priority, the smaller the road access area, the higher the priority order of the road to be closed.

Appendix C

SUMMARY

Results

Figure C-1 shows all the roads obtained by visual interpretation and digitizing on the IRS images (at a spatial resolution of 5 m x 5 m), and on the digital aerial orthophoto (at a spatial resolution of 0.5 m x 0.5 m).

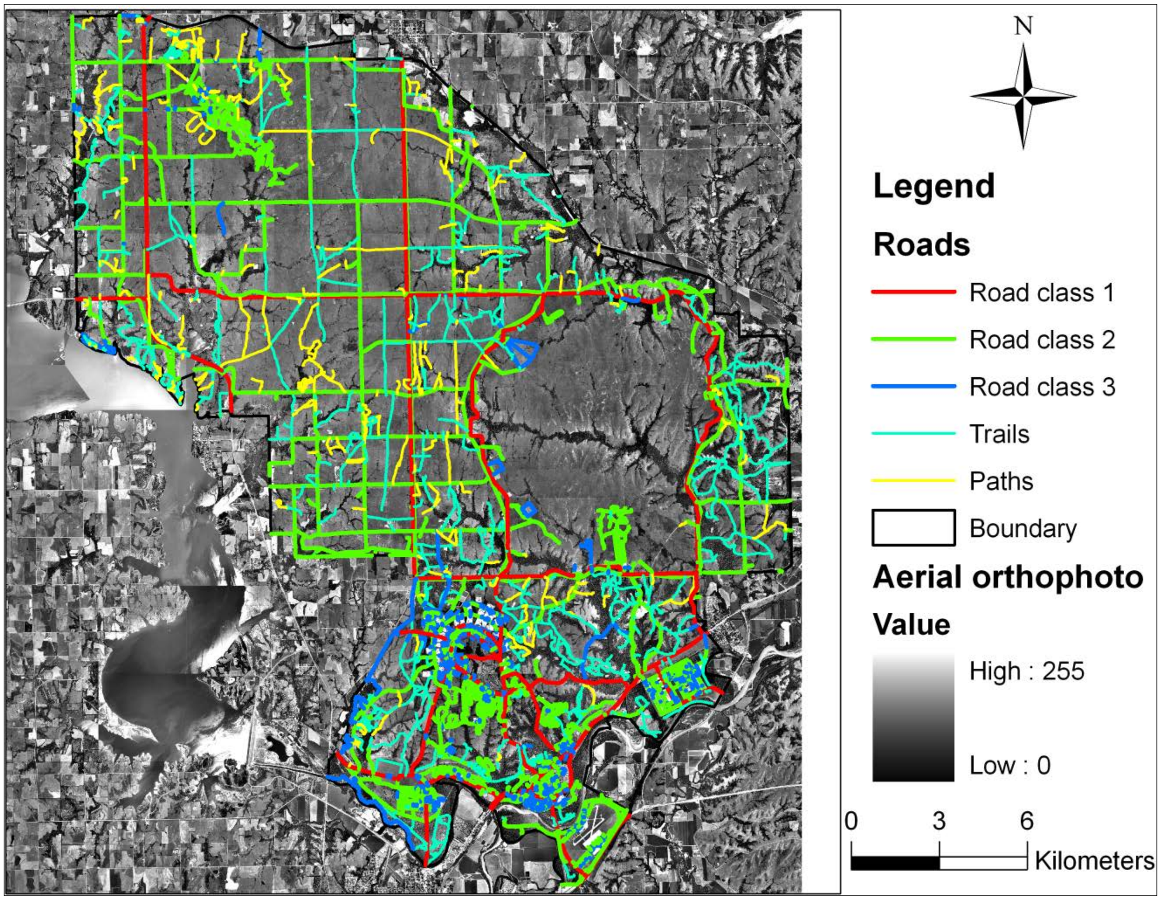

Figure C-1. All the roads, trails, and paths obtained by visual interpretation and digitizing on the satellite image and digital aerial orthophoto.

These roads were classified into the same five classes referred to in Appendix B: (1) primary road, (2) secondary road, (3) light-duty road, (4) trail, and (5) path. Classes 1–3 have hard or improved surfaces and exist on the original road map. In this study, the focus was on obtaining and updating the trails and paths. Class 4 (trails) included the improved roads with no maintenance, unimproved dirt roads, twin tracks, etc. They were easily interpreted and digitized because they were discernable due to exhibiting either very sparse or no surrounding vegetation. The paths were difficult to drive in a civilian 4x4 truck and had some tire tracks present; they were typically better seen from above than from the ground. The surrounding vegetation was only slightly impacted by the path.

The maintenance cost for all the roads was calculated and is shown in Figure C-2a. The cost mainly consisted of re-stoning, grading, rolling, and applying dust suppressant. These maintenance practices were used since they are the predominant practice for hardening of trails on military installations. Overall, the high maintenance costs took place at the southern part of the study site, one area in the north, and along the main roads (Figure C-2a).

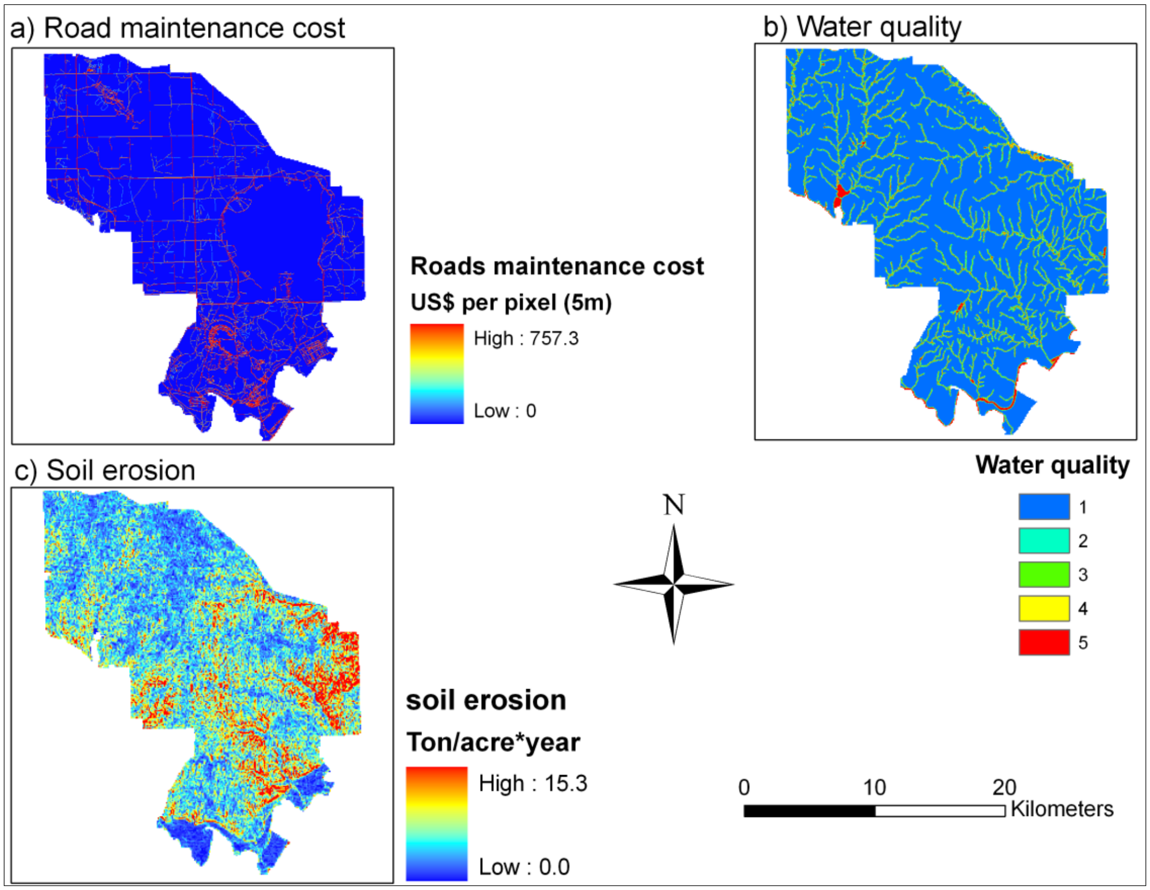

Figure C-2. Three factors that have impacts on both military land carrying capacity and environment.

Water quality was classified into five categories (Figure C-2b). The larger the categorical value, the lower the water quality. The values of water quality for the streams and water bodies was directly obtained from the national database on the MAWQ website (see Appendix E). The water quality values for other areas were determined based on their distance from the nearest streams and water bodies, and the effect decayed as the distance increased. When the distance was larger than 50 m, the effect had the least value. The soil erosion map for year 1999 by Wang et al. (2007) was directly used in this study (Figure C-2c). Soil erosion had greater values in the eastern, southern, and southwestern parts of the study area and smaller values in the northern and northeastern parts.

According to the USACHPPM website (see Appendix E), the greatest noise value from US Army equipment was 118 dB. Based on Equation 1 in Appendix B (Westervelt and White 2009), the effect of distance on mitigation of noise was mimicked by using the following distance decay function:

$$NL(u) = 118 + 10 \times \log(25 / d(u)^2 - 0.005212 \times d(u) \tag{3}$$

where:

$NL(u)$ is the noise level (dB) at a location u with the distance $d(u)$ from the sound source.

It is assumed that noise is generated on roads. The largest noise level (118 dB) was measured at a distance of 5 m from the equipment that produces the noise. As would be expected, he noise level values were greater along the roads and decreased as distance from the roads increased (Figure C-3d).

In this study, landscape fragmentation was quantified by using the product of patch perimeter and area (Figure C-3e). The smaller the product value, the more fragmented the landscape at patch scale. The spatial metrics in Figure C-3e was derived using IRS 5 m spatial resolution images acquired in 1999. Fort Riley landscape was more fragmented along the eastern borders and in the southern parts than elsewhere (Figure C-3e). Moreover, the landscape was also very fragmented along the east central borders of the impact area. There was also one hot spot of the fragmentation in the northern part.

The spatial distribution of training intensity for TTD in 1999 is presented in Figure C-3f. The training intensity was higher in the southwestern, central, and northeastern parts; training intensity was lower in the eastern and southern parts and one area in the north central part.

All factors were standardized by using the minimum and maximum values so that the normalized values ranged from a low of 0 to a high of 1 (Figure C-4a–f).

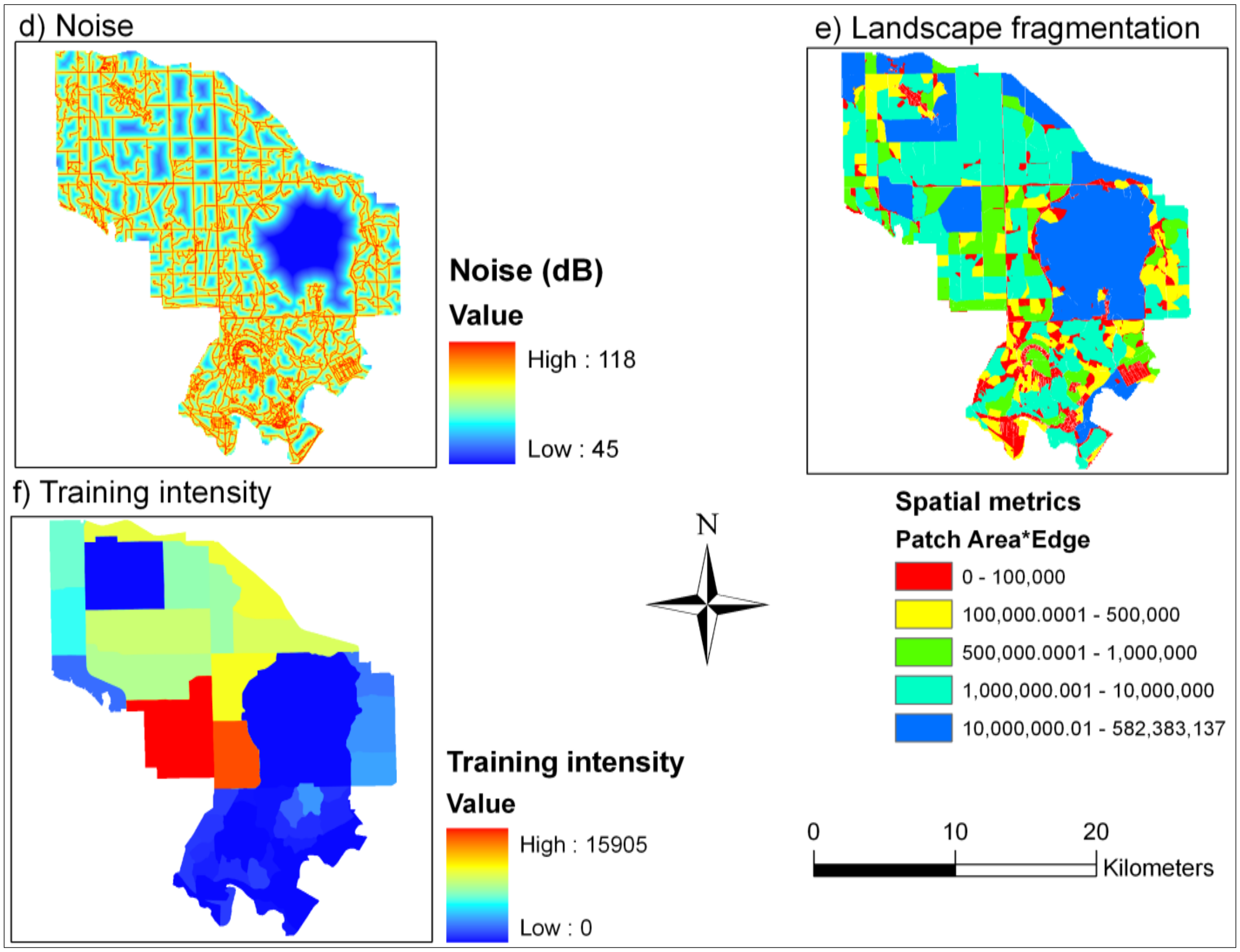

Figure C-3. Additional three factors that have impacts on both military land carrying capacity and environment.

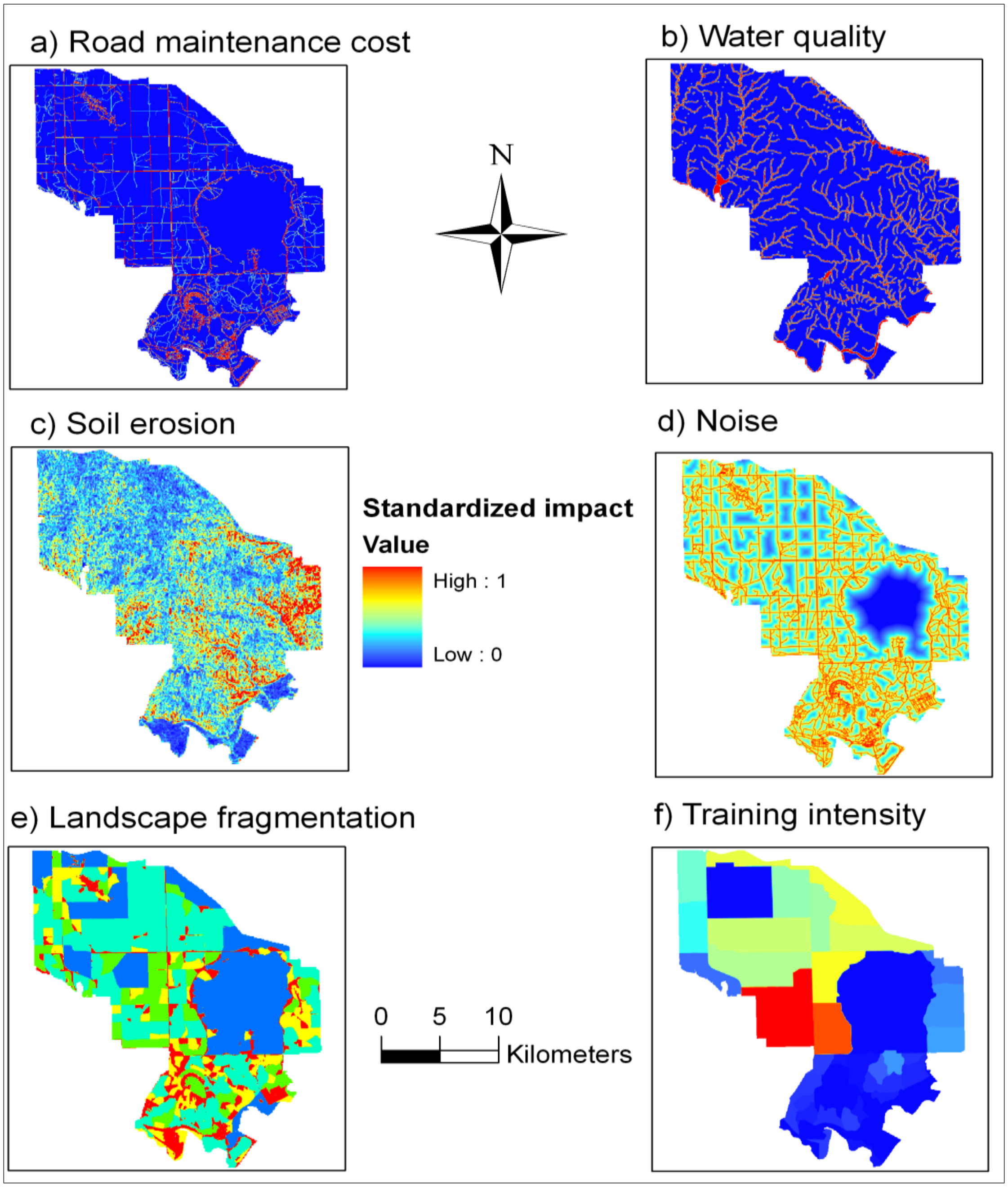

Figure C-4. Standardized impacts of the factors on both military land carrying capacity and environment.

Factors of water quality, soil erosion, noise production, and landscape fragmentation had negative impacts on environmental quality. The greater the negative impact values, the worse the environmental quality. The road maintenance cost had negative impact on military land management. The values of training intensity implied the capacity of roads to provide access to the areas. Thus, the training intensity had positive impact on military land carrying capacity. The larger the value of military training, the more the military land carrying capacity. Therefore, when the positive impact factor was combined with the negative impact factors, the values of training intensity were inversed.

Using pair-wise comparison method of spatial multi-criteria decision analysis, the weights of all the factors above were obtained from three military installation land managers and experts (Table C-1**Error! Reference source not found.**).

Table C-1. Weights of factors obtained from three military installation land managers* in terms of sustainable military land carrying capacity and environment.

	Training intensity	**Soil erosion**	**Road maint. cost**	**Landscape fragment.**	**Water quality**	**Noise**
Expert 1	10	8	7	3	8	1
Expert 2	10	7	5	3	5	2
Expert 3	10	7	8	9	2	1
Sum	30	22	20	15	15	4
Average weight	0.2830	0.2075	0.1887	0.1415	0.1415	0.0377
Relative weights						
Training intensity	1	0.7333	0.6667	0.5000	0.5000	0.1333
Soil erosion		1	0.9091	0.6818	0.6818	0.1818
Road maint. cost			1	0.7500	0.7500	0.2000
Landscape fragment.				1	1	0.2667

	Training intensity	**Soil erosion**	**Road maint. cost**	**Landscape fragment.**	**Water quality**	**Noise**
Relative weights (cont'd)						
Water quality					1	0.2667
Noise						1

*NOTE: Expert opinions on the weights of the six factors varied due to installation priorities and regulatory requirements; explanation of weight scale provided in next paragraph

The weights of six factors in Table C-1 were provided by three land management experts, using a scale from 1–10. A value of 1 indicated a factor was the least important, and a value of 10 implied this factor was the most important for sustainable military land carrying capacity and environmental concerns. The overall and relative average weights were then calculated and used to combine the spatial data layers of the factors.

Overall, military training had the greatest average weight (28.3%) followed by soil erosion (20.75%), road maintenance cost (18.87%), landscape fragmentation (14.15%), water quality (14.15%), and noise (3.77%). These numbers show that both military training and soil erosion were the most important for sustainable military land carrying capacity and environment. Maintaining all the roads could not be neglected for sustainable military land carrying capacity. Both landscape fragmentation and water quality had the same importance, and noise was the least important.

In pair-wise comparison, the relative weights of the factors were calculated (i.e., the importance of each factor compared to others was calculated). Compared to military training, for example, soil erosion was only as important as 73.3% of the military training. Similarly, road maintenance cost, landscape fragmentation, water quality, and noise respectively were as important as 66.7%, 50.0%, 50.0%, and 13.3% of the military training.

The weights of negative impacts from soil erosion, road maintenance cost, landscape fragmentation, water quality, and noise production were combined and the resulting impacts (in terms of both sustainable military land carrying capacity and environment) are shown in Figure C-5.

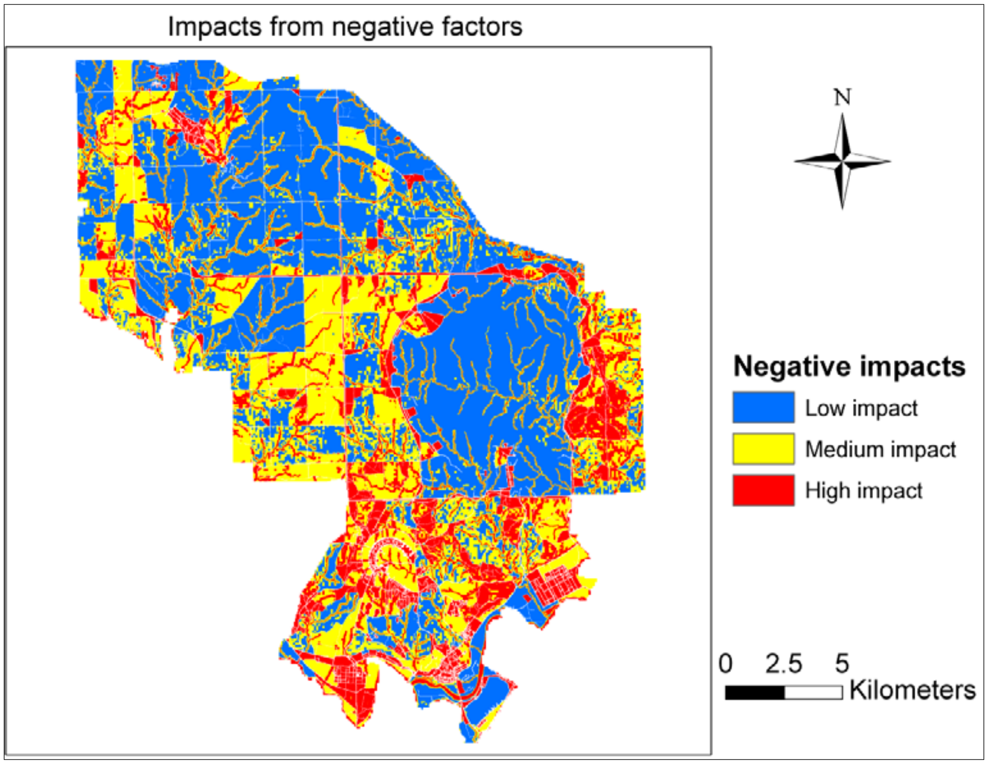

Figure C-5. Negative impacts of soil erosion, road maintenance cost, landscape fragmentation, water quality, and noise on both military land carrying capacity and environment by weighting the factors (using Equation 2 and the average weight values shown in Table C-1).

Figure C-5 shows that within the eastern and southern parts, along the borders of the impact area, and in one area of the north central part of the study area, the environmental quality was worse and the cost to maintain the roads was higher than in other parts of the study area.

Combining the negative impacts and the military training intensity led to the estimates of road priority for being closed in terms of sustainable military land carrying capacity and environment (Figure C-6).

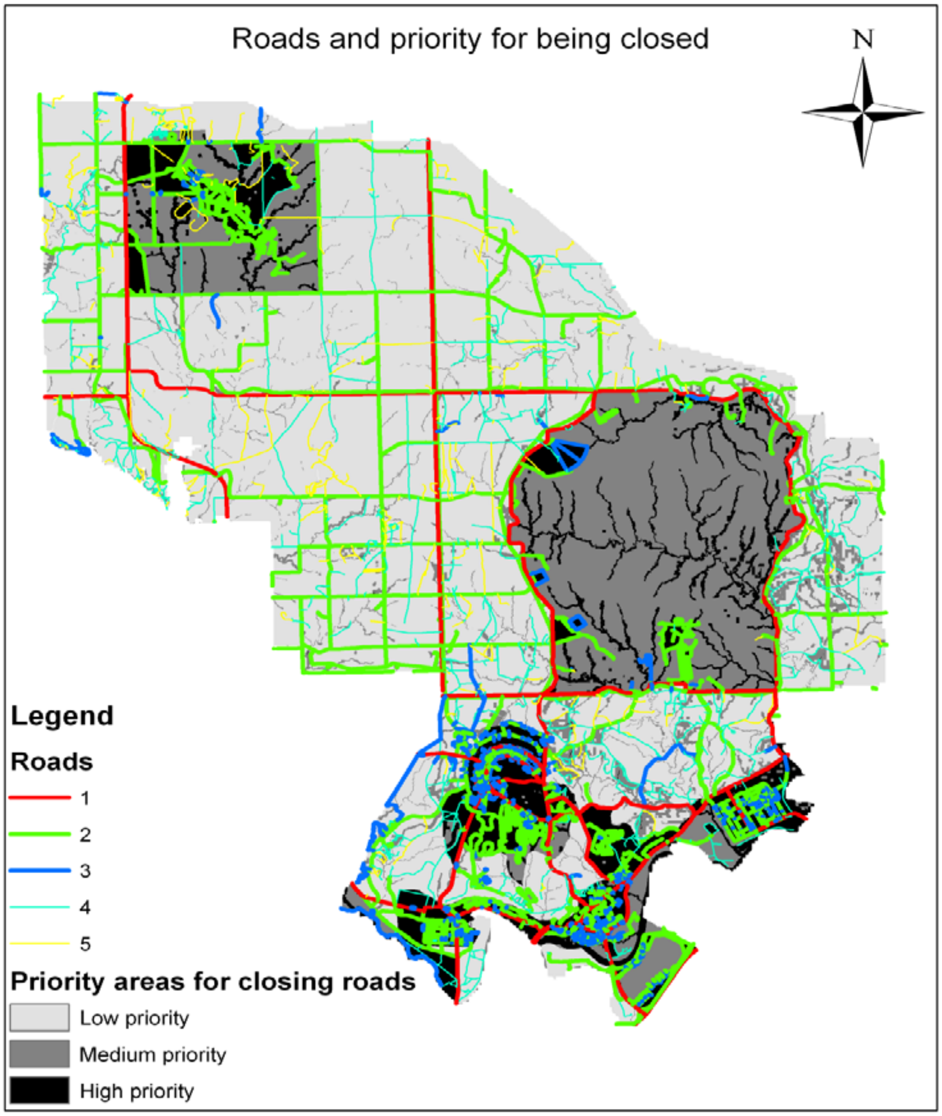

Figure C-6. Road priority areas for being closed with road categories overlapped: 1=primary road (red), 2=secondary road (green) 3=light-duty road (blue), 4=trail (aqua), and 5=path (yellow).

The roads that fell in areas of higher negative impact values and lower training intensity values had a higher priority for closure than those roads falling in areas where the environmental quality was better and the training intensity was higher. For example, the roads within the areas of the southern and north-central parts of the study area had higher potential for being closed (Figure C-6) because they had higher negative impacts from soil erosion, road maintenance cost, landscape fragmentation, water quality, and noise (Figure C-5)and lower military training intensity (Figure C-3f).

Figure C-6 provides land managers with the information of areas where roads, trails, and paths can be selected for closure. That is, land managers can use this map to identify the areas within which there is a high potential for roads being closed. However, this does not mean that within an area with high priority closure estimates, all the roads have to be closed. In order to further determine the order of individual roads to be closed within this area, a road access area map that showed the access areas provided by all the road segments was derived based on path allocation function (Figure C-7), and it can be used together with the priority map. Within a homogeneous priority area, the road segments that serve the smallest access area would be closed first.

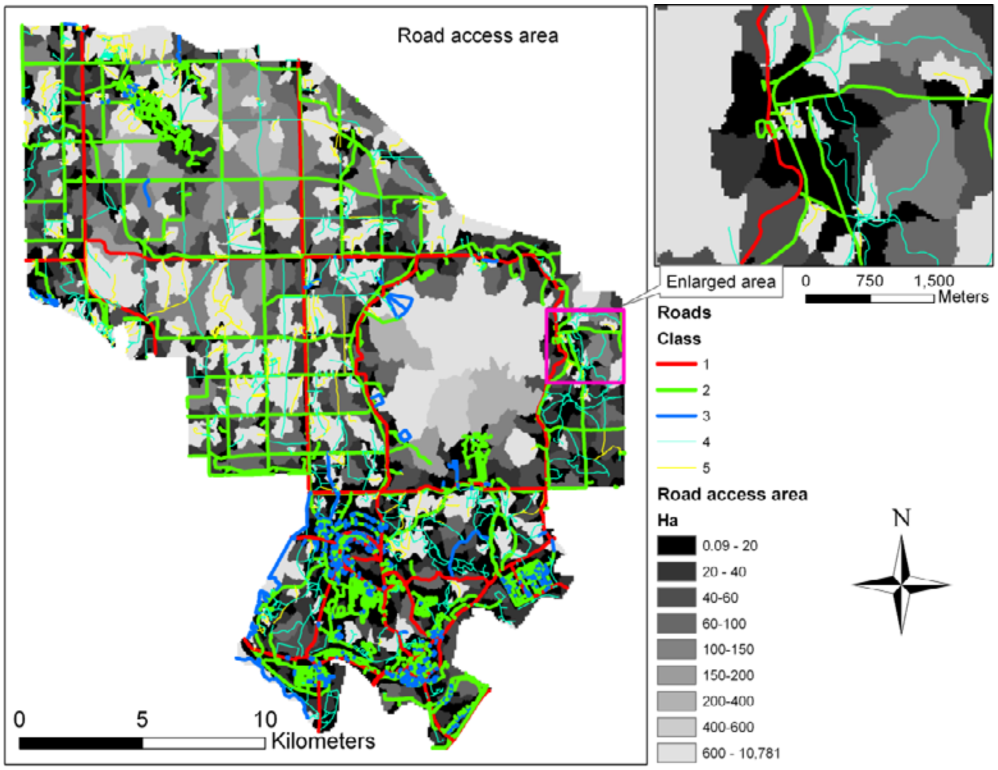

Figure C-7. Road access areas with road categories overlapped. (1=primary road (red), 2=secondary road (green) 3=light-duty road (blue), 4=trail (aqua), and 5=path (yellow).)

Conclusions and Discussion

Land managers often face a great challenge in maintaining a cost-efficient road network to be used for both military training and environmental purposes within each US Army installation. In this study, a methodology was developed and used to identify superfluous roads as candidates for closure in terms of both sustainable military training and environmental needs at Fort Riley. In this study, GIS and remote sensing technologies were used along with applying landscape analysis and modeling methods to derive various spatial data layers of factors that had significant impacts on both military training and environment. Those factors included maintenance cost, road access area, military training intensity, soil erosion, water quality, landscape fragmentation, and noise production. The factors were quantified and normalized. Then a spatial multicriteria decision and pair-wise comparison analysis was developed to derive weights for each factor. The weights were used to combine the factors to produce a priority map of all the roads for utilization, maintenance, and closure.

The resulting road priority map (Figure C-6) summarized the factors' negative and positive impacts in terms of sustainable military land carrying capacity and environment. The negative impacts on environment came mainly from soil erosion, water quality, landscape fragmentation, and noise from military training activities (Figure C-5). The road maintenance cost also had a negative impact in terms of land management. The positive impact is the military training intensity (Figure C-3f), implying the military land carrying capacity.

By combining negative and positive impacts, the spatial multi-criteria decision analysis led to the road priority map (Figure C-6). This map showed the spatial distribution of priority estimates for roads to be closed and is the first map that can be directly used by the US Army land managers to determine superfluous roads. This map thus provides useful guidelines and tools for land management and military training plans. This effort now provides a method for quickly ascertaining which roads are most cost-effective for closure without hindering the mission and at the same time offering benefits for environmental protection. The effort thus will provide land managers of US Army installations with a comprehensive analysis and assessment of alternatives at their disposal.

It has to be pointed out that the weighted values accounting for the impacts of the factors affecting both military land carrying capacity and environment quality were obtained by interviewing land managers and experts. This means that the weights are very subjective. For the purpose of improving objectivity, an advanced method is needed. Possible advancements may include developing a database in which the knowledge and importance of the factors is collected from various installation land managers and experts, then organized with general guidelines on how to derive the weights of the factors and made directly searchable.

There also is a need to develop advanced methods to improve the calculation of individual spatial data layers. In this study, for example, a visual interpretation and digitizing method on satellite images and digital aerial orthophotos was used to update the military off-road vehicle trails and paths. This method is time-consuming, and an automated procedure or program is urgently needed. Such a resource could then be used to produce timely updates of the trails and paths on existing road maps for US Army installations.

Appendix D

COMPLETE STEPS FOR CREATING A ROAD PRIORITY MAP FOR INDENTIFICATION OF SUPERFLUOUS ROADS TO BE CLOSED

1. **Data collection**. Collect datasets for the study area, including digital elevation model (DEM), military intensity, existing road map, road maintenance cost, water quality, RTLA (Range and Training Land Assessment) plot data, noise production, soil type map, rainfall isoerodent map, and various satellite images and aerial photos. In addition, ArcGIS, ERDAS Imagine, and IDRISI are needed.

2. **Updating of road map**. Use remotely sensed datasets to update the existing road map; add new roads, trails, and paths by visually digitizing them on the images or using an image-based automatic road detection program. GIS and image processing and analysis packages such as ArcGIS and ERDAS Imagine are needed.

3. **Road classification**. Carry out a road classification based on the military road classification system defined by Ayers et al. (2005) in which all the roads are classified into five different classes: (1) primary road, (2) secondary road, (3) light duty road, (4) trail, and (5) path.

4. **Calculation of road maintenance costs**. Use road maintenance cost information to create a road maintenance cost map based on the road classification developed in Step 3. Maintenance costs would include re-stoning, grading and rolling, dust suppressant, etc.

5. **Calculation of road access areas**. Calculate a slope map from a DEM and then, calculate road access areas for all segments of roads, trails, and paths by using a path allocation function in ArcGIS. The shortest path from a point to the nearest road is searched for based on the updated road map, and the slope map is used as a barrier factor in the search of the shortest path. For each of the cells within the study area, a road identification that has the shortest path to this cell is thus obtained, and output is transferred to the path allocation map. The cells with the same road identification are counted and timed by the spatial resolution, which leads to the road access area. The access areas then provide information on the relative importance of roads in the installation’s military training plans.

6. **Spatial characterization of training intensity**. Create the training intensity map based on military training records. The training intensity is quantified by total training days (TTD) per year. TTD is calculated by multiplying the number of days each soldier occupies a training area by the number of soldiers per training area. The training areas are first digitized and then TTD is spatially characterized by a choropleth map technique. This process includes digitizing training areas, assigning them the TTD value within each polygon, and then converting the polygons into raster layers.

7. **Creation of soil erosion potential map**. Create soil erosion map based on the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997; Wischmeier and Smith, 1978) and using a spatial interpolation method such as image-based cokriging[3] and conditional co-simulation developed by Wang et al. (2007). In the equation, soil loss is a product of five input factors including rainfall-runoff erosivity (R), soil erodibility (K), slope length (L), slope steepness (S), and cover management (C). A constant R value can be derived by interpolating the USDA’s R isoerodent map. The map of K can be obtained from soil survey based on the soil type map (USDA Soil Conservation Service, 1975). The topographic factor LS (as the product of L and S) can be calculated using a DEM that is based on empirical equations developed by Foster et al. (1977) and McCool et al. (1987). The cover factor varies depending on ground cover, canopy cover, and minimum rain drop vegetation height. The plot cover factor values can be calculated using measurements of RTLA sample plots which were based on the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978). To derive the map of cover factor, an image-aided cokriging or co-simulation can be applied to interpolate the values of the cover factor from the RTLA sample plots to unobserved locations (Wang et al. 2007). The map of soil erosion potential can be then computed by calculating the product of rainfall-runoff erosivity (R), soil erodibility (K), topographic factor (LS), and cover management (C).

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[3] Cokriging is an interpolation method for a variable available at scattered data points using multiple variable values of different natures at nearby locations. It is considered suitable to address data/image fusion needs.

8. **Creation of water quality map.** The water quality dataset can be obtained from website Monitoring and Assessing Water Quality (see MAWQ). The water quality values are available only for the streams and water bodies within the study area. For other areas, the water quality values can be derived using the values from the steams and water bodies within the same watershed and the distances of locations from the streams and water bodies. The users have to determine the distance decay effect, that is, water quality varies as the distance of a location from the streams and water bodies.

9. **Modeling landscape fragmentation.** Landscape fragmentation due to training activities can be quantified using spatial metrics - patch perimeter. The perimeter measures the edge of each patch. The high resolution remotely sensed data can be employed to divide the landscape into homogeneous polygons or segments using IDRISI's image segmentation method (referring to IDRISI website). The obtained polygons or segments are then applied to calculate the values of landscape patch perimeters.

10. **Modeling noise propagation.** Military training activities produce noise with the noise level of common Army equipment varying by the type of equipment. Generally, the largest noise level can be obtained and used in a study (see USACHPPM website – Appendix E). The noise level is then expanded from roads to other areas based on noise distance decay function or propagation models. Based on Westervelt and White (2009), the widely used noise propagation model is:

$$NL(u) = NL(u_0) + 10 \times \log(d(u_0)^2 / d(u)^2) - 0.005212 \times d(u) \quad (1)$$

where:

$NL(u_0)$ is the noise level (dB) at the location u_0,
$NL(u)$ is the noise level (dB) at a location u, and
$d(u_0)$ and $d(u)$ are the distances of the locations u_0 and u from the sound source.

A distance map from the nearest road is first created by using a straight-line distance function in ArcGIS and then obtaining the noise levels at any points based on the noise propagation model given in the above equation.

11. **Normalization of data**. All the data layers above are normalized or their values are transformed to comparable units by using a linear scale transformation based on maximum and minimum values. The transformed values range from 0–1 and are compatible.

12. **Obtaining weights of factors**. With spatial multicriteria decision analysis, the weight assessment of the factors or variables is made by using a pair-wise comparison method. This method includes developing a pair-wise comparison matrix and computing variable weights. If m is the number of the variables, there are a total of $m(m-1)/2$ comparisons. The information on relative importance of the factors can be obtained by interviewing the military land managers or other experts. The final weight for each factor is calculated by weighting the values of preferences and averaging them.

13. **Calculation of road priority estimates for being closed**. The data layers above are finally integrated by using the average weights and the priority estimates are obtained for all the roads considered for closure (Longley et al. 2005; Malczewski1, 1999):

$$\mathrm{Pr}\,iority(u) = \sum_{i=1}^{m} w_i\, f_i(u) \tag{2}$$

where:

m is the number of the factors considered,
$f_i(u)$ is the value of factor i at a location u, and
w_i is the weight of factor i.

The priority of a road for being maintained is defined based on its importance in terms of both sustainable military land carrying capacity and environment. This means that the higher the priority of a road for being maintained, the lower the priority of the same road for being closed. The roads that have higher values of negative impacts on environmental quality and maintenance costs and lower values of military training intensity should have higher priority values for being closed. Thus, the values of military training intensity should be inversed before the data layers are integrated.

14. **Determining the order of individual roads for being closed.** The priority map for road closure will show that roads within the high priority areas should be closed. When there is more than one road in a high priority area, the order of the roads to be closed should be determined. This would be done by combining the priority map and the road access area map. Within a homogeneous area of priority, the smaller the road’s access area, the higher the order of the road to be closed.

Appendix E

GENERAL REFERENCES

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Appendix F

ABBREVIATIONS

Abbreviation	**Spelled Out**
AR	Army Regulation
CECW	Directorate of Civil Works, U. S. Army Corps of Engineers
CEMP	Directorate of Military Programs, U. S. Army Corps of Engineers
CERL	Construction Engineering Research Laboratory
DA	Department of the Army
DEM	digital evaluation map
DPW	Directorate of Public Works
EPA	Environmental Protection Agency; also USEPA
ERDC	Engineer Research and Development Center
GIS	global information system
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HUC	hydrologic unit code
IDRISI	name of computer software designed to process and analyze raster information
IRS	Indian Remote Sensing
LCTA	land condition trend analysis
LTM	Landsat Thematic Mapper
PDF	portable document file
POC	point of contact
PWTB	Public Works Technical Bulletin
RTLA	range and training land assessment
RUSLE	Revised Universal Soil Loss Equation
TTD	total training days
URL	universal resource locator
USACE	US Army Corps of Engineers
USACHPPM	US Army Center for Health Promotion and Preventive Medicine
WBDG	Whole Building Design Guide
WWW	World Wide Web