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Research article

A dynamic simulation/optimization model for scheduling restoration of degraded military training lands

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ABSTRACT

Intensive use of military vehicles on Department of Defense training installations causes deterioration in ground surface quality. Degraded lands restrict the scheduled training activities and jeopardize personnel and equipment safety. We present a simulation-optimization approach and develop a discrete dynamic optimization model to determine an optimum land restoration for a given training schedule and availability of financial resources to minimize the adverse effects of training on military lands. The model considers weather forecasts, scheduled maneuver exercises, and unique qualities and importance of the maneuver areas. An application of this approach to Fort Riley, Kansas, shows that: i) starting with natural conditions, the total amount of training damages would increase almost linearly and exceed a quarter of the training area and 228 gullies would be formed (mostly in the intensive training areas) if no restoration is carried out over 10 years; ii) assuming an initial state that resembles the present conditions, sustaining the landscape requires an annual restoration budget of $957 thousand; iii) targeting a uniform distribution of maneuver damages would increase the total damages and adversely affect the overall landscape quality, therefore a selective restoration strategy may be preferred; and iv) a proactive restoration strategy would be optimal where land degradations are repaired before they turn into more severe damages that are more expensive to repair and may pose a higher training risk. The last finding can be used as a rule-of-thumb for land restoration efforts in other installations with similar characteristics.

1. Introduction

Degradation of training lands is an important issue for military installations. Land degradation reduces the ability of training lands to support the scheduled training activity and poses serious risks for the personnel and training equipment. Land degradation also affects the environment and ecosystem services in and around training lands through soil erosion and lowered water quality. In this paper, we introduce a decision support system involving a simulation-optimization model to minimize the adverse effects of a given training schedule by determining an optimal restoration of the damaged training lands over space and time. As a case study we apply the model to Fort Riley, Kansas. With appropriate modifications, the approach we introduce here can be applied to other installations that face similar land restoration challenges.

Several types of land degradation have been identified for Fort Riley: 1) maneuver damages, 2) gully formation, 3) damaged stream crossings, 4) damaged terraces/diversions, and 5) damaged roadside drainage ditches (ITAM Report, Fort Riley). The types of land damages listed above can be equally important at different times and different locations. In this paper, we focus on maneuver damages and gully formation only. These are the most common types of land degradation at all military maneuver-support installations and directly linked to training activity. Moreover, maneuver damage and gully formation have a causality relationship that justifies their joint consideration. Maneuver damages may result from each training event particularly due to heavy vehicle traffic that can create ruts and rills. This causes topsoil loss and

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destruction of the root system of ground vegetation cover, which in turn decreases the land's ability to resist further damages. If not repaired/restored (by land leveling, compacting, seeding, and mowing), such damages may turn into runoff channels and eventually develop into deep gullies that may cause further soil loss (USDA, 2002). Presence of gullies in a training area can be dangerous for fast moving vehicles especially when the gullies are hidden by tall vegetation and cannot be seen by vehicle operators. This increases training risk and leaves less area usable for future training (Diersing et al., 1988). Gullies are leveled, re-graded, and if necessary rock checks are installed to prevent further erosion. The area can then be reseeded and mulched as required (Fig. 1).

The objective of the military land management is to maintain the quality and safety of the training areas to the extent possible. Maintaining the training lands in good condition requires significant manpower, equipment, and financial resources to repair maneuver damages and fill gullies.[1] The two land management activities are intertwined, namely repairing the damaged training lands proactively may reduce the potential for gully formation, which in turn reduces or eliminates some of the gully repairs and related costs that would occur otherwise. Ideally it may be optimal to repair any land damage whenever it occurs, but this may not always be feasible. The availability of financial resources for land repairs is the primary limitation. Even if adequate financial resources are available, gullies may still form due to unfavorable weather conditions, such as severe continued rainfall and flood, which may physically restrict repair activities. In such cases, damages can be repaired at a later time that is convenient for the land managers. In any time period, an optimal land management strategy may involve a combination of these two options, namely repairing some of the damaged lands and filling some gullies to the extent allowed by resource availability and weather factors. Thus, we state the research problem as follows: for a given annual training schedule and resource availability, determine a dynamic optimum land restoration strategy, specifically when, where and how much damaged land and how many gullies should be repaired/restored, to maintain and improve the quality of the military training areas.

2. Methodology

The relationship between military training activities and land degradation is a key factor when making land restoration decisions. The dynamics of land conditions and quantifying the impacts of off-road military vehicle use on land degradation are complex issues. Existing land and water management simulation models developed for agricultural systems (e.g., SWAT and EPIC[2]) are not much useful for this since they deal with the impacts of controlled and systematic operations (e.g., tillage, irrigation) whereas military training exercises are of a completely different nature because of their irregularity and randomness. Since the introduction of the *Land Conditions and Trend Analysis Program* (LCTA) in mid-1980's, numerous studies addressed this issue and a fairly large literature has evolved (see, for example, Diersing and Severinghaus, 1984; Wilson, 1988; Diersing et al., 1992; Fang et al., 2002; Haugen et al., 2003; Anderson et al., 2005; Wang et al., 2009, 2014; Howard et al., 2013). The relationship between training and land damage impacts is assessed using repeated experiments at selected plots (e.g., Althoff and Thien, 2005) or considering different types of

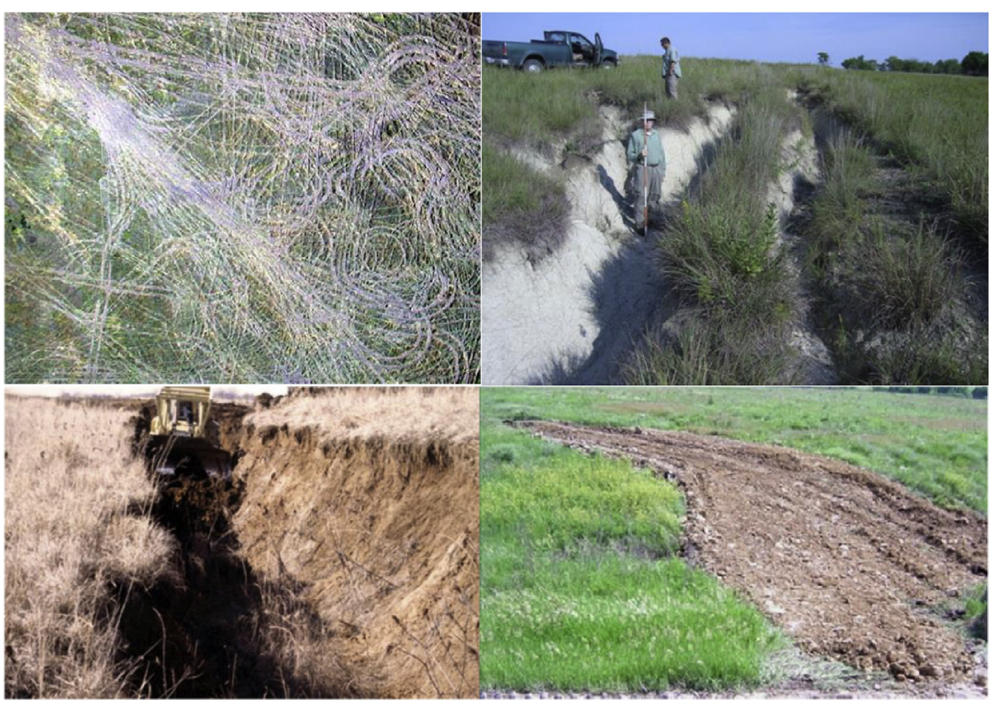

Fig. 1. Aerial photo of maneuver damages (upper left), gullies formed due to military vehicle traffic and runoff (upper right and lower left), and a repaired gully (lower right).

[1] The Fort Riley ITAM Report estimates that the cost of repairing a single acre of damaged land can be as much as $980 (in 1993 values). Based on Landsat satellite images, the estimated damaged area was 7180 acres, which would lead to a total cost of approximately $2.2 million to repair maneuver damages that are predicted to occur in 2011.

[2] See http://swat.tamu.edu/documentation/and http://epicapex.tamu.edu/manuals-and-publications/.