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Base Facilities Environmental Quality

Optimal Management Of DoD Lands for Military Training, Ecosystem Services, and Renewable Energy Generation

Framework and Data Requirements

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and James D. Westervelt

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Framework and Data Requirements

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Abstract

This report documents the development of a framework for a numerical modeling application that can help installation managers develop optimal land-use policies that support competing uses to the greatest extent feasible. Specifically, this framework is designed for modeling landscapes that must concurrently maximize a military training mission, conservation of ecosystem services needed by species at risk, and development of renewable energy resources. These competing land uses have become necessary in recent decades due to emerging regulatory requirements for environmental conservation and strategic requirements for producing renewable energy on military lands.

The modeling framework includes a table of land-use needs, land-use suitability maps, and a land-use compatibility matrix, which will be implemented as part of the user interface for the proposed numerical model. In a later phase of this work the framework will be extended to include the time domain, which will play a significant role in scheduling military training and testing activities to avoid interfering with certain essential but conflicting factors such as endangered species breeding cycles or the seasonal availability of solar exposure for photovoltaic production.

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Preface

This study was conducted for the Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA(ALT)) under Research, Development, Test, and Evaluation Program A896, “Base Facilities Environmental Quality; Project 328285, “Optimal Allocation of Land for Training (OPAL).” The technical monitor was Steven W. Sekscienski, DAIM-ED-N.

The work was performed by the Ecological Processes Branch (CN-N) of the Installations Division (CF), US Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, William D. Meyer was Chief, CEERD-CN-N; Dr. John T. Bandy was Chief, CEERD-CN; and Dr. Alan B. Anderson was the Technical Director for Military Ranges and Lands. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

COL Kevin J. Wilson was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

1 Introduction

1.1 Background

The Department of Defense manages approximately 25 million acres of federal lands, about half of which is managed by the US Army. The Department of Army has long maintained that the capacity of land available for military training uses is not adequate for training requirements (Diersing et al. 1992). Optimization of land use for military training, therefore, has been a high priority for installation range managers.

Emerging defense requirements have increased the need for new and different kinds of ordnance and equipment testing as well as new military exercises utilizing that technology. At the same time, it is now well understood that Army installation lands represent important habitats for threatened and endangered plant and animal species. Having been protected from intensive urbanization and agricultural development, DoD lands host approximately the same number of threatened and endangered species as found on lands managed by US Forest Service (USFS), and significantly more than the number of species on the lands managed by the National Park Service (NPS), Fish and Wildlife Service (FWS), and Bureau of Land Reclamation (BLM) (Flather et al. 1994; Flather et al. 1998; Stein et al. 2008). Military lands have three times the density of such species than the NPS (see Figure 1).

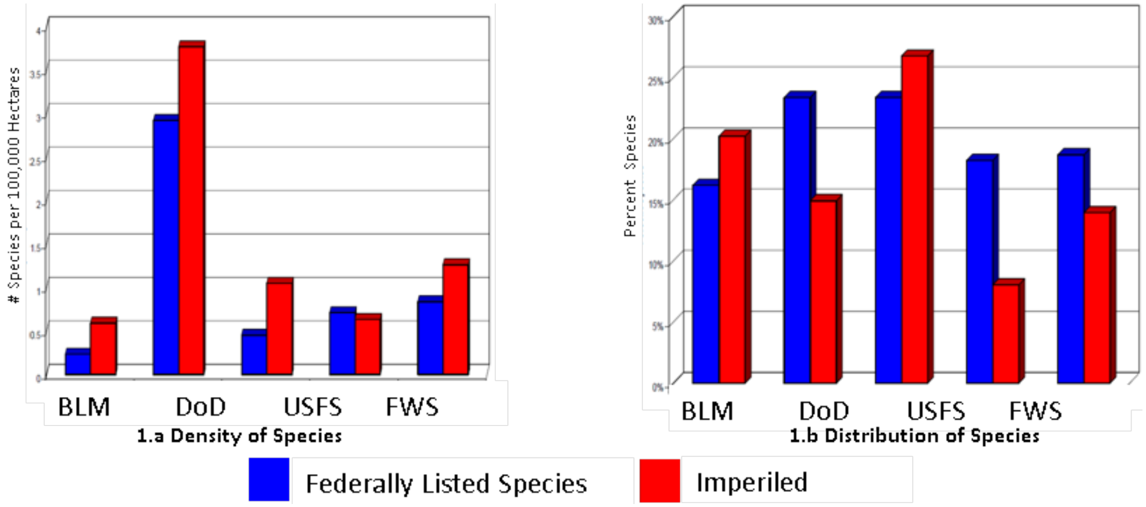

Figure 1. Distribution (a) and density (b) of endangered and imperiled species on federal agency lands. (Source: Nature Serve Central Databases, based on data from US natural heritage programs, Feb.2007.)

Because training and testing activities can have adverse impacts on the environment and ecosystem services provided by these lands, the National Environmental Protection Act (NEPA) and Endangered Species Act (ESA) require the Army to manage military lands in ways that support environmental conservation and ecosystem restoration. A substantial amount of DoD resources have been dedicated to nonmilitary management activities in order to comply with federal law and achieve Army environmental goals for its installations. In 2006, for example, DoD spent $4.1 billion on environment-related expenses, including $1.4 billion for environment restoration and $204 million for conservation (Benton 2008). The amount spent by DoD per unit of managed area is nearly 10 times higher than the amount spent by USFS (Hodapp and Benton 2001).

Given limitations on available conservation resources and the almost fixed availability of training lands[*], efficient and effective management of military landscapes is needed to meet environmental obligations without impeding training goals or the military mission. Achieving these objectives is complex because military and conservation requirements uses present conflicting land-management priorities. A number of studies addressing these issues have developed systematic land-management tools using statistical and simulation approaches (see, for example, Childress et al. 1999; McLendon et al. 1998; Diersing et al. 1992).

Over the past decade, another requirement has emerged to further complicate military land management: support for renewable energy production. DoD is required to comply with the Energy Policy Act of 2005 and the Energy Independence and Security Act (EISA) of 2007. Both acts emphasize the use of renewable energy, but EISA imposes specific renewable fuel standards for transportation fuels (USEPA 2010)[†]. Being the largest single user of energy (with a 75% share of federal energy consumption at a cost of about $3.5 billion annually), the DoD has set medium-term goals to (1) reduce energy consumption through conservation and (2) increase the share of renewable energy in its total electricity consumption by at least 25% by 2025. To achieve this ambitious goal, DoD is considering a diverse energy portfolio that includes wind, solar, geothermal, hydrogen, and biomass-

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[*] Land purchase by military is still possible, but compared to the needs the amounts are negligible.

[†] Specifically, the Renewable Fuels Standard (RFS) introduced by EISA mandates blending 36 billion gallons of ethanol with gasoline annually by 2022, which corresponds to about 20% of the total transportation fuel consumption. At least 21 billion gallons of the renewable fuels must be advanced biofuels, defined by their GHG intensity relative to conventional gasoline (USEPA 2010).

generated power (bioenergy). wind, solar, and bioenergy sources each have significant land-management implications, so this third land-use requirement for Army installations will compound an already complex military land-management regime.

In order to meet this triple requirement for utilization of Army installation lands, planners and managers need more effective methods of allocating land over time to optimally support all competing priorities. Numerical modeling capabilities have been successfully applied to similar problems for Army installations (Dissanayake et al. 2011a, 2011b). In this project the authors developed a framework and data requirements for optimally allocating land for military training, sustainment of ecosystem services, and renewable energy generation over time and space. A matrix that identifies the compatibility of different land uses is applied as an input to linear integer programs that optimally allocate land uses. It is expected that the optimal land-use patterns returned by the models will provide valid and useful quantitative information to support planners and managers in their complex task of satisfying competing triple land-use requirements.

1.2 Objective

The objective of this research was to develop a quantitative land-use allocation framework to analyze the best land-management allocation strategies across time and space given the impact of two secondary land-use options—ecosystem conservation and renewable energy generation—on the primary land-management driver, the military training.

1.3 Approach

The modeling framework was developed to generate a Pareto optimal solution in which none of the three objectives can be improved further diminishing the efficacy of the other objectives. User inputs, model outputs, and model processes of a future system were selected to support planning and management decisions that will lead to the best combinations of land use that will concurrently satisfy training, testing, ecosystem, and renewable energy production requirements.

The results of this work are intended to facilitate discussions to further refine the planning and development of software decision-support tools that can be used in the field.

1.4 Mode of technology transfer

The final models and results will be presented at conferences and seminars to inform military installation land managers, conservation agencies, academics, and researchers of

1. the ability to incorporate military training requirements, renewable energy generation, and endangered species protection within one unified land allocation framework
2. the availability of these models for direct application at various locations.

The theoretical contributions resulting from this work will be submitted for publication in journals.

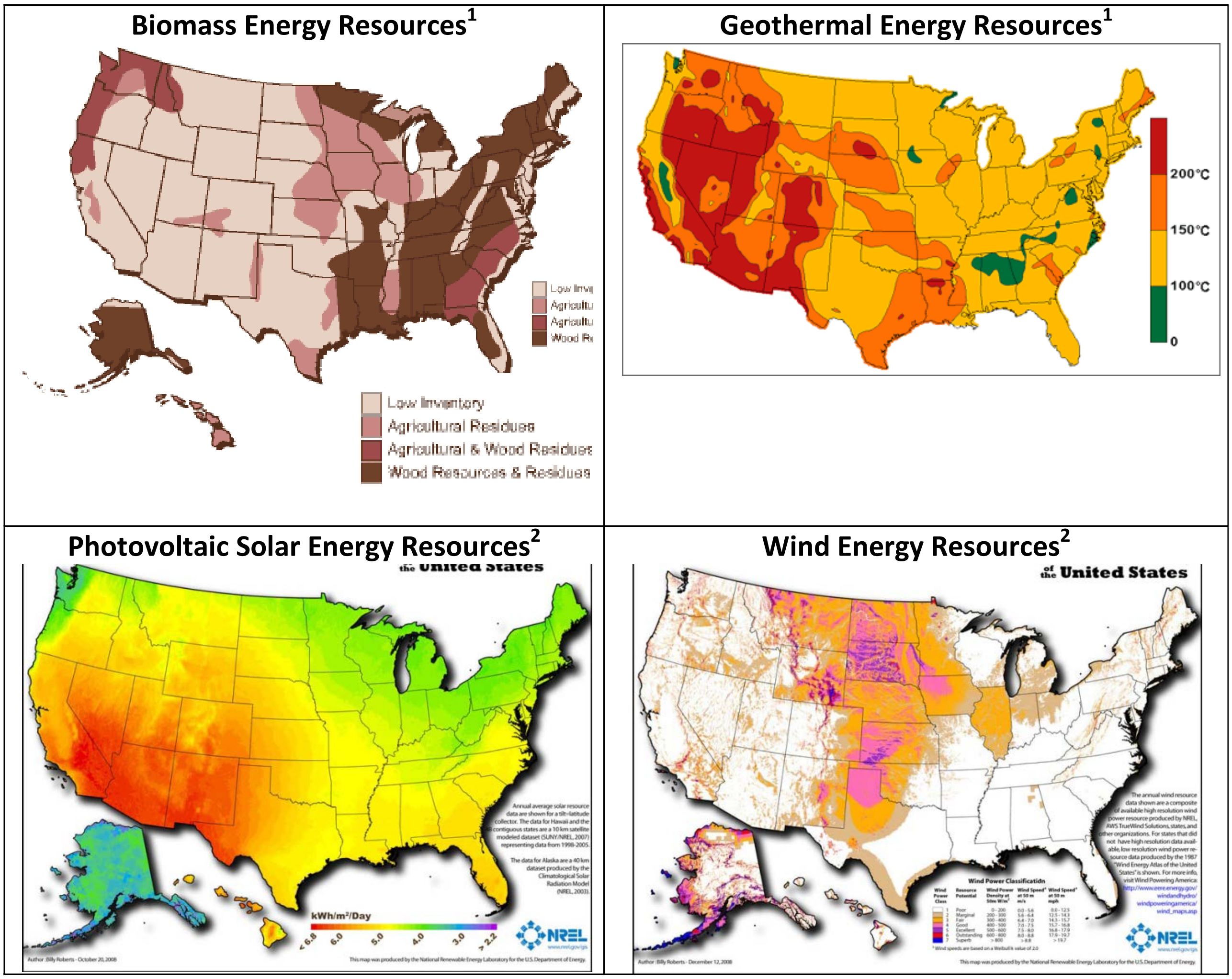
2 Framework Development

2.1 Competing land-use requirements

When determining the best land-management strategies or practices to satisfy the triple requirements for Army installations, the two secondary land-use requirements (i.e., ecosystem sustainment and renewable energy generation) must be analyzed in a unified framework that considers the compatibility of each option with the primary land-management driver (i.e., military training and testing) and with each other. The three land uses have a number of competing requirements. However, through optimal scheduling of training exercises in terms of both time and location, and other considerations in designating ecosystem management and renewable energy production, the adverse impacts of conflicting requirements can be minimized.

The regional differences in wind, solar, and bioenergy potential (Figure 2) suggest consideration of three representative installations in the south-southeast, south-southwest, and west-northwest regions of the United States. The Appendix describes these renewable energy options in detail. The maps indicate that a typical installation in each of these three regions would have different renewable energy options depending on the ‘input’ availability (feasibility of adopting a particular renewable energy option) in that region. This somewhat simplifies the energy component of the problem. We propose to develop a generic model(s) for each representative installation and apply the generic model(s) to a selected installation in each region.

A representative installation in each of these three regions will be treated as a case study where a specific set of land-use issues and types of military training activities will be considered.



Biomass Energy Resources[1]

Geothermal Energy Resources[1]

Photovoltaic Solar Energy Resources[2]

Annual average solar resource data are shown for a tilt=latitude collector. The data for Hawaii and the 48 contiguous states are a 10 km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005.

The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

Author: Billy Roberts - October 20, 2008

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

Wind Energy Resources[2]

* Wind speeds are based on a Weibull k value of 2.0

The annual wind resource data shown are a composite of available high resolution wind power resource produced by NREL, AWS TrueWind Solutions, states, and other organizations. For states that did not have high resolution data available, low resolution wind power resource data produced by the 1987 "Wind Energy Atlas of the United States" is shown. For more info, visit Wind Powering America: http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_maps.asp

Author: Billy Roberts - December 12, 2008

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

Figure 2. US renewable energy maps. (Sources: 1 US Department of Energy, http://www1.eere.energy.gov/maps_data/renewable_resources.html; 2 National Renewable Energy Laboratory, http://www.nrel.gov/gis/maps.html.)

Land requirements for each installation will be specified in terms of the applicable type of renewable energy source; the local species that require protection and their specific species habitat needs; and the current and prospective training activities that will be conducted on that installation. The training activities may include maneuver, live fire, combat engineering, and aviation, each of which can be further broken down into different types of sub-activities that require a specific land type, timing, and duration of training. Training events may involve ground and air maneuvers or exercises occurring over a determined time period. Some activities may require forest land while others may require open space, desert-like conditions, or a combination of land and water space.

Each type of training activity may have an impact on the natural resource base (e.g., degradation in soil, water, and vegetation conditions), ecosystem services, or renewable energy generation. Therefore, the framework will need to incorporate the compatibility of each land use with all other simultaneous land uses.

2.2 User interface requirements

The modeling framework requires user input in the form of

1. a list of prospective land-uses and their requirements
2. a suitability index for each land use per land parcel in the form of geographic information system (GIS) maps (shape files or raster files)
3. a suitability index that represents the compatibility of different land-use options for military training, ecosystem services and renewable energy.

2.2.1 Table of land-use needs

The table of constraints needs to incorporate land use types, requirements, areas available, and constraints associated with the target land uses. An example is shown in Table 1.

Table 1. Land-use types and constraints.

Code	Description	Amount	Areas	Min Compact	Min Connection
TVT	Tracked Vehicle Training	20,000 vehicle training days	1-4	0.7	2 km
IZ	Impact Zone	300 HA	1	0.9	0
RCW	Red Cockaded Woodpecker	600 individuals	1	0.5	0
GT	Gopher Tortoise	300 individuals	1-4	0.6	1 km
WT	Wind Turbine	100 turbines	1-3	0.2	4 km
BF	Biofuel	1000 HA	1-4	0.5	1 km
SC	Solar Collector	500 HA	1-2	0.3	10 km

The Code column specifies the shortcut name for the land use, and the Description column provides a plain-language descriptor for it. The Amount column specifies units that are appropriate to the land use, typically a count or an area measure. The Areas column indicates the number of disconnected areas that are acceptable for the listed land use. The Min Compact column is a 0.0 – 1.0 index that indicates how compact the areas need to be: a value of 1.0 requires that the area be circular while 0.0 requires only the most tenuous connectivity (e.g., a narrow floodplain along a stream). The Min Connection column indicates to the minimum distance separating areas.

Table 1 represents an example, but the table is likely to expand as more land-use constraints are identified. Adding constraints may refine the results returned by the model, but it will also increase the computational time to find a solution.

The framework treats military training options as hard requirements, and addresses specific goals such as training area for 50 tanks, 500 infantry training hours in 2 acres of land, etc. In contrast, options for ecological and renewable energy land use are treated as soft requirements, such as minimum species populations or minimum energy-generation goals. A sensitivity analysis will be conducted for a full range of management strategies to analyze how the parameter values impact the final objectives.

A crucial aspect of site selection is the spatial coherence of sites assigned to a given mission. This is particularly important for military and conservation areas. However, terrestrial species may require compactness and physical connectivity of the conservation areas while avian species may tolerate reasonable habitat fragmentation. Spatial optimization models have been developed in previous work to address land use for multiple purposes, selection of clustered conservation areas, relocation of species into such areas (Dissanayake et al. 2011b), and joint management of multiple species (Dissanayake et al. 2011a). These previous studies support quick development of some of the models needed for the current work. Also, some issues relevant to the current research can be addressed through modification of the previously developed models.

The land-use optimization models for the selected representative installations will be coded using the General Algebraic Modeling System (GAMS) numerical modeling platform. The output from GAMS will be mapped using a geographic information system (GIS) such as Esri ArcGIS. Model output will include maps identifying the optimal locations of lands allocated to different purposes, with military land use being the highest-priority mission. Depending on the values in the compatibility matrix, the final output maps may be differentiated in terms of seasonal land uses.

2.2.2 Land-use suitability maps

For each land use under consideration, suitability maps are needed. These maps must indicate the capacity of each type of land use on a grid cell. For military training, capacity is indicated by the number of units that can train on the land unit. For species and habitat, it is indicated by the carrying capacity of the land unit. For renewable energy production, it is indicated in terms of the amount of energy that can be generated. Figure 3 conceptually illustrates stylized suitability matrices for three different land uses. Figure 4 illustrates a Gopher Tortoise suitability matrix that was used in Dissanayake et al. (2011b) on optimal land allocation for GT areas within military installations.

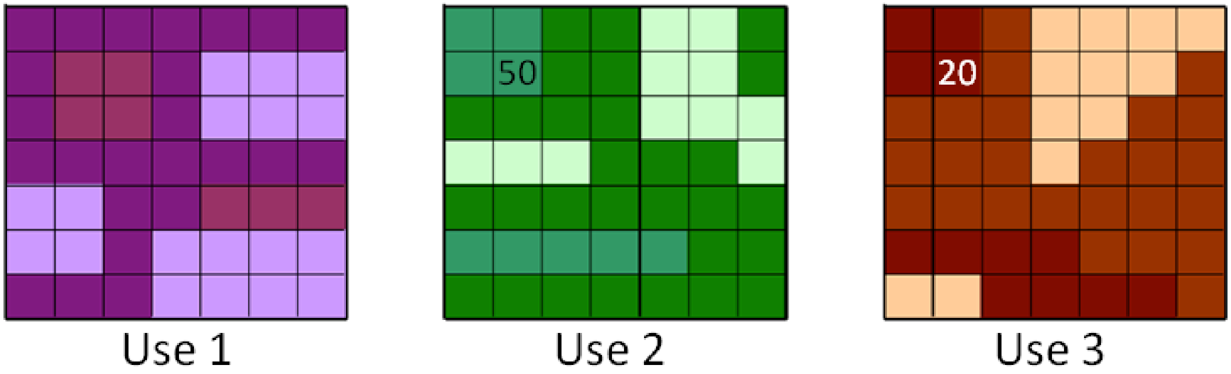
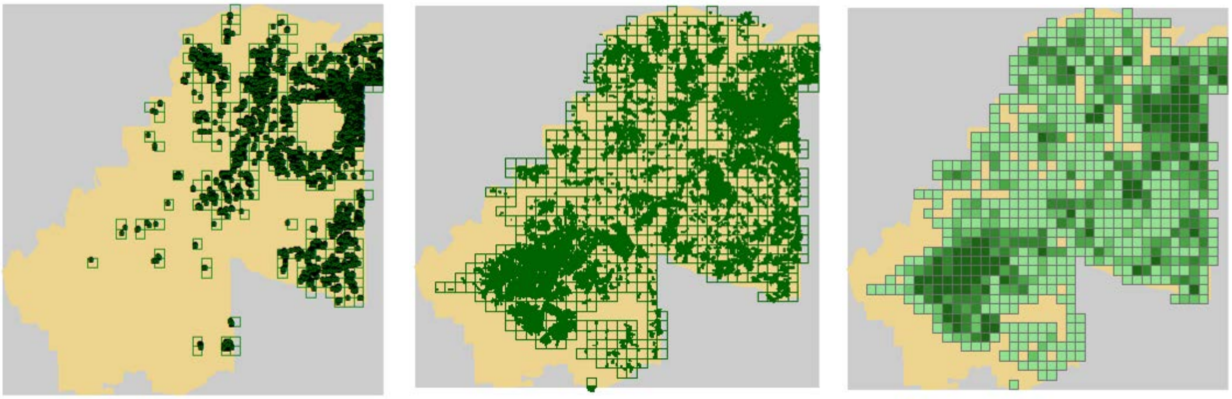


Figure 3. Sample capacity maps for three generic land uses showing capacity values in cell (2,2) for Uses 2 and 3.



(a) (b) (c)

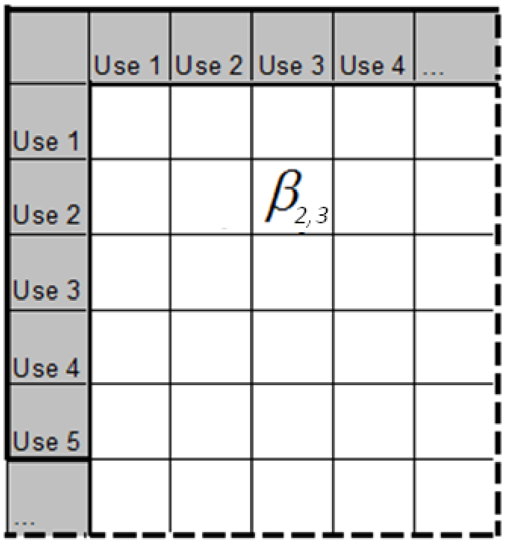
Figure 4. (a) Location of observed GT habitats (based on burrow counts); (b) location of suitable GT habitat areas, (c) quality of suitable habitat areas (darker shade indicates higher quality.

Additionally, cost maps would be necessary for any land use that requires construction or other modifications (e.g., creating ponds needed by gopher frog or nests for woodpeckers). Cost can be represented as maps or, if the costs are uniform across the landscape, in the form of a table.

2.2.3 Compatibility matrix

Unlike previous optimal land allocation approaches, this framework allows for the assignment of two (or more) land uses to each raster GIS patch. This requirement is driven by two issues. First, in reality, multiple land uses may be accommodated in a single area. Forest tracts can simultaneously support endangered species habitat and training. Second, the size of military installations and the limitations of current computer technology require that the optimization process divide the area into 10,000 raster patches or less. When patches are large enough, even incompatible land uses may be accommodated within the boundaries of the same area.

As indicated previously, a compatibility matrix is necessary to consider possible concurrent uses of a given land area. All land uses are affixed as labels to the columns and the rows of the matrix. Figure 5 illustrates a generic compatibility matrix. The cells in the matrix will contain numbers between 0 and 1 indicating the compatibility of the row use with the column use. The value in cell (2, 3), $\beta 2,3$, indicates that if a land unit is designated for Use 2, then it will also use up $\beta 2,3$ percent of the suitability (or training capacity or electricity generation) required for Use 3.



	Use 1	Use 2	Use 3	Use 4	…
Use 1					
Use 2			$\beta_{2,3}$		
Use 3					
Use 4					
Use 5					
…					

Figure 5. Compatibility matrix of different land uses.

As a more detailed example, assume Use 2 in Figure 3 refers to Gopher Tortoise and Use 3 refers to armor training. The number 50 in cell (2, 2) in the suitability map for Use 2 indicates that cell (2, 2) can support 50 Gopher Tortoise individuals. The number 20 in cell (2, 2) in suitability map for Use 3 indicates that cell (2, 2) can support the training of 20 armor units. If $\beta 2,3 = 0.50$, this would indicate that using land for GT will decrease the training capacity for armor by 50%. Therefore if cell (2,2) were selected as a GT area and 50 GTs were placed in the cell, then the cell could support the training of only 10 armor units. As an alternative, if only 25 GTs were placed in the cell, then the cell will be able to support the training of 15 armor units[*]. Even though the compatibility matrix allows for multiple uses of the same land whenever possible, the model will operate to reduce the need for multiple land uses on the same land.

Also, the compatibility matrix is multilayered so that individual entries may be specified for different time periods (months or seasons) because the impacts of implementing a particular land-use option on a given parcel may also differ over time (such as breeding periods or other habitat uses of focus species, harvest periods for biomass, or periods in which sunlight is adequate for photovoltaic production). The optimal scheduling of training activities over time may reduce or eliminate adverse effects of a particular training activity on the competing land uses without restricting military training benefits. Because every installation has different requirements for military training, conservation areas, and renewable energy production, a compatibility matrix will be unique to a specific installation.

2.2.4 The time dimension

The first phase of model development, based on this framework, will exclude work on modeling the time domain. The initial model will focus on land allocation for three competing uses. Once this portion of the model has been tested, the framework will be extended to incorporate temporal considerations. Initially, two distinct types of temporal change are expected, based on the permanency of the land use. Land uses such as built infrastructure and impact areas will be considered as permanent or irreversible changes over time. As such, these will limit the future land-use options. In contrast, land uses such as training areas, species habitats, etc., are reversible over time, and so they allow for changes in future land use.

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[*] The capacity of the secondary use (the 15 armor units) is calculated as:

full capacity_j – full capacity_j* compatibility_ratio_i_j * used_capacity_i/full_capacity_i

full_capacity_armor – full_capacity_armor *$\beta gt,armor$*used_capcaity_gt/full_capacity_gt

$20 - 20 * 0.5 * 25/50 = 15$

2.3 Data requirements

To implement the model, the data structure will need to accommodate the following parameters and capabilities:

- user specifications for land-use requirements
- suitability maps for each land use
- quantification of the compatibility of different land uses.

3 Conclusion

The amount of land available for use by military installations in the United States is limited and not likely to significantly increase in the foreseeable future. Because these lands represent high-value national assets, and because new regulatory and strategic requirements for using these lands have emerged in recent decades, DoD installation managers are faced with unprecedented difficulties in effectively

The product of the work documented here is the framework for a numerical modeling application that can help installation managers develop optimal land-use policies that support competing uses to the greatest extent feasible. Specifically, this framework is designed for modeling landscapes that must concurrently maximize a military training mission, conservation of ecosystem services needed by species at risk, and development of renewable energy resources. The framework includes a table of land-use needs, land-use suitability maps, and a land-use compatibility matrix, which will be implemented as part of the user interface for the proposed numerical model.

The framework is also designed to accommodate modeling of the time domain, to be accomplished during a later phase of development, in terms of applicable units such as months, years, or seasons. The time dimension will play a significant role in scheduling military training and testing activities to avoid interfering with certain essential but conflicting factors such as endangered species breeding cycles or availability of solar exposure for photovoltaic production.

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USEPA. Renewable Fuel Standard (RFS). http://www.epa.gov/otaq/fuels/renewablefuels/index.htm

Appendix: Renewable Energy Options

Bioenergy may involve either onsite power and fuel generation or engaging in offsite power generation by providing renewable inputs (such as solid waste or biomass) to civilian energy and fuel producers[*]. Known renewable bioenergy inputs include grasses, crop residues, and woody biomass (a byproduct of logging in managed forests). Particularly woody biomass may be a viable option for installations managing large amounts of forest lands. Adopting the bioenergy option may require management of some lands within the boundaries of installations differently (compared to the present situation), where biomass production may be one of the important economic drivers. Depending on the size of the managed forest area, an installation may process its own biomass to produce bioenergy, such as co-firing with coal to produce electricity[†], or trade biomass and electricity with local electricity producers[‡]. Although this additional management objective may not necessarily conflict with the environmental or ecological conservation objectives (depending on the nature of the conservation programs implemented by individual installations), it will likely conflict with the military training objective, the extent of which may vary from one site to another.

Wind and solar may be the most important and viable options for some DoD installations that have access to sufficient amounts of wind and solar radiation (wave energy may also be an option for some coastal installations). The solar and wind energy viability across the US is shown in Figure 2. A 2005 assessment found that about 200 installations have some onsite wind energy development potential, but only a few sites are able to support utility scale wind energy production. Likewise, the 2005 assess-

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[*] It is likely that the energy equivalent of the trash and biomass supplied by military will be considered toward the renewable energy goal if used for offsite energy production. However, it is not clear whether purchasing electricity from utility companies that produce energy from their own renewable sources may be accounted towards the 25% renewable energy goal.

[†] Converting biomass to cellulosic ethanol is another option, but this requires expensive investments and very large amounts of onsite biomass production even for a small-scale refinery facility. Therefore, it is an unlikely option for individual military installations.

[‡] The Food, Conservation, Energy Act of 2008 provides a variety of subsidies to farmers for production of cellulosic biomass and for blending cellulosic biofuels with gasoline. However, current provisions do not allow subsidized production on federal lands. Therefore, if DoD installations choose to supply biomass they have to offer a price low enough to compete with subsidized prices that private-sector producers offer. This may make the biomass option economically unattractive.

ment identified several specific solar technologies. Some solar technologies are potentially cost-effective at almost all DoD sites, but solar photovoltaic can be economic only in areas where electricity prices are high and state utility incentives for solar power are attractive. Besides their economic disadvantages vis-a-vis the energy produced from conventional fossil fuels, both wind and solar energy options have the disadvantage of seasonal inconsistencies (variations) in input supply (wind and sunlight). Timing, storage and distribution of the generated energy are other important logistic issues that have to be taken into account. Moreover, although the land requirements of wind turbines and solar panels may not be significant, they may have serious impacts on non-energy land-use activities, particularly military training. For instance, wind turbines may interfere with or impede military training activities that require low altitude air space (such as helicopter flights) or interfere with aircraft radar. They may also affect the wellbeing and safety of endangered bird species if protected in the same area. Likewise daytime reflections caused by solar panels may obstruct some military training activities.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report documents the development of a framework for a numerical modeling application that can help installation managers develop optimal land-use policies that support competing uses to the greatest extent feasible. Specifically, this framework is designed for modeling landscapes that must concurrently maximize a military training mission, conservation of ecosystem services needed by species at risk, and development of renewable energy resources. These competing land uses have become necessary in recent decades due to emerging regulatory requirements for environmental conservation and strategic requirements for producing renewable energy on military lands.

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15. SUBJECT TERMS

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