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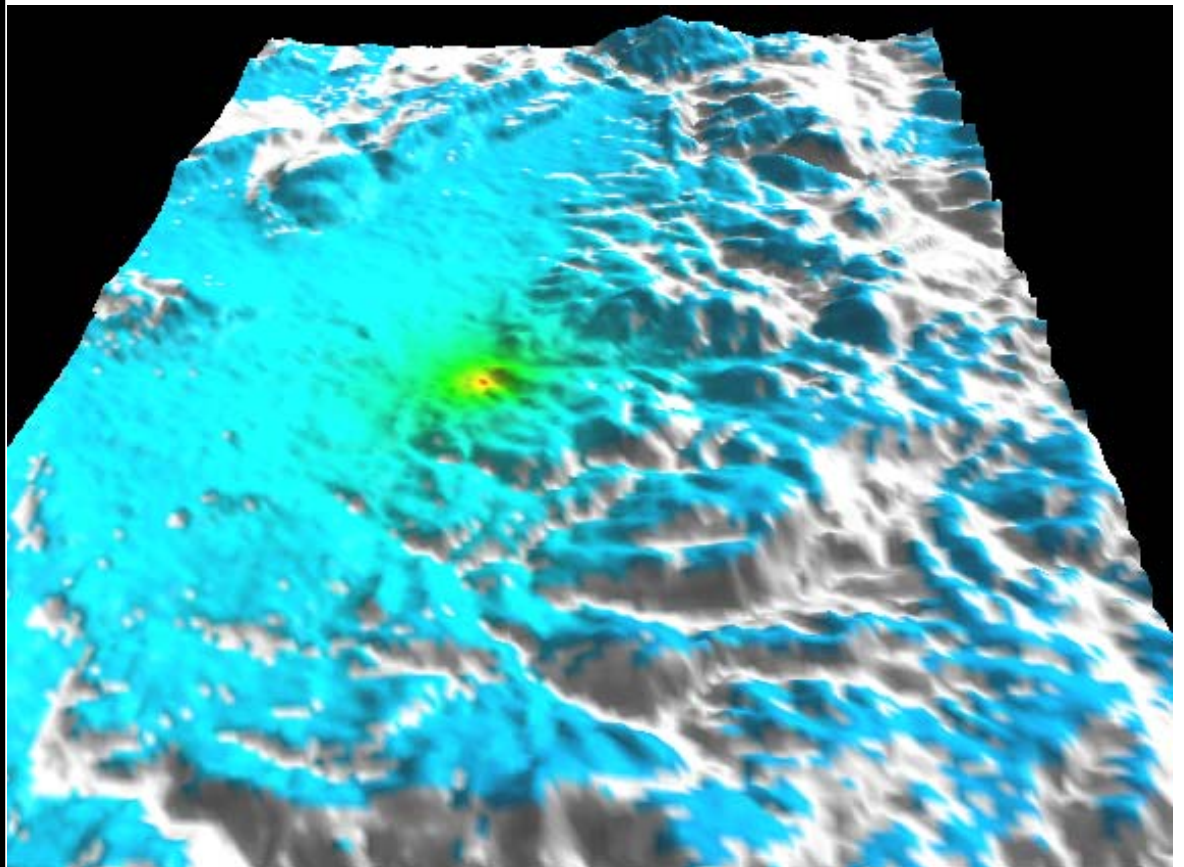


US Army Corps  
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# Approaches for Evaluating the Impact of Urban Encroachment on Installation Training/Testing

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March 2004



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## Final Report

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Under Work Unit # CS-1257, "The Evolving Urban Community and Military Installations: A Dynamic Spatial Decision Support System for Sustainable Military Communities."

**ABSTRACT:** Military installations intended for training and testing purposes have historically been placed in areas remote from human settlements. Over time, land uses and land ownership near installations can change. After such changes, nearby land owners may demand that installations curtail mission-related activities that are incompatible with civilian residential areas. This research was undertaken to provide a foundation for a research agenda to produce software capabilities that predict: (1) the impact of current/planned military installation training/testing activities on surrounding communities, and (2) the impact of projected urban growth on the opportunities to train/test on military installations and other areas. This work identified and analyzed approaches for predicting: urban land-use change off-installations, land-use change on installations, the impact of installation training and testing on surrounding communities, and the impact of urban growth on the future options to train and test on installations. Research and development recommendations are offered to provide future tools that will help regional planners understand the impacts of proposed investments and policies on an installation's training and testing opportunities.

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## Conversion Factors

Non-SI\* units of measurement used in this report can be converted to SI units as follows:

<b>Multiply</b>	<b>By</b>	<b>To Obtain</b>
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	$(5/9) \times (^\circ\text{F} - 32)$	degrees Celsius
degrees Fahrenheit	$(5/9) \times (^\circ\text{F} - 32) + 273.15$	kelvins
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
horsepower (550 ft-lb force per second)	745.6999	watts
inches	0.0254	meters
kips per square foot	47.88026	kilopascals
kips per square inch	6.894757	megapascals
miles (U.S. statute)	1.609347	kilometers
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

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\* *Système International d'Unités* ("International System of Measurement"), commonly known as the "metric system."



## Acronyms and Abbreviations

<b>Acronym</b>	<b>Spellout</b>
ATTACC	Army Training and Testing Area Carrying Capacity
BNOISE	Blast NOISE
CERL	Construction Engineering Research Laboratory
CUF	California Urban Features
EIA	Environmental Impact Analysis
EIS	Environmental Impact Study
ERDC	Engineer Research and Development Center
EPA	Environmental Protection Agency
GIS	Geographic Information System
GRASS	Geographic Resource Analysis Support System
JLUS	Joint Land Use Study
LEAM	Land use Evolution and impact Assessment Model
MIDM	Maneuver Impact Distribution Map
MLEAM	Military Land use Evolution Assessment Model
ModSAF	Modular Semi-Automated Forces
MPRC	Multi-Purpose Range Complex
NEPA	National Environmental Policy Act
NLCD	National Land Cover Dataset
OEA	Office of Economic Adjustment
OneSAF	One Semi-Automated Forces
RFI	Radio Frequency Interference
SARNAM	Small Arms Range Noise Assessment Model
SERDP	Strategic Environmental Research and Development Program
SERM	Sustainability, Encroachment, and Room to Maneuver
USGS	United States Geological Survey

## Preface

This study was conducted for the Strategic Environmental Research and Development Program (SERDP) Office under Project 4A162720A896, “Environmental Quality Technology”; Work Unit CS-1257, “The Evolving Urban Community and Military Installations: A Dynamic Spatial Decision Support System for Sustainable Military Communities.” The technical monitor was Dr. Robert W. Holst, Compliance and Conservation Program Manager, SERDP. The Executive Director of SERDP is Bradley Smith.

The work was performed jointly by the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL) and the University of Illinois’ Department of Urban and Regional Planning. The CERL Principal Investigator was Dr. James Westervelt. The UI Principal Investigator was Dr. Brian Deal. Mr. Bradley P. Smith was the Executive Director, SERDP. The technical editor was William J. Wolfe, Information Technology Laboratory (ITL), Champaign site, Stephen E. Hodapp is Chief, CEERD-CN-N, and Dr. John T. Bandy is Chief, CEERD-CN. The associated Technical Director is Dr. William D. Severinghaus. The Director of CERL is Dr. Alan W. Moore.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL John Morris III, EN and the Director of ERDC is Dr. James R. Houston.



# 1 Introduction

## Purpose

The document provides a starting point and a research path for developing software that will help military installation planners understand the long-term impact of proposed regional planning investments and policies on the training and testing capacity of installations and their associated regions. Many of the increasing restrictions on training and testing are caused indirectly by the development of urban patterns that result incompatible land uses on either side of installation fencelines. Increases in complaints of dust, noise, smoke, and radio and TV interference are directly related to the development of urban patterns near installations. Increases in pressure to protect endangered species and sensitive habitat is directly related to the percent of the habitat in the region on the military installations. Loss of appropriately dark training areas can be lost as city lights follow urban development.

The Strategic Environmental Research and Development Program (SERDP) is funding projects that directly tackle: (1) identification of patterns of urban growth and (2) analysis of those patterns with respect to changes in training and testing capacity and potential. The U.S. Army Corps of Engineers' Engineer Research and Development Center (ERDC) is developing a Web-based system to support military installation planners called "Fort Future," which is adopting the SERDP funded approaches to urban growth projection and impact analyses.

The key question that this document addresses is:

What is the best way to approach analyzing projected urban growth patterns around military installations with respect to changes in community pressure to restrict training and testing, and how might the approaches be different when addressing short (1-5 year), medium (5-15 year) and long (20-50 year) planning issues.

The conclusions drawn will guide the development of military impact analysis software that will be integrated with existing urban growth modeling software to complete the Military Land use Evolution and Assessment Model (mLEAM).

## Background

Military installations with training and testing missions have historically been placed in relatively remote areas where few or no human settlements nearby would be adversely affected by the military activities, and where the large contiguous tracts of land necessary to support assorted large-scale activities were readily accessible. Purchased property boundaries were demarcated with fences and signs. Military training and testing could then take place “within the fence line.” However, some impacts of those activities do extend beyond the fence line.

Figure 1 shows typical impact such as dust (including smokes and obscurants), Radio Frequency Interference (RFI), blast noise, and chemicals, the latter moving off the installation in surface and ground water. Examples of other effects include the possible release of exotic species brought in from remote areas, aircraft noise, lasers, and airborne chemicals.

Even though there is a specific sense of land ownership inside and outside of a fence line, that fence represents changes in ownership of only some of the rights associated with property. Ownership of land is really ownership of a bundle of rights. While installations have assumed the “right” to allow the effects of training and testing to move past the fence, they often do not have legal (*de jure*) authority to do so. However, continued use of surrounding “unowned” areas can establish a *de facto* situation that courts will allow to endure. Owners of surrounding lands might include other government agencies, farmers or ranchers, and commercial enterprises such as timber companies.

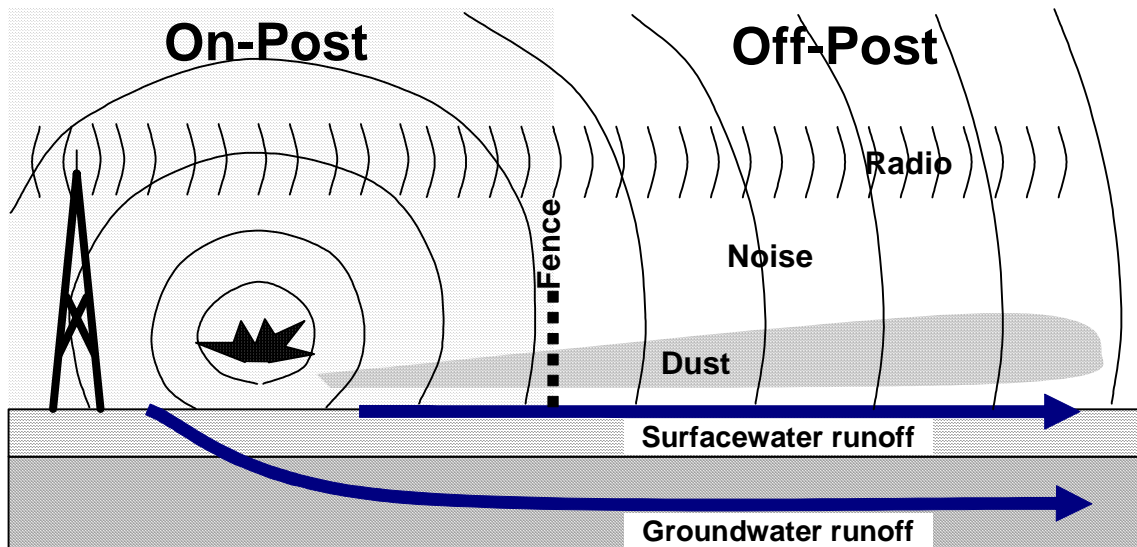
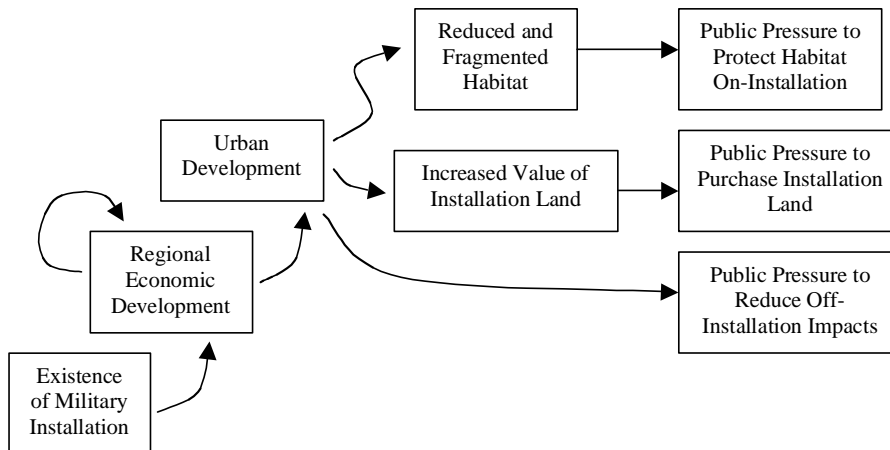


Figure 1. Installation land use outside the fence line.

The installation's use of this land outside of the fence is generally not called into question because the landowners do not perceive that the use causes any "injury" to the landowner or reduces the value of the land. Over time, land uses and land ownership near installations change. After such changes, owners can claim that the land use historically enjoyed by the installation are in fact not rights owned by the installation and that the uses must stop. For example, occupants of a residential neighborhood recently developed near an installation may demand that blast noise cease, that dust-producing activities be stopped, and that interference with radio and television reception be ceased.

The installation itself can be directly involved in the chain of events that continues over many decades and that results in pressures that reduce the ability of the installation to perform the training and testing for which the installation was created (Figure 2). Installations commonly provide an influx of government funding into the local economy, which contributes to regional economic development. That development can be self-sustaining and can result in the development of an economy that, over time, depends less and less on the persistence of the installation.

Local economies are made possible by the location of workers that require housing. The creation or expansion of businesses and housing requires land, and results in urban development. That development, as discussed above, can directly result in pressure on the installation to reduce off-installation impacts. Since urban land is more valuable than undeveloped farm, range, or natural land, urbanization can cause changes in the market value of installation land. This can result in pressure to sell installation land to developers and local communities.



**Figure 2. Causal links resulting in decreasing installation training/testing capacities.**



**Figure 3. On-installation forest habitat has been retained (south) while off-installation forest has been lost (north).**

Finally, while installation land might originally have been carved out of a vast area of undisturbed habitat, regional economic development can indirectly and cumulatively result in the destruction of surrounding habitat. Habitat remaining within the installation properties thus becomes increasingly important to maintain local indigenous populations—especially of threatened and endangered species. Figure 3 shows an example of an installation boundary where land on-installation (south of the white “fence line”) is wooded with native species and the land off-installation has been significantly changed through farming and grazing on farms and ranches. The result can be a public demand for installation training and testing to be moderated to support the maintenance of remaining native bird, animal, and plant species.

A number of efforts have addressed the notion of exploring alternative future scenarios in areas/regions surrounding military installations with respect to the impact on the military mission. Adams and Steinitz conducted an extensive study of the urban growth around the Southern California coast installation, Camp Pendleton (Adams and Steinitz 2000) and then for the Fort Huachuca area (Steinitz, Arias et al. 2002). The Corps of Engineers and the Strategic Environmental Research and Development Program (SERDP) are supporting the development of urban encroachment prediction and military impact analysis software. One of those products is part of the Sustainability, Encroachment, and Room to Maneuver (SERM) program

(Westervelt 2003). The University of California at Berkeley conducted a study for the California Technology, Trade, and Commerce Agency to assess key California military installations threatened by urban growth (Landis, Reilly, et al. 2001).

Camp Pendleton Marine Corps Base provides one of the most dramatic examples of urban growth that has led to regional contentions. At approximately 200 square miles and about 17 miles of shoreline, Camp Pendleton provides jobs for about 60,000 people in 3800 buildings and habitat for 400 species of birds and animals—including 18 Federally listed endangered and two threatened species. Growth of suburban beach communities now borders the base at the north and south and is enveloping the installation to the east. Training and testing has been substantially curtailed due to the dramatic settlement of the southern California shoreline. Loss of habitat due to this development highlights the ecologic importance of the remaining habitat on base. Neighbors are sensitive to the effects of training on their lives. Developers indicate that the economic potential of the Pendleton land is much greater than the value associated with the current military use. Sustaining Pendleton's ability to support its mission continues to be a challenge in the face of the urban development.

To address such challenges, the State of California passed the Defense Retention and Conversion Council Act, which facilitates planning interactions among communities and military installations. The Council is currently authoring a number of reports to identify how to best maintain military installations in that state through continuation and development of policies that will help ensure compatible land uses surrounding installations.

An important DOD-level report (entitled *Sustainable Planning: A Multi-Service Assessment 1999*) aggressively identifies standards and approaches for sustainable planning across all services (1999). This document takes standard principles of sustainable development and identifies, evaluates, and promotes DOD policies that addresses these principles to sustain military training and testing within the context of the natural systems the nation depends on for its future.

The DOD Office of Economic Adjustment (OEA) promotes and supports the Joint Land Use Studies (JLUS) program. The JLUS program and purpose are:

JLUS is a cooperative land-use planning effort between affected local government and the military installation. The recommendations present a rationale and justification, and provide a policy framework to support adoption and implementation of compatible development measures designed to prevent urban encroachment; safeguard the military mission; and protect the public health, safety, and welfare.



JLUS grants to installations and local communities have been very useful in developing and maintaining common regional visions among co-located municipalities and installations.

### ***Consequences***

Incompatible land uses involving military installation activities have been addressed in the following ways:

- Firing ranges can be moved away from boundaries.
- Ranges can be operated at lower frequency (only at specific times).
- Military air traffic hours can be reduced.
- Military air zones of operation can be reduced.
- Bombing ranges can be relocated.
- Bombing ranges can be shut down.
- Night training can be less effective with increasing city lights.

However, these responses to developed incompatibilities can be expensive and can leave troops inadequately trained. Hindsight suggests that many incompatibilities could and should have been avoided. In so doing, training and testing could have proceeded in a more efficient and cost effective manner. This hindsight enables us to more carefully scrutinize trends in land-use changes on and around installations, and changes in training/testing doctrine and equipment that might lead to future land-use incompatibilities.

### ***Necessary Steps***

It becomes necessary and appropriate for military installation managers to become deeply immersed in the drivers that shape the future land-use patterns on and off installation. An understanding of these processes can enable installation managers to more intelligently participate in the development of regional land-use policy development and ownership patterns that will optimize the training and testing opportunities available to installations for many decades to come. Two basic, necessary steps are to:

1. Identify potential future land-use conflicts
2. Evaluate alternative policies to avoid conflicts.

To identify potential future land-use conflicts, each installation needs to be evaluated with respect to alternative on and off-installation futures. Questions that need to be addressed include:

- What are the potential and anticipated missions of the installation 5, 10, 20, and 50 years in the future?
- What are the on-installation land-use requirements associated with these potential missions?
- What are the off-installation impacts associated with the mission?
- What is the future for population growth in the areas adjacent to and near the installation?
- How will per-capita income and associated expected standards of life change in the future?
- How will land-use patterns change off-installation?
- What changes in local, state, and Federal laws are anticipated that might affect land-use patterns?

### ***Future***

What challenges can we anticipate in the future that may arise out of developing land-use incompatibilities? Off-installation changes are primarily associated with increases in population and standards of living. Population increases in areas close to military installations can result in more complaints related to noise, dust, smokes, and water/air quality. Increases in personal income allow people to build or buy housing in remote areas, thereby decreasing local densities. This can lead to pressures to preserve remaining habitats that exist on-installation. Therefore, it becomes very important for military installation planners to pay close attention to trends in population, settlement, and land-use conversion, and to the ways those trends may affect lands immediately adjacent to installations.

On-installation changes (“inside the fence line”) are equally important. In the immediate future, installation land-use patterns can be predicted from the current patterns. Installations tend to change slowly because of the expense involved in rearranging military land-use patterns. In the 5- to 10-year planning horizon, installations can see the development and upgrade of firing ranges and test areas. The acquisition and use of emerging, long-planned, weapon systems and vehicles make it necessary to augment installation capabilities by changing existing training and testing areas and to occasionally construction completely new areas, like multi-purpose range complexes (MPRC). As the political structures that connect the nations of the world evolve, doctrine that guides military behavior in conflict must also evolve. Doctrine changes must be reflected in training requirements, which can result in changing land-use patterns.

Finally, the laws of the United States and its states, counties, cities, and other municipalities also continually change to reflect the will of the people with respect to our use and treatment of natural resources, species, and recreational areas. New laws can have significant and long-lasting effects on the land-use patterns both on and off installations.

Tremendous progress is being made at installations to develop goals, programs, funding lines, and authorizations to address sustainable installation planning at many levels. Fort Bragg, for example, has established goals to: (1) dramatically increase recycling and reuse to severely limit the amount of trash generated, (2) decrease the per-capita consumption of water through conservation, reuse, and recycling, (3) decrease energy costs through smart applications of technologies and efficiencies, and (4) work closely with local counties and cities to define and achieve a common desired future for the region.

## Objectives

This objective of this work was to provide a foundation for a research agenda to produce software with capabilities to: (1) predict the impact of current/planned military installation training/testing activities on surrounding communities, and (2) predict the long-term impact of projected urban growth on the opportunities to train/test on military installations and other areas. A secondary objective was to consider approaches to conducting urban growth projections.

## Approach

The sustainability challenges associated with urban growth around military installations are very real for many installations today and certainly many more in the near future. DOD recognizes the challenge and has funded analyses of the situation and, through the JLUS program, funds joint planning with local communities. The focus is on the future—specifically analyses of alternative futures with respect to the goals and aspirations of numerous stakeholders.

This document identifies and analyzes approaches for predicting:

- urban land-use change off-installations (Chapter 2, p 10)
- land-use change on installations (Chapter 3, p 20)
- the impact of installation training and testing on surrounding communities (Chapter 4, p 30)

- the impact of urban growth on the future options to train and test on installations (Chapter 5, p 42).

The document concludes with research and development (R&D) recommendations to provide future tools for supporting the designs of the installations of the future.

## Scope

The encroachment analyses discussed in this report are intended to support the continued operation of DOD installations with missions that may be adversely affected by nearby urban growth. Specifically, this work attempts to describe and explain: (1) how to recognize and anticipate the dynamics of urban growth in areas neighboring DOD installations, (2) how to identify off-installation areas that may be affected by on-installation training and testing, and (3) how to identify the ways in which urbanization may limit training and testing opportunities on-installation.

## Mode of Technology Transfer

It is anticipated that the results of this work will form the basis for planning further ERDC research in support of encroachment analyses. This report will be made accessible through the World Wide Web (WWW) at URL:

<http://www.cecer.army.mil>

## 2 Approaches for Predicting Off-Installation Land Use

Changes in land use *off-installation* are the primary driving forces behind complaints of military installation “encroachment” — especially complaints associated with noise, dust, RFI, and light. Similarly, changes in land use off-installation can reduce off-installation habitats for sensitive species, which can result increased pressure to protect neighboring habitats for those species that still exist on-installation, by reducing installation training/testing.

Installation managers need to understand that a number of specific indicators can predict a potential for changes in off-installation land-use. The answers to some key questions will help installation planners select from a variety of approaches for predicting changes in off-installation land use. It is essential to know where people will be residing, since the level of complaints about military activities is associated with where people are within the footprint of direct and indirect impacts of training/testing. It is also important to be able to predict the pattern of residences many decades into the future because investments in military installation infrastructure require many decades of use.

Not *all* information related to urban growth patterns relates to questions of “encroachment.” For example, current housing prices, residents’ income, and locations of neighborhood streets, and, indeed, most short-term changes, have little bearing on the potential for off-installation land-use changes. Short-term changes are a function of economic and environmental sensibilities, of the personalities and motivations of landowners and developers, and also of the current local political climate.

The sections that follow describe a number of different approaches for predicting the potential for encroachment on military installations, ranging from simple graphical extrapolation to spatially explicit landscape simulation modeling.

### Historic Change

The simplest approach for predicting urban growth is to look at past growth patterns. The U.S. Geological Survey (USGS) has developed the national land cover

dataset (NLCD) for 1992 and 2001. Viewing maps of an area for these two moments in time illustrates a decade of actual growth, which provides a basis for an “educated guess” at future growth. Similarly, the Census Bureau publishes historic population facts and future projections for the United States by county. Graphing these provides another source for estimating the potential future urban growth challenges surround installations.

## Population Projections

Complaints about military “encroachment” typically come from people living near installations. The potential for complaints is a function of the training/testing on the installation and the number of people living close to that activity. It is reasonable to assume that, as the number of people living within a certain zone of installation influence grows, the number of complaints and the probability of impacted training/testing capacity will also grow.

The steps involved in this approach are:

1. Determine the zone of influence of the installations training/testing activities. This will vary according to the particular training and testing.
2. Divide the zone of influence into a small number of bands (optional). This can accommodate differences in growth rates at different distances from installations.
3. Collect population data for the census tracts within the zone of influence over the course of 50 or more years.
4. Collect Census bureau population change predictions for each census tract.
5. Plot total population within each zone over the past 50 years and the anticipated next 30 years.

This approach is inexpensive and relies on readily available data. Some geographic information system (GIS) analysis and overlay can help identify the census tracts, but this can be accomplished using paper maps. Results can be rapidly generated.

## Analysis of Land Developer Holdings

In the near future (e.g., 10 to 15 years) development is likely to happen in direct response to the activities of land investors that have already taken place. Identifying the land holdings of investors and the political and economic activities of these landowners will help identify the near-term land-use changes.

The benefits of this approach are that it specifically captures the plans of the local influential landholders and will provide the foundation for making very accurate local predictions. Land developers and investors can already own land that, through a decade or more of their efforts to steer local policy and investment, is likely to be developed within two decades. This approach may have many drawbacks. Collecting this information is arduous and expensive. It requires access to public records, completion of surveys by landowners, or direct interviews of landowner. However, a detailed understanding of the local stakeholder holdings and interests can be very useful in participating in regional planning exercises.

## GIS Land-Use Projections

The population projection approach relies on projections automatically generated at national Census Bureau offices and cannot account for local land ownership patterns, local geography, or local benefits associated with state-level transportation and infrastructure investments. The application of GIS data and analysis techniques can begin to address these shortcomings.

The steps involved in this approach are:

1. Develop a GIS database that contains:
  - a. urban population growth predictions for the region
  - b. historic and current land use
  - c. no-growth areas
  - d. employment centers and road/highway network
  - e. installation outline
  - f. training/testing range outline
  - g. undevelopable areas (high slope, wetlands, national and state parks, water, etc.).
2. Generate travel-time maps to nearest business area.
3. Expand city along travel-time contours to accommodate population/economic projections—avoiding no-growth areas. Simultaneously, increase city density.

The primary advantage of an approach that applies GIS data and techniques is that it can use local, spatially explicit environmental, social, economic, and geographic considerations to improve the urban growth analysis. This approach can be costly. It requires the expertise of a GIS technician and knowledge of urban growth and urban gravity modeling. Collection and preparation of GIS data can be challenging.

## Urban Growth Simulation

Spatially explicit hedonic (attractiveness) model approaches can be used to identify the value of land for different land uses based on the combination of a number of factors that contribute to the overall attractiveness. The previous approach can be expanded by developing a spatially explicit context for each geographical location. The attractiveness of each location for human settlement development can then be considered in standard GIS overlay analyses, when in the process of allocating those changes in land use. This can be done all at once, or over a series of time steps:

1. Develop a GIS database that contains:
  - a. Urban population growth predictions for the region. The United States Census bureau publishes 25-year population projections for each state and current/historic population information at the county level. A simple combination of this information can be used to estimate population growth for one or more counties in a region. This can involve doing a trend analysis using historic census information.
  - b. Historic and current land use—housing density and value. The USGS sponsored National Land Classification Data (NLCD) program provides standard land-use classification maps for 1992 and 2001 for most of the United States. This data set can be augmented with state or local land cover information.
  - c. Road networks.
  - d. Installation outline.
  - e. Training/testing range outline.
  - f. Employment locations represented as the number of jobs available for each location.
  - g. Slope.
  - h. Zoning plan, if available.
2. For each location, calculate:
  - a. Proximity to high density urban.
  - b. Proximity to low density urban.
  - c. Proximity to natural areas, such as parks, forests, wildlife areas, etc.
  - d. Proximity to city services (schools, library).
  - e. Proximity to employment areas.

This step characterizes each location (grid cell) with respect to things that make the location attractive for housing. This must be done for each land-use type being considered.
3. Calculate attractiveness of each location for each land use with respect to:
  - a. High density urban (jobs).
  - b. Low density urban.
  - c. Suburban.



- d. Manufacturing.
  - e. Habitat, parks, refuges, open lands.  
GIS based analysis using, for example, an inverse-distance-weighting algorithm can be used to identify the level of access to each of these services or types of locations. The relative attractiveness of services/locations can be computed using multi-regression analysis holding recent development as the dependent variable. Relative attractiveness can also be developed using input from local stakeholders.
4. Project urban growth using the spatially explicit current state of the area in question and the estimates of population growth. Sample steps to accomplish this are:
    - a. To generate a change probability value, at each location in the map (e.g., a grid cell) calculate the overall attractiveness with respect to the associated proximity information, the current state of the cell (e.g., slope, current land use, etc.), state of surrounding cells, and regional needs for land-use change. Capture this in a running change probability state variable.
    - b. Repeat to generate a time-series of urban growth.
    - c. At appropriate intervals in this simulation, recompute any attractiveness maps that are based on information that has changed on the landscape during simulations. For example, the development of new job centers changes the job attractiveness map.
    - d. At appropriate intervals in the simulation add in the scheduled creation of roads, highways, parks, zoning, and other regional policies and investments that are being tested.

The primary benefit of this approach over the simpler GIS approach is that this approach can more accurately project the pattern of future land use because it considers the regional context of each location more completely. This increases the cost of the analysis, especially of the validation of the relative importance of each of the proximity, land definition attributes, intensive computation involved in analyzing each location with respect to its regional setting, and of the intensive simulation of land-use change. However, it is a fairly cost-effective step to move from the simpler GIS analysis to this one as most of the cost is in the development of the GIS database.

## Urban Growth Simulation Models

Many urban growth simulation models have been developed by a variety of different organizations for purposes ranging from research, education, city planning, and regional planning (EPA 2000). Each captures a different combination of the factors

involved in growth to answer certain questions. Models can be separated into two distinct spatial scales: city and region. Models such as DRAM/EMPAL and MEPLAN are popular in the United States and overseas, respectively, and focus on identifying growth by income and housing costs. These and other models focus on the city itself and deal with growth over the course of a couple of decades.

Regional models concern themselves with addressing questions regarding gross growth patterns over many decades and the associated implications with respect to environmental measures. Military installation encroachment questions are asked at this scale and include:

- Where are people likely to be living in the next 50 years?
- What percent of important habitat in the region will be on local military installations?
- What limitations will regional land-use patterns place on military installation activities?

Models (EPA 2000) that specifically address regional growth patterns over the course of many decades include: CUF-2, SLEUTH, Smart Places, "What If?", and LEAM. CUF-2 is the California Urban Futures model, version 2. This model employs a set of econometric models to project future population, household, and employment. The landscape is gridded into 1-hectare developable land units (DLU). The value of each DLU for each competing land use is computed and land-use change is based on comparing these relative prices. SLEUTH derives its name from the types of raster GIS data inputs: slope, land use, exclusion, urban, transportation, and hillshading (Clarke and Gaydos 1998). It is a cellular automaton model that updates the state of each cell in each time step based on the state of each cell and its immediate neighbors. LEAM, the Landuse Evolution and impact Assessment Model, takes a similar approach (Deal 2003). Using a 30-meter grid-cell cellular automaton approach, each cell is assigned a variety of development attractor values. The landscape evolves based on equations that assign future cell states based on the state of cells and their immediate neighbors. Smart Places is designed to be relatively easy to use by those familiar with ESRI's ArcView GIS as it is implemented as an extension to that system (Croteau et al. 1997). "What If?" is a standalone product that used ESRI shape files (Klosterman 2003). Parcels are represented as entities using the ArcView shape files and they change through time based on the growth needs of the region, the state of the parcel, and the state of its neighbors.

To be useful for projection, all urban growth models must be calibrated, which involves a process that can be time consuming and difficult. The SLEUTH model has

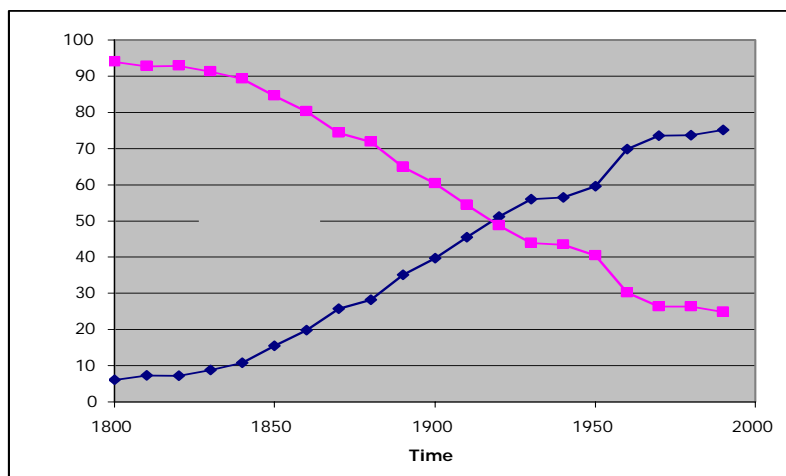
been calibrated by testing thousands of combinations of coefficients using very fast computers. LEAM model calibration has been accomplished using a statistical technique (Deal 2003). These and other models can be run for a location using default calibrations and can be useful for educational purposes and for generating thoughtful conversation among stakeholders and other participants.

Many land-use change models have been developed and are being used to test alternative land-use policies with respect to their impact on future land patterns in and around cities and towns (EPA 2000). The Corps of Engineers is adopting the Land Evolution and Assessment Model (LEAM) to help evaluate how alternative regional policies and land ownership patterns affect future land development. The primary interest is to help minimize future land-use conflict resulting from the development of new uses in areas that are and will be impacted by military training and testing activities.

## **Caveats**

Prediction of urban growth is more art than science, but extremely important as part of the necessary conversations among stakeholders. In the short term (e.g., up to 10–15 years) urban development will likely proceed along the lines established by stakeholders—especially landowners and those that invest in anticipation of development. Strategic purchases of land are followed by aggressive and persistent pressure on and participation in the political processes concerned with infrastructure investments and zoning issues. Urban growth models developed to predict the short-term patterns must capture the goals, ambitions, and expectations of landowners, investors, and the political processes. Modeling at this scale will therefore not only be extremely data intensive, but the model can actually change the process and therefore the future.

At the other extreme, 30 to 50 years (or longer), unanticipated changes in technology can dramatically change the way land-use patterns develop. The advent of the automobile allowed unprecedented connections of cities to surrounding agricultural land. Adding engines and motors to the farm continues to reduce the farm labor requirement and the percent of population in the cities has jumped from 6 percent in 1800 to 40 percent in 1900, to 75 percent in 2000 (Figure 4). Predicting the technology drivers that will continue this trend or begin reversing it is challenging and exciting. For example, we may be on the verge of having sufficient Internet bandwidth to allow businesses that rely primarily on information exchange to support remote employees to a far greater extent.



**Figure 4. Rural-to-urban population shift.**

Imagine a home office that has a wall window that can be virtually shared with anyone anywhere with a similar device. With a flip of a switch people across the world can virtually share an office space as needed — nearly eliminating any need for businesses to support a central office. When the window is not being used for business the office worker can switch to any of hundreds of live scenes from across the world, the Moon, or Mars. Without the need for physically going to work, the rural landscape may see a dramatic infusion of business people. What technologies will really completely change the patterns of human settlement?

Another caveat is that the potential for a single model to predict urban growth anywhere is very limited. Differences in physical and economic geography make it necessary to calibrate any model for the local circumstances. Differences in culture, demographic patterns, and personal income levels will result in different overall settlement patterns. The poor tend to live more densely and simply while the rich tend to own and occupy land at much lower densities. Therefore, calibration to account for current, historic, and anticipated demographic makeup of populations is necessary. Urban growth projection models must be applied very carefully.

## Comparison

Table 1 lists the approaches (described in the preceding sections) for projecting urban growth side-by-side, for easy comparison. They are roughly ordered from least to most expensive and from least to most accurate. Where possible, the least expensive options that provide useful information should be employed.

**Table 1. Summary of approaches for projecting urban growth.**

Approach	Benefits
Historic Change: With GIS, access and display USGS NLCD data	Historic land use facts
Population Projections: Collect and analyze census tract level data	Historic population facts
Analysis of Land Developer Holdings: Collect local landowner holdings. May be paper. May be difficult to find and process.	Provides a picture of the intent-to-develop over the next 10–15 years.
GIS Land Use Projections: With GIS, create growth potential contours and “grow” cities to match population projections.	Can take into account differences in geography.
Urban Growth Simulation: Like GIS Land Use Projections, with the addition of long simulation runs.	Allows a landscape to evolve – capturing feedback of past growth on future growth.

## Recommendations

The appropriate approach depends on the goals, funding, available time, and need for accuracy. Some sample decisions that might need urban growth analyses follow.

### ***National Comparison of Military Installations***

At this scale, nationally available data sets must be relied upon to: (1) provide fairness in comparison, and (2) minimize the cost of data collection. Fortunately, much national-level data is available through such organizations at the U.S. Environmental Protection Agency (USEPA), USGS, U.S. Census Bureau, and others. However, much important information is still not available including land ownership and land value. The information that is available is provided in a form that is provider-centric rather than location-centric.

For example, a web site will offer information on a particular theme for the entire country, but information from dozens of sites must be patched together to create a full picture of a particular location. The cost of integration is left to the data user. Eventually a Web interface should be developed that allows one to download a set of maps for a user-chosen area that are all in the same coordinate system and the same GIS format. The least costly way to compare the susceptibility of installations to urban encroachment is to use on-line U.S. Census Bureau population predictions and population trends for states and counties.

The next step is to do some simple GIS-based land-use projections to get some local context into the encroachment threat. Create boundaries of influence around military training lands of a size appropriate for the particular training. Create growth

bands around nearby cities and towns to represent anticipated growth. Overlay these two maps to identify areas of encroachment concern. The most expensive aspect of this analysis is the labor-intensive regional data collection.

### ***Long-Term Analysis of Encroachment Concerns Around an Installation***

Regional planning is a multi-decade activity that often results in investments that have long-term implications on urban growth patterns. Growth can be very different location-to-location depending on unique historic cultural, climate, topography, and economic differences. Application of urban growth simulation models can be very important for predicting the implications of alternative regional investments and policies with respect to achieving specific future goals. The primary costs in such analyses result from interactions with local stakeholders and acquiring and processing spatial data. Simulations, though computer-intensive, are inexpensive.

### ***Short-Term Analysis of Encroachment Concerns Around an Installation***

Over the course of one or two decades, the specific land-use changes that will occur are based largely on the plans and dreams of landowners. Whether or not development occurs in two areas primed for urban growth depends on the goals and aspirations of the current landowner. Differences in age, health, belief, and ambition will cause one owner to develop or sell to developers while another will not. GIS hedonic analyses can be used to identify the relative values of land for development, but such an analysis must be heavily augmented with surveys of local landowners. Spatially explicit simulation models may provide little predictive power over the course of one or two decades.

### 3 Approaches for Predicting On-Installation Land Use

If future land-use patterns on military installations can be predicted, evaluation of the impact of the region on the ability of the installation to support future training and testing would be straightforward. Unlike off-installation land use change, very few players are involved in the development of the land. Land-use patterns are based on centralized historic and predicted construction, maintenance, use, and operation decisions. These decisions involve responses to actual and perceived needs at a number of different scales in time and space. Major construction projects result in the placement of buildings, infrastructure, and transportation networks that persist far into the future and, in turn, influence the timing and placement of minor construction projects. Can future land development be predicted within an installations' fence line and if so, how?

Four representative approaches are:

1. Ask the Experts.
2. Maintain Current Patterns.
3. Apply Land Use Suitability Modeling.
4. Use Doctrine-based creation of patterns.

The following sections discuss each approach, giving a general description, an evaluation of benefits, and some examples.

#### Ask the Experts

##### *Description*

Associated with each installation is a master planning office, which coordinates and manages long-term development plans for installations. Participants in the planning process include top leadership at the installation, supporting regional offices, and headquarters level installation planners. These participants are entrusted with the power to develop the installation to optimally meet the military requirements.

Collectively and individually, these participants control the future of the installation's land use and are in the best position to "predict" the future.

### ***Costs/Benefits***

The primary benefits of this approach are that: (1) no computer simulations need be developed and run, and (2) the answer is "politically correct." That is, the experts will not be challenged with the predictions.

## **Maintain Current Patterns**

### ***Description***

Land-use patterns at military installations can and should persist over time. Training land patterns at Fort Benning are based, in part, on the forest management compartments established by timber companies before the installation was created. Each compartment represented tracts of trees at similar stages of growth that provided different training opportunities. Roads, even though only dirt, had been constructed to get logging trucks in and out of the forest. Of course, it made economic sense for the installation to use these roads. The original placement of the roads took into account the terrain and possibly followed trails that preceded the timber companies.

Once an installation takes over management of training and testing lands, certain infrastructures are added to support the associated objectives. Areas are hardened to support staging, targets are established (some at great cost), roads are reinforced, water and electricity are provided, and various buildings are constructed. Training and testing objectives are then serviced by the natural resources. Those involved become accustomed to using the areas and choose to return again to these known locations. As a result, the use of military installation training lands is fine-tuned through that practice in physical and psychological ways. This helps ensure that the patterns of training and testing uses will be repeated, making it easy to predict training use distribution in the near term.

### ***Examples***

The Army Training and Testing Area Carrying Capacity (ATTACC) program provides a formal methodology for identifying the amount of training or testing that Army lands can accommodate. It is part of the Integrated Training Area Manage-



ment (ITAM) program, which supports the monitoring and management of Army installation training and testing areas (AR 350-4, 1998). To identify carrying capacities for training areas, it is necessary to understand and predict the pattern and intensity of the environmental footprint resulting from the associated training and testing. The current approach used in ATTACC is the Maneuver Impact Distribution Map (MIDM) methodology (Sullivan and Anderson 2000). The MIDM approach uses vegetation disturbance field measurements, satellite imagery, topography, training use, and vegetation maps in a GIS, resulting in the creation of a training “probability surface.” Measured disturbance is correlated with the information contained in the other GIS maps using a variety of techniques (e.g., regression, logistic regression, neural networks). Once a satisfactory correlation is obtained mathematically, the resulting model is applied to every location (grid cell) in the installation’s GIS database to create a training disturbance map. This map captures the current pattern of training that is expected to persist into the near future barring significant changes in the mission of units stationed at the installation. Actual training intensity for a given time period is then a function of this “probability surface” and the total training conducted in that time period. The basic impact pattern persists, but the intensity changes with use.

### ***Costs/Benefits***

Maintaining current patterns into at least the near future is, in most cases, accurate, acceptable, and easy to implement in any model of military installation land use. There is essentially no cost. However this approach becomes less acceptable with doctrine and weapon system changes, and with restationing.

## **Apply Land Use Suitability Modeling**

### ***Description***

In a free-market system, the attractiveness for development is reflected in the value of land. There is a value of each parcel of land for supporting any type of land use. That value is a function of the intrinsic suitability of the parcel for the land use and the local need for developing the particular use. Shopping centers, for example are located on relatively level ground with many acres of contiguous space at intersections of major roads or highways that provide short trips to people’s homes. Once there are adequate shopping facilities in an area, the remaining sites that meet the above requirements may be associated with other local needs. As land uses are established through the investment of construction, the land-use suitabilities and as-

sociated values of nearby land can and will shift. In fact, the conversion of one parcel of land to a new land use can negatively affect the suitability of other already developed parcels. Planning and zoning are often used to direct development towards a specific future urban or regional design to avoid or ameliorate these situations.

Some areas across the United States show little planning and zoning, while other areas are strictly planned. The trajectory of urban and regional development therefore follows from a combination of evolving free-market values of land parcels and local planning and zoning efforts.

Military installation land-use patterns also evolve based on the immediate value of land parcels for alternative uses and mid- to long-term installation master plans. Figure 5 captures the process beginning with a current land-use scenario and a master plan. The first step is to establish the suitability and value of land to support alternative uses. That, along with guidance from the master plan, is used to site new land-use requirements. The result is a new pattern of land uses that, in turn, alters the suitability and value of areas surrounding the changed locations.

This process can be formalized at varying levels of detail for military installation planning. Land uses may be classified simply with very few specified uses (e.g., cantonment, training, testing, water, and natural), or they may be classified into detailed categories, which might include specific types of training and testing, specific building types (office, mess hall, store, vehicle cleaning, barracks), and specific land uses (park, golf course, exercise area, marching field, parking, storage, etc.). A computer-based simulation modeling system can capture the processes outlined in Figure 5 to help predict changes in on-installation land-use patterns.

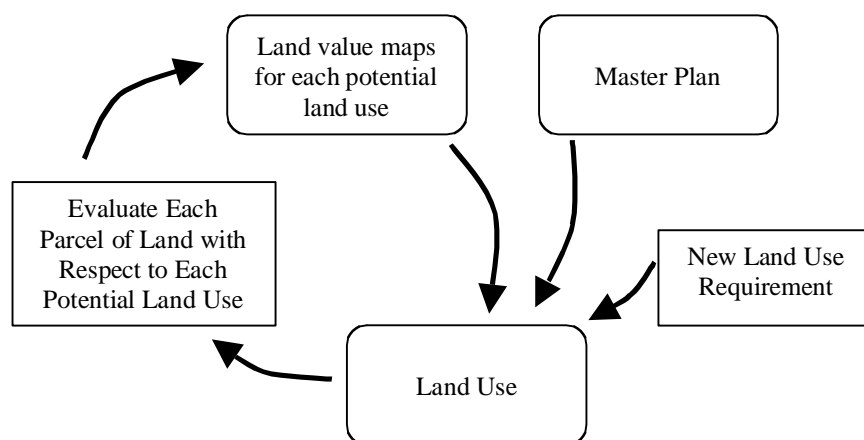


Figure 5. Land use change dynamics.

## ***Examples***

This document considers the needs to project military installation on-installation land-use patterns into the future. Of equal importance is the need to project land-use pattern evolution outside and adjacent to military installations. On and off-installation patterns affect and influence each other. Neither can be considered alone. To address off-installation urban growth pattern development, the ERDC has developed the Landuse Evolution and Assessment Model (LEAM), which could also be useful to assess on-installation land-use development. LEAM uses a cellular automaton approach in which the landscape of interest is divided into regular patches of land (grid cells). The state of each cell is a function of its state in the recent past (last time step), the state of its immediate neighbors, and equations and logic that capture the dynamics that lead to the future state. The LEAM algorithms predict the probability that each grid cell will change from one land use to another and then stochastically initiate land-use changes.

UrbanSim (Waddell 2002) provides another example of a software system that evolves urban landscapes. It captures exogenous public policy decisions as input and then simulates the evolution of the landscape based on household, worker, business, and developer decisions. Households choose to move or stay, and decide where to move based on desired housing type and housing prices. Similarly, businesses choose to move or stay and identify required office characteristics based on the type of business and its number of employees. Developers decide where to place new development, to do redevelopment, and to establish land uses and use densities. Public policy inputs include land-use plans, development fees, infrastructure, mass transit, highways, and various fees and regulations.

Development of on-installation land-use pattern evolution models could be based on the capabilities of LEAM and UrbanSim. At each time step, the operations and considerations outlined in Figure 5 would be addressed in detail. Predictions of future land use patterns could then be evaluated with respect to the impact on planned training and testing and/or to changes in training and testing opportunities.

## ***Costs/Benefits***

There are no significant benefits of this approach. All available simulation models have been developed for multi-ownership free-market situations—which do not exist on installations.

## Use Doctrine-Based Creation of Patterns

### *Description*

Associated with each weapon system and military units are specific military engagement doctrines and the training required to gain and maintain competency. This training must be accomplished, at least in part, in realistic battlefield conditions. The training areas at military installations provide this opportunity, but the quality of the training degrades because of the impact of training on those areas. It is necessary for the natural vegetation recovery processes to develop the training areas into landscapes that provide realistic natural settings. The actual footprint of training exercises on a training area becomes important in the evaluation of the ability of the training area to support a certain amount of training within a particular period of time.

If new or different training activities are going to be scheduled for a particular training area, computer simulation may be helpful in identifying the traffic patterns that a particular exercise will generate. Through simulation, it then becomes possible to better estimate “carrying capacities” of training areas.

### *Examples*

The Modular Semi-Automated Forces (ModSAF) and now the One Semi-Automated Forces (OneSAF) Objective System products provide force-on-force simulation models that accurately capture weapon system capabilities, doctrine, and environmental constraints to generate vehicle movement patterns. Although these software simulation packages were developed to assist in the training of soldiers, they can be potentially useful to predict environmental impact patterns that result from repeated reuse of training areas to accomplish specific training objectives using vehicles.

### *Costs/Benefits*

The ability to accurately predict how a training exercise will impact a landscape (training area) using accepted military software environments should provide an acceptable tool for assisting in the optimal use of military training lands. OneSAF embodies accepted training doctrine that can be applied virtually to real and artificial landscapes. Applying such software does require significant computational horsepower however and will likely necessitate the use of supercomputers.

## Implications of Time and Space Scales

The approaches to predicting future land-use patterns on military installations outlined above are each optimally useful at different scales of time and space (Figure 6). The “Maintain Current Patterns” approach is optimally useful for predicting training intensities in the next few years. Training that has taken place has left obvious patterns on the landscape and that training can be expected to use and enforce those patterns. The “Ask the Experts” approach can be useful in the development of installation land-use master plans. Such plans are the result of collaborations among soldiers, engineers, land-use planners, ecologists, and others. The plan captures the expertise of this broad array of individuals representing different agencies and disciplines. Therefore, these individuals and the collective plan are extremely important for predicting land-use changes in the 1–10 year time frame. The “Land Use Suitability Modeling” approach is probably not useful at any scale.

The “Doctrine-based creation of patterns” approach can be most useful when managing land within training areas. Detailed land impact patterns can be predicted before training exercises are introduced into an area. From those, impact patterns on hydrology, species habitats, individual animals and birds, and vegetation can be inferred.

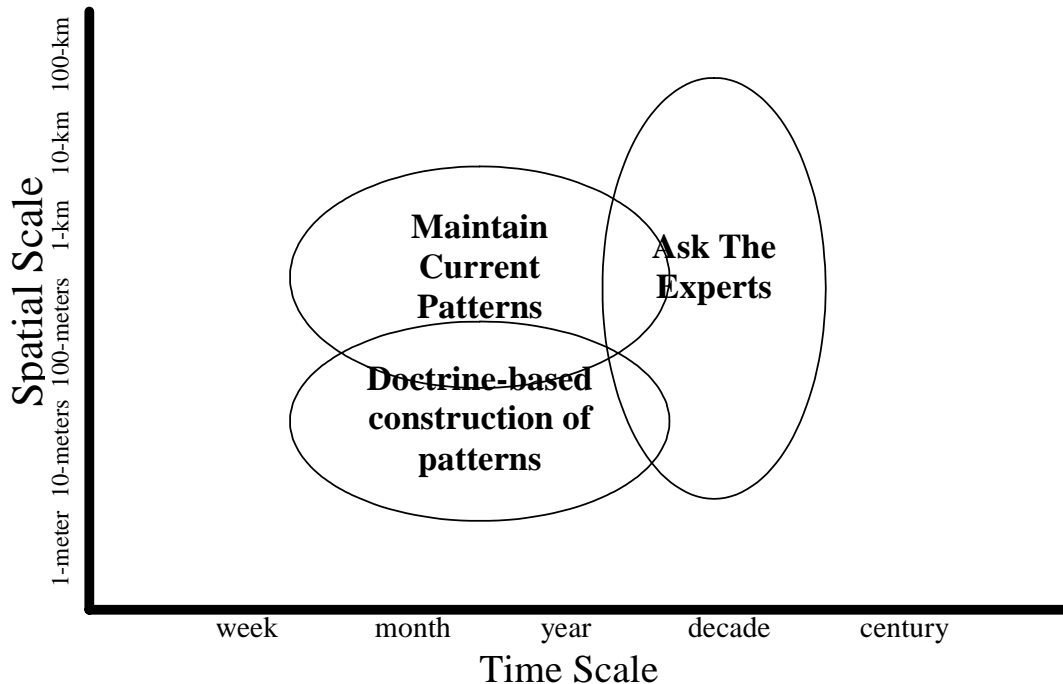


Figure 6. Suitability of approaches at different scales.

## Predictability of On-Installation Land Use

To estimate and evaluate potential future land use incompatibilities between on- and off-installation land uses, it is necessary to predict on-installation land use patterns. Unlike properties outside of installations, installation property is generally managed by a single owner. Consequently, changes in the use of that property are centrally controlled. The ability to predict the behavior of a single owner and therefore the future use of installation land is much more difficult. Nevertheless, some approaches are discussed below. They are grouped by time horizons: 1–5 years, 5–20 years, and 20–50 years.

### **1–5 years**

#### **Military Activities**

There is significant short-term persistence in the land-use patterns in general and on military installations in particular. The costs associated with change are often far greater than the costs of maintaining the status quo. Military doctrine changes slowly because the threats to the country do not frequently change. Infrastructure, including roads, electrical, targets, water lines, building, and other structures are built to last many decades and help maintain persistence in the land-use patterns.

Training and testing lands patterns can remain the same over time, but the actual intensity of use may change with short-term deployments and with changes in fuel availability over time. The pattern is the shape of the footprint of land use, while intensity is the weight behind the footprint. Patterns of land use at the scale of the entire installation remain constant as a result of persistence in training requirements, training and testing area designs, travel time to and from training/testing areas, and knowledge of the terrain of the training/testing areas.

ATTACC reflects the persistent patterns in its allocation of land use through the MIDM approach and is therefore very useful for management of training and testing lands in the 1–5 year time frame.

#### **Role of Computer Software**

Computer software provides three interdependent capabilities that together make it possible to manage training and testing areas: (1) recording land use, (2) measuring

environmental responses to land use and land recovery, and (3) predicting environmental consequences of alternative land-use schedules. The processing of satellite and aircraft-based images yields information about the status of training and testing areas, including the identification of vegetation patterns and training intensities. Regular on-ground vegetation sampling and measurements helps to establish installation-wide trends. When combined with imagery, this can help develop installation vegetation pattern and health maps. The Installation Training Area Management (ITAM) program embraces all three software roles to help understand the relationships between training and environmental impacts and recovery.

Another use of software is to illuminate the interactions and impacts among on and off-installation land-use patterns. One example is military installation noise patterns resulting from blast and small arms training and testing (Figure 1). Software programs such as BNOISE (Blast Noise) and SARNAM (Small Arms Range Noise Assessment Model) predict the installation-caused noise levels on and off installation. Within a GIS, noise contour maps can be combined with actual and potential residence locations to identify current and future conflicts. Similarly, water and air quality models can be used to show or predict the off-installation consequence of military training and testing. Noise and air/water quality monitoring are essential components of model verification.

## **5–20 years**

### **Military Activities**

In the 5–15 year planning timeframe, the training and testing patterns typically persist, but are likely to be modified in response to changes in some weapon systems and training/testing doctrine. Many of these changes are predictable because they are (or could be) part of long-range plans and investments. It takes many years to complete a weapon system production run in peacetime. This follows many years of design, development, and testing during which development of new training and testing areas can be completed.

### **Role of Computer Software**

In this planning time frame resides the potential to “grow” an installation. Installation land-use change, or growth, is based on analyses of land capacities and installation requirements. One approach might analyze each part of the installation with respect to the “habitat suitability” for various land uses (offices, airport, small-arms, tracked vehicle, bombing, etc.). Human input to the model will be identification of

future office and training/testing requirements. As additions are made to the installation, all land-use suitabilities/values will be recalculated. Land-use allocations will be made with respect to minimizing land development and land-use costs within the context of what the land can support and what land use is required on the installation. Figure 6 outlines the basic steps. The military installation landscape is divided into management parcels (at a number of scales) and the parcels are evaluated with respect to a number of land uses that encompass all primary military activities from office work to MPRCs. The land-use requirements and intensities are deduced from the planned installation needs and the activities are allocated with a minimum cost algorithm. Land uses may change from year to year based on changing resources and changing needs.

On-installation land-use patterns must be evaluated with respect to off-installation land-use pattern predictions. Simulation models that represent the dynamics of water and air quality, noise propagation, and radio transmissions are used to evaluate potential land-use incompatibilities.

## **20–50 years**

### **Military Activities**

Planning in the 20–50 year timeframe becomes increasingly difficult. Military training and testing requirements are based on Congressional funding that is, in turn, based on the political state of the world's countries and the current technology. Dramatic weapon system changes are possible, but not altogether predictable—making it necessary to plan for simultaneous alternative futures. The potentially exists for dramatic doctrine changes and for fundamental changes in the military organization structure. Will the Navy, Air Force, Army, and Marines be reorganized to take advantage of new integration opportunities? It becomes increasingly important to simply maintain military installation training and testing opportunities.

### **Role of Computer Software**

Software developed to address the 5–20 year time frame can be useful, but will require the ability to dramatically change military installation missions, land-use configurations, training doctrine, and weapon systems. Currently, land-use planning software helps illuminate the impact of military installation activities on off-installation areas. For long term planning purposes it will be equally important to evaluate the impacts of off-installation land-use patterns on the training and testing options available to the installation.



## 4 Predicting Impacts of On-Installation Land Use on Neighbors

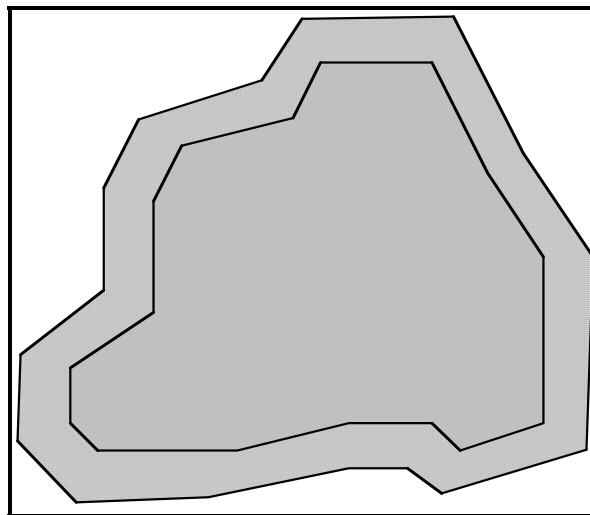
### General Approach

From a legal perspective, land property can be defined as a bundle of rights associated with a particular location. The simple common view is that a piece of property has a clear legal edge and that, within that boundary, the property owner is free to use the land as he/she chooses. The “punctuation point” on this view is the fence that is erected on the property line. Property law, however, is much more complicated and involves *de jure* and *de facto* rights, bundled (often in unique ways) for each property. *De jure* rights are those codified in laws and written agreements, while *de facto* rights are those based on historic land-use patterns. As population density increases, *de facto* rights are often converted to codified *de jure* rights to avoid arguments and confusion. Most military installations were initially established in remote locations where few local property ownership rights were written down into law and legal documents. As land develops around installations, opportunity for development of incompatible land-use patterns increases.

*De facto* property rights are based on historic patterns that have been accepted by local landowners. Military installations with a history of generating acceptable levels of dust and noise have established, through that history, the ownership of rights to continue making noise and dust — without any legal documentation. Establishing those patterns can help ensure an installation’s ability to retain those rights. Patterns can be established through documented historic records, testimony of local residents, and computer simulation modeling. Note that the “rights” to generate such impacts (both on- and off-installation) can be lost through legislative, regulatory, legal, or even political action. Potential future impacts of on-installation activities on off-installation land can also be predicted using computer simulations. If military installation land-use patterns in time and space are known or explicitly planned, it is straightforward to predict the extent of the associated off-installation patterns of noise, dust, and RFI.

## Simple Approach

The most basic questions are “Where will off-installation effects of training occur, and how can conflicts be avoided in these areas?” A simple approach advocated by many is to choose some pre-set distance to be used to establish a buffer around installations (in Figure 7 the gray installation is surrounded by a cross-hatched buffer). With a GIS, a buffer can be quickly created and historic land-use maps can be digitally inspected to identify growth trends within the buffer. Graphs can be created to show how different land-use types have changed over time to identify those



**Figure 7. A fixed-buffer around an installation**

installations that appear to be associated with potential future encroachment challenges and for which further studies might be appropriate.

The steps involved in this approach are:

Establishing the buffer must be done carefully to capture the installation's future zone of influence. All land-use incompatibilities must be considered, including noise, dust, smokes, obscurants, RFI, and light interference. Expected training/testing, landform, land cover, and weather all play roles. Large guns generating loud low-frequency noise over hard ground or water require relatively large buffers. Operation of vehicles in dry areas with significant wind on sparsely vegetated land can result in dust problems far from installation boundaries. Lights from cities 10 or more miles away on cloudy nights can generate ambient light levels too high for night training. However, suggested buffers are typically no more than a couple of miles.

1. Develop a raster GIS database that contains:
  - a. installation boundaries
  - b. historic land use.
2. Create a fixed buffer zone (or nested zones) around installations.
3. Sum the total area of the various land uses within the zone(s).
4. Graph the changes.

This approach is simple, easy to accomplish, and easy to understand, but is associated with a number of caveats. For current and planned training/testing, the buffer

zone should be around these areas—rather than around the entire installation. The potential for urban growth within the zone is strongly influenced by the size and growth of cities that might lie outside of the zone. Ownership of land is very important as the potential for growth varies dramatically depending on the goals of that owner. Federal, state, county, and municipally held land is associated with different purposes and goals. Private land owners may or may not be interested in allowing development. Environmental groups are currently purchasing land around military installations with the express purpose of maintaining that land for habitat. While each of these caveats can be addressed, doing so requires additional expensive data collection—especially if dozens or hundreds of installations are to be studied.

## Noise Impacts

Perhaps the best-known and most common off-installation impact of military training/testing is noise. Military noise can be generated from weapon firing, projectile impact and explosion, aircraft takeoffs and landings, and various test activities.

A hypothetical 100 years of urban growth is represented for an installation with the current noise energy impact pattern overlaid (Figure 8). Over the century, the original urban area has grown in size and three new urban centers have developed on the southern and eastern edges of the installation. By 2020, urban growth will have pushed into an area with higher noise levels and will likely result in increased noise complaints. The installation commander will face pressure to change the timing and frequency of occurrence of blast noise production. The installation may need to consider moving the offending firing range to alleviate the problem.

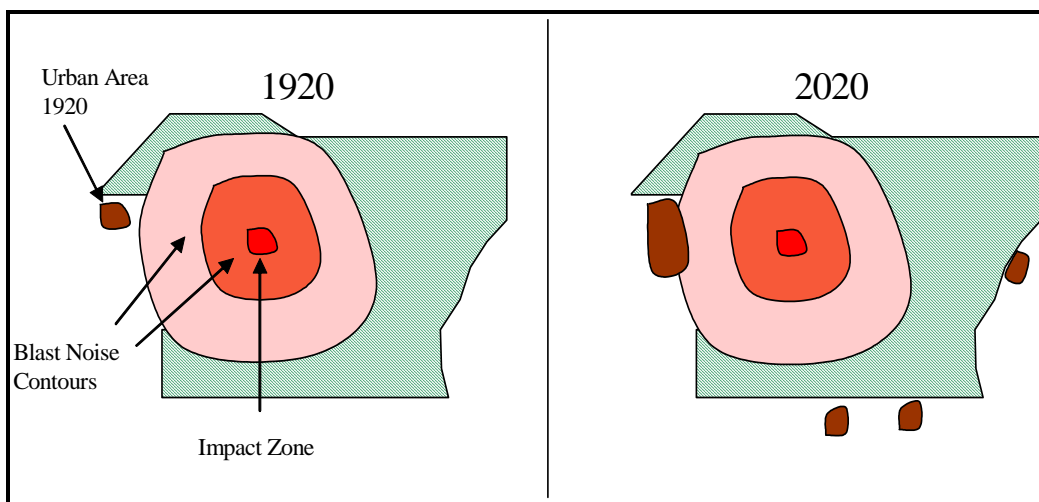


Figure 8. View of urban encroachment impact on noise complaints.

Commonly used spatially explicit noise computer models for blast noise and weapons firing include BNOISE and SARNAM, respectively—both developed at the Construction Engineering Research Laboratory (Pater et al. 1999). The prediction of noise intensities across the landscape resulting from noise-producing activities is surprisingly complicated. Models can consider the frequency spectrum and directivity pattern of the original noise (the source), the terrain, land cover, and meteorological conditions. With undirected sound propagating across a nonabsorbing land cover (e.g., water or rock) and in an atmosphere that refracts sound toward the ground, the sound exposure decays as the inverse of the distance from the sound source. Because the sound is trapped near the surface, its constant energy is confined to the perimeter of an expanding circle. (*Sound exposure* is the time-integrated square of sound pressure.) This worst-case scenario is realized commonly under nighttime temperature inversions, but does occur in the early morning, in daytime with overcast conditions, or in directions downwind from the source. Usually, daytime surface heating causes strong upward refraction in the afternoon. In weather conditions that refract sound upward, the sound exposure follows an inverse square, or higher, power of the distance from the source. Vegetation (e.g., forests) can significantly attenuate higher audible frequencies. Hills reflect and diffract sound, increasing the reverberation time. The actual pattern of the sound exposure can therefore be very irregular and can change dramatically as weather conditions change, minute to minute, throughout a day, and throughout a year.

Once noise level spatial patterns are established through measurement or predicted using computer models, the problem of attaching meaning to those patterns can be addressed. From the standpoint of human receptors, how annoying or damaging is the noise? The sound level, spectrum, and duration are parameters of the equation, but these must be considered with respect to the time of day, the day of the week, the season (windows opened or closed), and the activity of the people. Noise that causes permanent damage (e.g., broken windows) is clearly a problem. In these rare cases, installations are often held responsible for replacement and repair. Noise masked during the day by other ambient noises can become very annoying at night—during sleeping hours in seasons when sleepers leave windows open. High frequency sounds can be readily blocked with walls, while low frequency sounds can travel through buildings.

Over time, installations and their neighbors come to general agreement on what kinds of noise are acceptable at what times. Installations will limit training/testing that generates certain noises to specific times of the day. Neighbors accept some level of noise through habituation and through knowledge that the noise is part of the local economy and the “sound of freedom.”

Predicting the spatial pattern of the intensity of noise resulting from a training/testing event or over the course of months or a year of events is, today, straightforward using sophisticated modeling software.

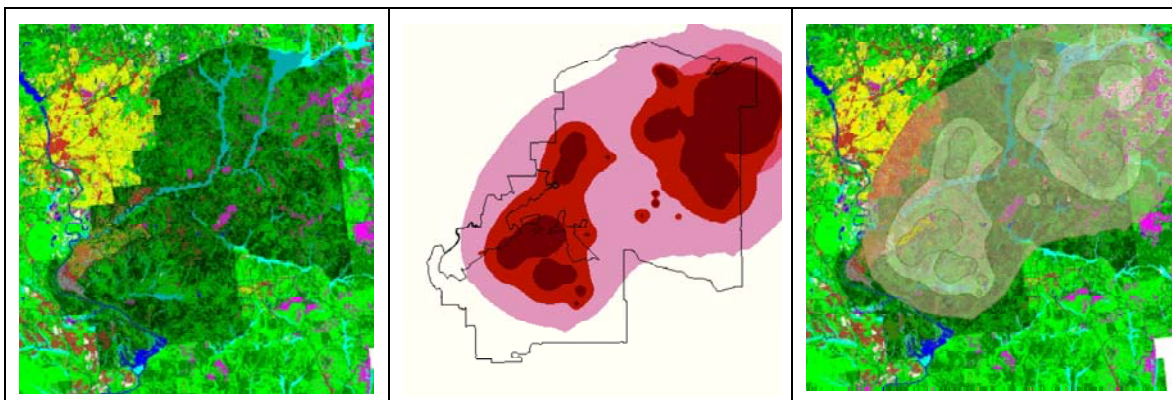
The steps involved in this approach are:

1. Develop a raster GIS database that contains:
  - a. digital elevation
  - b. land use
  - c. land cover.
2. Develop a record of actual or planned weapon firing and explosive impacts, including:
  - a. weapon location, firing time, weapon type, munition fired
  - b. munition impact location.
3. Develop weather/climate data, including temperature, humidity, and pressure as a function of elevation.
4. Run the model.
5. Use BNOISE for large weapons.
6. Use SARNAM for small weapons.
7. Capture the results into a GIS for further analysis and display.

Model outputs can provide a variety of standard measures of noise received at each position on a map grid. Combining this information with human response data, it is possible to identify likely locations of people that are affected by the training/testing. The left image in Figure 9 shows Fort Benning (dark central area) and Columbus, GA (light area in the upper left). The center image represents anticipated noise levels associated with training and testing after construction of a proposed range. The right image shows the overlap of the noise contours with land uses off the installation. Note the relatively low noise level impact on Columbus, but a higher noise level on lands just northeast of the installation. This type of analysis can be very helpful in understanding impacts of noise on neighbors and is conducted on a regular basis by the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM).

## **Dust Impacts**

Many installations, especially those in desert and dry environments undertake training and testing situations that generate dust—especially from tracked vehicle maneuvers. Training and testing can also generate smokes and obscurants that can leave installation and disturb local populations. Desert landscapes naturally develop a protective crust, called “desert armor,” which resists further wind erosion.



**Figure 9. Projected Landuse and Projected Noise Contours around Fort Benning, GA. (The city of Columbus, GA, is NW of the installation.)**

Bacterial and fungal mats can contribute to the cementing of this armor. Vehicle traffic readily disrupts this armor and immediately kicks up sand and dust that can be carried long distances by the wind. Disruption of the armor leaves scars that allow windstorms access to dust and sands that are no longer protected. Predicting the on- and off-installation footprint of sand in windstorms that result from training is as straightforward as predicting noise patterns.

The following algorithms are being used to create maps of dust deposition as a result of training exercises:

1. Develop a raster GIS database that contains:
  - a. digital elevation
  - b. land use
  - c. land cover
  - d. soil types and characteristics
  - e. historic intensity of vehicle traffic.
2. Develop a record of actual or planned training exercises, including:
  - a. vehicle types
  - b. location of training
  - c. miles of driving
  - d. date and time of training.
3. Develop weather/climate data, including:
  - a. annual rainfall averages on a weekly basis
  - b. wind direction and strength frequencies on a weekly basis.
4. Run the model to predict sand/dust distribution during training/testing exercises.
5. Using regional wind direction and strength probability information, combined with local topography and ground cover, use the training/testing schedule to generate and move dust and sand. Various models may be adapted to provide results.

6. Run the model to predict sand/dust distribution changes during windstorms.  
This is a similar model, but instead of vehicles injecting dust and sand into the wind, the wind itself picks up the particles.
7. Capture the results into a GIS for further analysis and display.

The results of such an analysis will, like the noise analyses, show the impacts that installation training and testing has and will have on surrounding off-installation areas.

## RFI Impacts

RFI occurs when an unauthorized use of a radio band interferes with an authorized use. In the United States, the Federal Communication Commission (FCC) is responsible for band allocation (spatially and spectrally) and for international coordination of the radio spectrum. The notion of radio frequency interference as a serious encroachment threat to military installations and its activities has both a national and a local dimension. At the national level, the primary encroachment problem involves reallocation of the radio spectrum. Consumer demand for new technology requiring wireless networks is growing rapidly. This demand has already precipitated two different rounds of spectrum reallocation in 1994 and in 1997 (Hurt, Cerezo et al. 1995; Drocella, Jones et al. 1998). Additional reallocations are under study. This document is, however, only concerned with local interference, which occurs when a party is transmitting at frequencies allocated to other parties. The Army uses frequencies allocated to other users in three different circumstances: test range telemetry, force-on-force training, and training with foreign-made equipment. Conflict is avoided if the parties to which the used bandwidth has been assigned are not using those frequencies in the same area.

The Future Force is currently designed to be extremely dependent on the ability to monitor vast amounts of information in the battlefield through the application of electronic communication equipment. All means of electronic communication possibilities are being exploited and involve radio broadcast and reception over wireless, wire, and optical channels. Broadcast and reception involve all frequencies from almost 0 Hz to more than 300 GHz (wavelengths in the range of millimeters). At the lowest frequencies, very low symbol rate transmissions can penetrate the earth to communicate critical information with submarines and aircraft on the opposite side of the earth. The highest frequencies are used to image things at great distances (the ground from satellite and objects from hundreds of miles away).

Radio frequency impact analyses associated with military training and testing can be accomplished in a manner that is spatially explicit through GIS analyses. The potential for interference is a function of:

- signal frequency, bandwidth, and modulation protocol: TV, AM, FM, SSB, GSM, frequency hop, etc.
- receiver frequency, bandwidth, and demodulation protocol: TV, AM, FM, etc.
- transmitter power
- landscape
- height, location, size, orientation, configuration, polarization of transmitter antennas
- height, location, size, orientation, configuration, and polarization of receiver antennas.

Radio transmitters are tuned to generate information on specific frequencies measured in cycles per second, or Hertz (Hz). Typically, the signal information is contained within the broadcast bandwidth, and by some protocol, modulated with and centered on the transmitter frequency. Receivers are tuned to demodulate the information signal from carrier frequency, and reject frequencies outside of the signal band. Neither sent spectrum nor received spectrum will lie wholly within their intended bands, for a number of reasons. Nonlinear effects in high power transmitters drive the transmitted signal out of band. Imperfect tuning and imperfect filtering in both transmitters and receivers can lead to interference. Imperfect shielding of *any* electronic equipment can lead to internal components acting unintentionally as either transmitters or receivers.

Electromagnetic radiation is used and is composed of electric and magnetic waves traveling with their field vectors simultaneously oriented at right angles to one another, and to the direction of energy propagation. The radiation may be polarized where the angle of the electric field with respect to (for example) the ground is fixed, circularly polarized (where the angle rotates synchronously with the wave frequency), or nonpolarized (where each wave arrival can be oriented at any random angle). The radiated power of the signal is important for good reception, because the received power generally follows the inverse square of the distance between the transmitter and the receiver. However, the signal can be directed by a shaped antenna or antenna array to maximize the apparent initial signal strength.

Depending on the frequency and geometric configuration, there are opportunities for a signal to be reflected, refracted, scattered, and absorbed. Radio waves interact strongly with objects that are roughly the size of the wavelength and larger. Waves shorter than the size of the object are reflected, while longer waves diffract around



the object. Radio waves with a frequency of less than about 30 kHz are reflected off the earth's ionosphere, which is strengthened by the ionizing effect of the solar wind. The ionosphere is most reflective in late afternoon on a long summer day. The ground is most reflective (for vertical polarization) when it is conductive. Hence, lakes, seawater, and wetlands are especially good reflectors. The combined reflectance of the ground/water and the ionosphere makes it possible to receive information that has been bounced one or several times from the transmitter. At very high frequencies, leaves reflect radio waves and forests block all transmissions. At medium frequencies radio waves hug the earth and easily remain attached over rolling hills. Abrupt edges (at a scale similar to the frequency) cause diffraction of waves.

The bottom line is that it is very difficult to know exactly how a military radio transmission will affect surrounding communities. Still, the effect can be predicted by knowing the frequency, power, point of transmission, location of receivers, surrounding landscape, and state of the ionosphere. Radio frequency bands and their common uses are:

- VLF (very low frequency, < 300 kHz)
  - radio navigation (nondirectional beacons)
  - LF (30 kHz to 300 kHz — 1000–10,000 meter)
  - maritime mobile
  - radio navigation
- MF (Medium Frequency, (300 kHz to 3 MHz—100–1000 meters)
  - radio navigation
  - mobile, maritime, aeronautical
  - AM radio (amplitude modulated, 525–1600 kHz)
  - global positioning system
- HF (high frequency, 3 MHz to 30 MHz—10–100 meter)
  - skips via ionosphere – optimal late afternoon after UV has ionized atmosphere
- SW (short wave) radio 2.2–22 MHz
  - aircraft, mobile
  - search and rescue
  - novice
  - amateur
  - beacons
  - alarms
  - model controls
- CB (citizen's band, 27.6–28 MHz)
  - satellite downlinks
  - space research

- radio astronomy
- VHF (very high frequency, 30 MHz to 300 MHz—1–10 meter)
  - line of sight transmission
  - good for transmissions over water and rolling hills
  - FM radio 88–110 MHz
  - TV channels 2–6 — 54–216 MHz
  - radio astronomy
  - fixed communications
  - space research
  - amateur
  - satellite radio-navigation
- UHF (ultra high frequency, 300 MHz to 3 GHz—0.1–1 meter)
  - very reflective—useful in cities with skyscrapers
  - fixed communications
  - satellite
  - radio navigation
  - meteorological
  - broadcasting
  - amateur
- SHF (super high frequency, 3 GHz–30 GHz 0.01–0.1 meter)
  - typically used in point-to-point situations rather than broadcast
  - traffic radar X-band—10GHz; K-band ~24 & 33 GHz
  - microwave (1000 MHz–40 GHz)
  - fixed communications
- XHF (extremely high frequency, 30 GHz–300 GHz 0.001–0.01 meter).

## Approach for Predicting RFI

While the primary RFI encroachment of current concern to the military involves Congressional supported reallocation of frequencies in response to the public demand for wireless communications, quick GIS-based analyses can be useful in some instances to predict interference among public and military applications. VLF and LF band frequencies are not often used and the signals penetrate large objects including (at the lowest frequencies) the earth. At the more energetic end of the radio spectrum the SHF and XHF frequencies have line-of-sight transmissions and are readily stopped by even small objects. Typically transmissions are highly directional and point-to-point. For example microwave towers used for telephone signal transmission focus and receive signals that are highly focused—making it possible for the same frequency to be used in the same geographic location. The potential for mili-

tary and public application interference is minimal if there is no direct line-of-sight. The greatest potential for conflict lies in the HF, UHF, and VHF bands.

HF frequency analysis is relatively straightforward and involves a dense assortment of uses. HF frequencies travel great distances—bouncing off the ground and the ionosphere—that vary with the time of day, location on the earth, and season. Frequency interference can occur at distances up to thousands of miles. The general reader can consider AM radio reception. At a thousand miles from a favorite home radio station, reception can vary from none to very good. Licensing of stationary transmitters considers the wattage and location of other transmitters across the country transmitting on the same frequency. The GIS analysis of HF frequency uses can simply consider placing a shape, centered on the transmitter, that represents the signal strength as a function of azimuth—often circular. The radius of that shape is a direct function of the transmission power. Within the area of the shape, the location of receivers operating at different frequencies within the HF band can be located to determine the potential for interference with transmitters to which those receivers are listening. We should assume that every frequency in this band is spoken for and is being used and that restricting military transmissions to frequencies assigned to the military is prudent. This greatly restricts the need for any GIS analysis and places all encroachment issues squarely in the management and allocation of frequencies.

VHF and UHF frequency band footprint analysis has the greatest potential for GIS analysis. Because these frequencies are all above 30 MHz, they are not reflected off the ionosphere and therefore can be primarily analyzed with GIS-based line-of-sight software. Such tools are standard in raster-based GIS systems and have primarily been used for viewshed analyses. Suggested steps for carrying out a GIS-based RFI analysis for VHF and UHF frequencies are:

1. Develop a raster GIS database that contains:
  - a. digital elevation
  - b. location and elevation of receivers of the desired frequency
  - c. location and elevation of transmission antennae.
2. Invoke a line-of-sight analysis.
3. Submit the DEM and location and elevation of transmitting antennae.
4. Make sure that the curvature of the earth is considered. This can be accomplished by subtracting the curvature of the earth from the DEM—centered on the antenna location (zero correction for that location).
5. Overlay the coverage map with receivers.

Figure 10 shows the sample results of a line-of-sight analysis. A transmitter antenna is set up to the left of the center of the image at some elevation above the ground. The image is a shade-relief map with the areas visible to the antenna highlighted primarily in blue. Comparing the blue areas with locations of receiving antennas will indicate the potential for interference. Further considerations would include other aspects of the sent signals, such as polarization and modulation as discussed above.

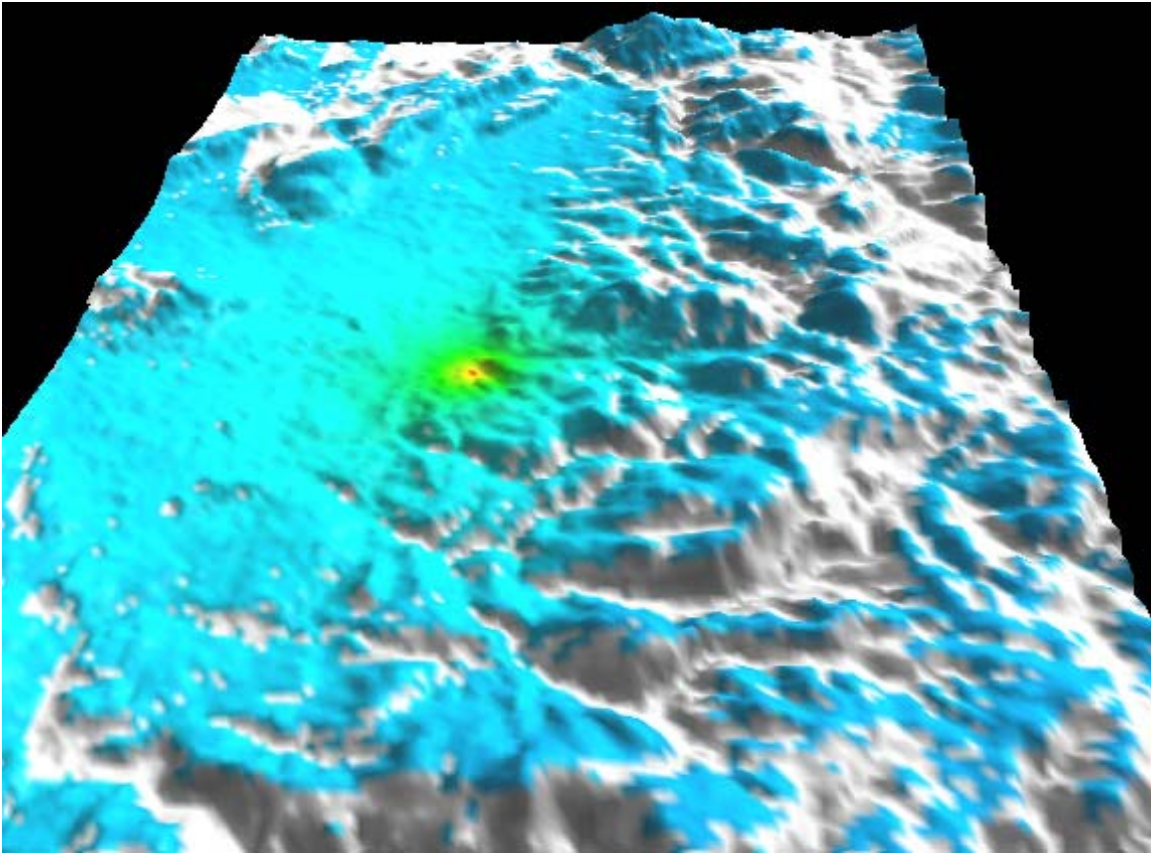


Figure 10. A line-of-sight analysis; colored areas can be seen from a tower located near the center.

## 5 Predicting Impacts of Off-Installation Land Use on Training/Testing Opportunities

### General Approach

Evaluating the impact of military activities on surrounding land uses can work well if the on-installation land uses can be predicted. However, weapon systems and training doctrine will continue to develop as technology evolves. Such development inevitably results in potentially dramatic changes in the demands of the installation and surrounding lands. A rapidly developing technology base is a healthy, desirable circumstance since new technologies have historically been a cornerstone of establishing military advantages. Instead of relying on any ability to predict future weapon systems and training doctrine, for long-term installation planning it is more prudent to turn the tables and predict changes in land-use suitability for on-installation training and testing based on future off-installation land-use changes. Because the off-installation landscape is associated with infinitely many alternative futures, it becomes increasingly important for installations to participate vigorously in regional planning exercises.

Our general approach is to assume that the military owns and controls land within established boundaries and uses other lands under various agreements with other Federal agencies, states, and counties, but that the desired use of that land is unknown. Consider, for example, that the installation is completely open for development or redevelopment. The general question to be answered is:

At every point on my installation, what are the projected limitations on training and testing, with respect to:

- noise generation
- dust/smoke generation
- RFI generation
- night-vision limitations.

This chapter explores approaches for answering this question for each of these limitations.

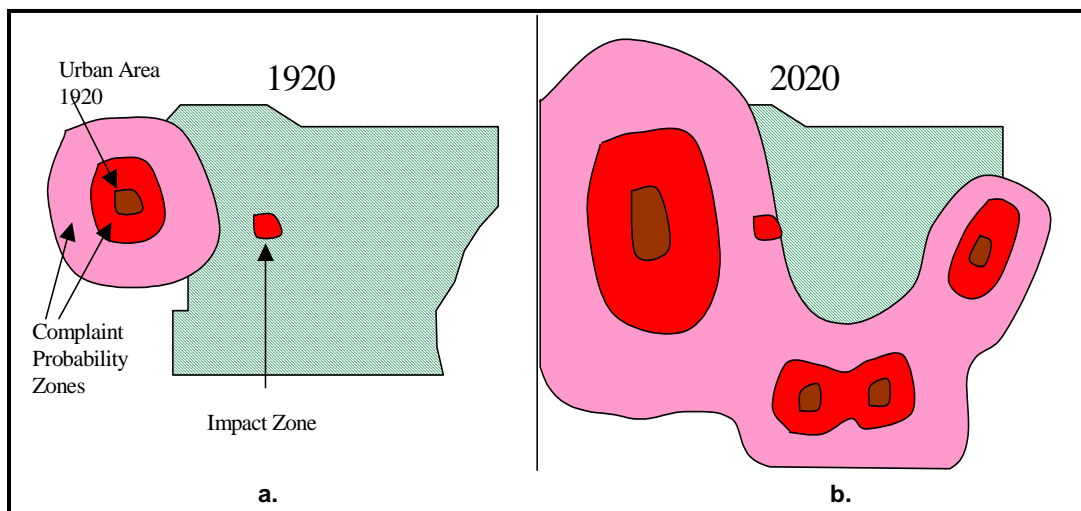


Figure 11. Areas where noise may not be tolerated can grow with urban development – decreasing available on-installation training land.

## Noise Limitations

Reconsider Figure 11a where off-installation urban pattern after a hypothetical 100 years of urban growth is overlaid with the current (or anticipated) noise energy impact pattern. Figure 11b shows a more alarming view of the same situation. Instead of showing blast noise maps that capture the noise energy as a function of space, this figure maps the noise complaint zones that result from the urban settlement patterns. Both maps can be interpreted to show that the urban growth has resulted in land-use incompatibilities associated with blast noise in the impact zone. Figure 11b, however, more clearly shows that the installation's future opportunities for locating and using firing ranges have dramatically diminished as well.

There may be a very straightforward approach to producing the type of map displayed in Figure 11b for blast noise. The current computer simulation model for generating sound exposure contours is BNOISE. Consider a blast set off at a specific location SRC and received by listeners in a house at location RCV. The probability of noise complaints generated by occupants of the house (at RCV), due to the blast, can be derived from BNOISE simulation. Because BNOISE produces sound exposure estimates on a horizontal grid, probabilities are usually estimated for *any* reception position RCV on map grid.

Because of acoustic reciprocity, in some situations (no wind, isotropic source and receiver, etc.) source and receiver positions can be swapped, with identical received sound level. By applying this principle, the same sound exposure map can be re-

interpreted as the probability of a single household (located at the source position) to complain of the blast originating from any location (the receiver positions) on the map. For example, simulation of the probability of the house (at RCV) to complain of a blast sound at *any* source position SRC can be accomplished by supplying with the house coordinates when prompted for the source location. Therefore, determining sensitivity of a house at RCV to a particular kind of blast can be rapidly performed without changing any existing tools, and will allow the generation of a map that shows the probability of receiving a noise complaint arising from setting off a blast anywhere on the map. So, running BNOISE with supplied coordinates of each residence surrounding the installation may result in maps that can be processed into noise complaint probability maps like those shown in Figure 11b.

The steps involved in this approach could be:

1. Develop a raster GIS database that contains:
  - a. digital elevation
  - b. land use and land cover
  - c. projected location of homes
  - d. military lands.
2. Develop BNOISE input file.
3. Identify the blast noise level being considered.
4. Supply locations of homes as source locations.
5. Run BNOISE.
6. Capture the sound exposure level outputs of BNOISE on the installation.
7. Convert these levels to probability of complaints associated with single and multiple blasts.
8. Repeat the process.
9. Develop alternative projected locations of homes, or a time-series of projected locations.
10. Run the above steps.
11. Combine the final outputs into a time-series of images or a movie.

Alternately, instead of using looking at the problem from the perspective of the noise generation sources, investigate it from the standpoint of the noise receptors (local homeowners). Ask the question, "How much noise can be generated from any location with respect to where the people live?" Consider addressing the challenge to identify the amount of noise that can be generated in any location around one homeowner. The noise tolerated from immediate neighbors is very low while the noise generated from a factory a mile away will be very high. The level of noise received at a homeowners residence is roughly proportional to the inverse square of the distance to the source of noise.

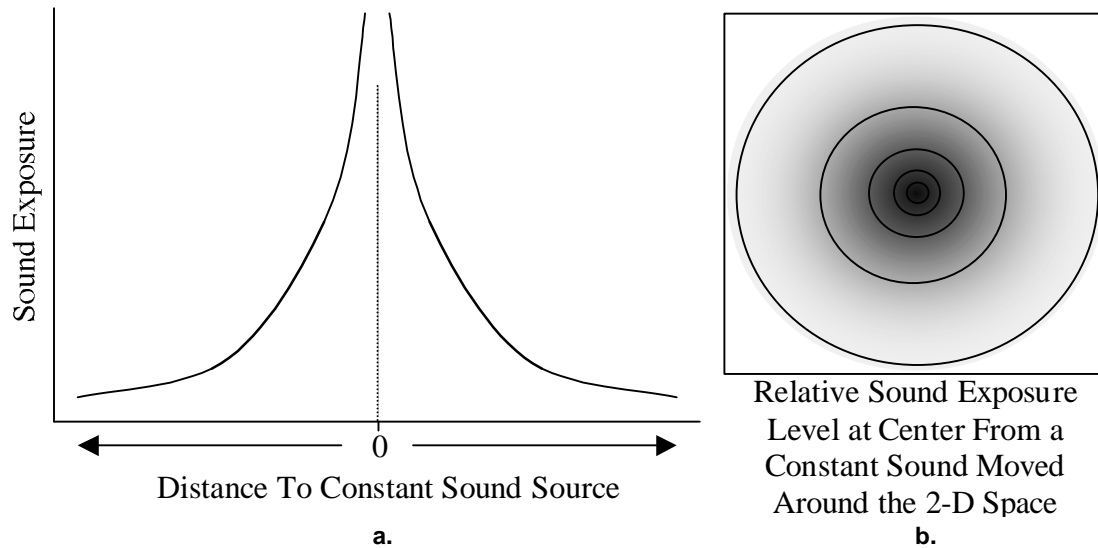


Figure 12. Noise reception decreases with the square of the distance.

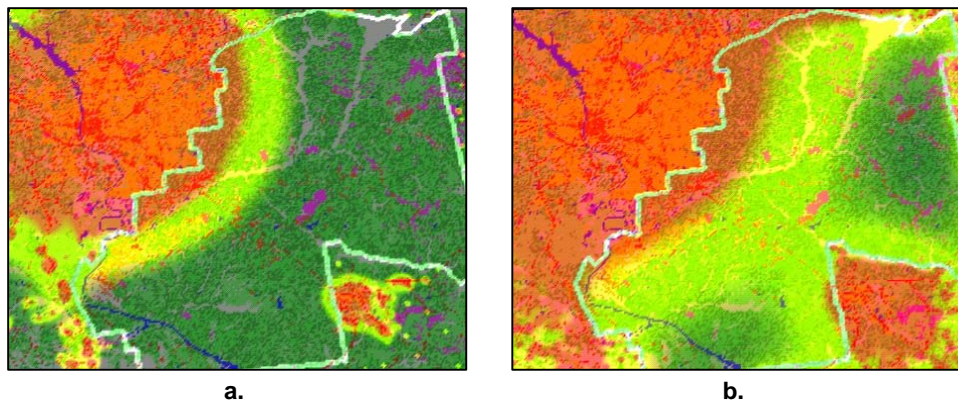


Figure 13. Decrease in an installation's training opportunities over time.

Figure 12a shows a one-dimensional representation, depicting the sound levels received from a constant sound source as that source is set at varying distances to the left and right of a receptor, which is fixed at location 0. It is possible to create a map indicating the level of noise received by the homeowner from each surrounding location (Figure 12b.)

Consider asking the question “What is the noise exposure to the surrounding community from a sound generator placed anywhere on my installation?” We are trying to determine the effect of urban encroachment on the opportunity to generate sound anywhere on the installation. Sound impact surfaces (Figure 13a) were generated and summed for every residential location to create a view of the amount of sound received by local residents from a blast generated anywhere in the region (Figure 13b). The left image represents the sound received by residents today; the right by residents sometime in the future after significant urban growth.



Increased numbers of residential receptors are likely associated with increased numbers of noise complaints, which can reduce the training throughput on the installations training areas. Turning these analyses into noise complaint predictions will be an involved social science challenge that must include the sound frequency, time of training, frequency of training, weather conditions, potential for windows and doors to be open, and relationship of human receptors to the installation.

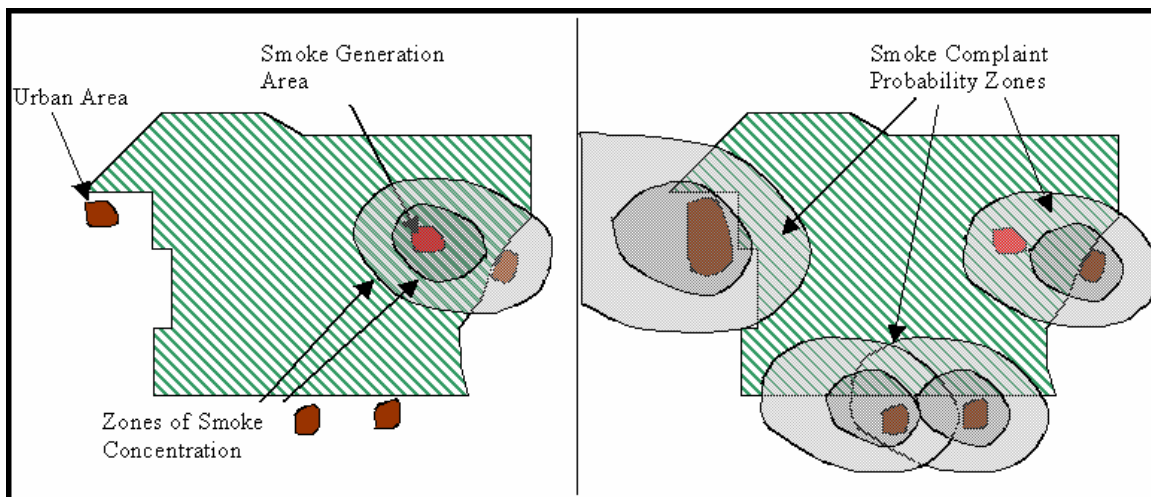
The steps involved in this alternate approach are:

1. Develop a raster GIS database that contains:
  - a. projected location of homes
  - b. military lands.
2. Formulate individual probability of complaint function of sound exposure, using best available information.
3. Generate a total probability for complaint map by summing probability-of-complaint functions centered on each residential location.
4. Calibrate the map with this data.
5. Acquire historical complaint data that associates complaint, complaint location, and blast location.
6. Calibrate the map with this data.
7. Alternately, use local expertise to predict total probability for complaints to calibrate.
8. Repeat the process.
9. Develop alternative projected locations of homes.
10. Run the above steps.
11. Combine the final outputs into a time-series of images or a movie.

With this technique, the potential for complaints associated with each of many installation activities can be summed to estimate the total number of complaints. By evaluating each type of sound source and its frequency of operation in this way, maps can be prepared that demonstrate the confinement of types of training to limited areas on the installation. The main point of this analysis is to model (and predict) the long-term impact of urban development on the potential or opportunities to train/test on the installation in the future.

## **Dust and Smoke Limitations**

The general approach can be repeated for dust, smokes, obscurants, and even ground and surface water quality. The left side of Figure 14 captures the zones of dust intensity or smoke concentrations over the course of a year. Smoke is generated in the dark central area and wind moves the smoke into the surrounding area.



**Figure 14. "Anti-smoke" example.**

The shape is not circular because the summary of the wind speeds and directions over the course of a year (a wind rose) is not evenly distributed. The lighter (second) zone covers an urbanized area just to the east of the installation. This type of analysis is straightforward and can be achieved with available computer software, or even with pencil and paper. In any case, it is clear that there is a land-use conflict. Moving the activity that generates the smoke must be considered. A next step might be to create a map showing a (current and future) uninhabited area where this activity could be relocated. Consider the image on the right side of Figure 15, which shows smoke complaint probability zones around settled urban areas. Existing smoke plume prediction models should be useful in creating such outputs.

The steps involved in this approach are:

1. Develop a raster GIS database that contains:
  - a. land use and land cover
  - b. soils
  - c. wind direction and speed distributions over directions and months.
2. Develop the smoke annoyance map (Figure 15).
3. Submit the GIS data maps to a new analysis program.
4. To implement the GIS-based algorithm:
  - a. create a dust/smoke annoyance surface
  - b. choose a specific month
  - c. choose a particle size (e.g., smoke, dust, sand)
  - d. capture the wind-rose information for that month
  - e. generate associated dust/smoke annoyance surface.
5. For each residential location:
  - a. center the dust/smoke-annoyance surface on that location

- b. add to the total annoyance surface
  - c. write-out the final map.
6. Calibrate the map using actual local complaint data, or using local expertise.

The benefit of this approach is that it recognizes that the ability to accurately predict patterns of land use on military installations diminishes after 5 to 10 years. Yet it is still important to retain—indefinitely—as much of the military installation’s training and testing potential as possible. Therefore, associating predicted urban patterns with anticipated loss in opportunities helps inform the long-term value of on-base investments.

## RFI Limitations

Knowing where urban residential areas are or are expected to be, it is straightforward to identify approximately where RF transmitters can be placed to avoid interference if the frequencies of concern travel line-of-sight (frequencies above 30 KHz). As with the dust and noise approaches described above, the locations of receivers using a frequency of interest are located, and based on these locations, viewsheds are established for each, and are then combined. Viewshed analyses generally offer the ability to limit the distance, and depending on the power output of the military transmitters, the viewshed analysis can be limited to a distance associated with the attenuation of the signal. The analysis steps are:

1. Collect the GIS data, including:
  - a. digital elevation model.
  - b. location of receivers.
  - c. transmission power.
2. Create the transmission visibility surface.
3. Implement the GIS-based algorithm. For each receiver location:
  - a. Generate a transmitter visibility map using GIS viewshed software.
  - b. Sum these maps to give a result that shows the total number of receivers that can be reached from each potential transmitter location.

Figure 15 shows an image resulting from these analysis steps. In this instance a frequency was chosen that might be in use by residences (e.g., VHF or UHF television or FM radio) that are indicated by the black areas on this shade-relief image. At every location on the image a color represents the number of residential areas that a transmitter, if located there, might affect. The colors range from green (a very few interference hits) to red (a large number). Areas with no color are safe if the transmission antenna is on the ground.

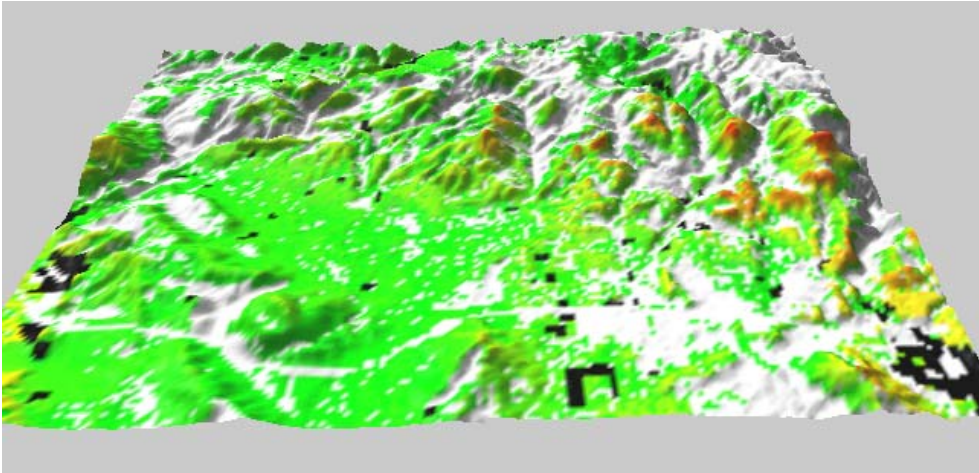


Figure 15. Transmitter areas that will cause interference.

## Night-Vision Training Limitations

In recent conflicts, the U.S. military has “owned the night.” Electronic night vision tools allow near-daylight operations in complete darkness. Night vision capabilities currently make it possible for U.S. forces to operate with less risk at night when the enemy is blinded. However, to operate effectively, soldiers must train with the night-vision equipment. Two “night vision” encroachment challenges potentially relate to land development. The first eventuality—potentially catastrophic—occurs when a driver of a vehicle with headlights approaches a driver of a military vehicle who is using night-vision systems. The driver wearing night vision equipment can be “blinded” by the direct light. This can occur at installation boundaries where training lanes run near off-installation public roads. The second challenge involves the ambient light that is particularly noticeable when low clouds cover over brightly lit public and private lands.

The first challenge must be met on a case-by-case basis. Trainers can use maps of on- and off-installation roads and trails to easily spot potential problems. Once identified, a variety of specific treatments can be applied to ameliorate the problem. Roads can be rerouted, barriers of natural vegetation developed, and fences erected. As this challenge can occur in real battle situations, next generation night-vision equipment might help address this particular problem.

The second challenge is directly related to the growth of urbanizing areas and has been a serious challenge to astronomers for many decades. GIS analyses are appropriate and analysis steps are presented below. However, local ordinances and practices can significantly reduce the ambient light problem.

Army trainers can use filters to block out light of specific wavelengths. The brightest commercial and public lighting uses sodium vapor and mercury vapor lamps. Incandescent bulbs generate light by heating metal filaments and create light across the visible spectrum. Sodium and mercury vapor lamps generate light in distinct spectral lines that are associated with the decay of excited electrons from higher to lower states. Unlike the full-spectrum black-body radiation of heated filaments, these lamps can only generate light at specific energy levels, or colors. Unfortunately, there are a number of variations of these bulbs that employ various mixes of phosphors to help create more “natural” light and therefore different patterns of spectral lines. However, local ordinances that specify the use of specific high-intensity lights, combined with military filters that block the spectra of the allowed lights can significantly “darken” the ambient light received by the night-vision equipment. Another local ordinance or practice can require that all lights have reflective hoods that focus all of the light downward. This helps darken the sky and also helps brighten the ground. The amount of ambient light experienced on the ground is a function of:

- intensity of nearby light sources (up to 20 miles away)
- distance from the sources
- spectra of the light sources (blue light decays faster in the atmosphere)
- density of the cloud deck
- height of the cloud deck
- relative humidity.

For multi-decade predictive purposes, the weather information can be anticipated via analyses of local climate conditions to provide monthly frequencies of cloud cover and humidity. This, combined with the other information, predicted from urban growth models, can be used to predict the percent time that night-vision training can occur. The steps in this analysis are:

1. Collect the following data:
  - a. local humidity probabilities by month
  - b. local cloud cover by month
  - c. predicted land-use patterns
  - d. predicted intensities and types of bulbs associated with the land-use patterns
  - e. predicted percentage of light reflected up.
2. Run the analysis.
3. Input data into a new GIS program.

This program visits each area of land that serves as a light source and generates a surface showing the total light energy received in surrounding lands under the given conditions of cloud cover and humidity.

## 6 Research and Development Directions

Each section in this chapter describes research and development efforts required to cost-effectively apply the analyses outlined in this document.

### Development of Standardized GIS Data Sets

Acceptance of GIS technologies began to grow in the 1980s as a grassroots process. Each installation chose from among a number of GIS vendors and developed maps from local sources in a locally specific manner. As a result, installations have a tremendous legacy of digitized data, but the data layers are inconsistent installation to installation. The Army's ACSIM (Assistant Chief of Staff for Installation Management) has established a new GIS-R (GIS Repository) (Delmonico 2003). The GIS-R program supports the development of standard GIS data sets developed, maintained, and managed by each installation. Data sets are to be developed using the SDSFIE (Spatial Data Set for Facilities, Infrastructure, and Environment) standard, developed in coordination with DOD users, commercial GIS vendors, standards organizations, and others. It is imperative that GIS data and data analysis tools be developed with respect to a standard to allow interoperability of analysis tools. Most of the GIS analysis tools developed over the past three decades for military installation use have been specific to one installation.

### Tools for Predicting Off-Installation Impact of Military Activities

#### ***BNOISE***

The Construction Engineering Research Laboratory (CERL)-developed software programs BNOISE and SARNAM have been under development since the 1970s and continue to be well-accepted tools for understanding current, past, and future spatially explicit noise patterns. These programs set the standard for development of equivalent tools for other off-installation impacts of training and testing.

### ***Dust and Smokes***

A spatially explicit smoke model could be adapted for rapid analysis of planned military training and testing to identify resulting concentrations of smokes and dust in neighborhoods surrounding an installation. Kemme, et al. (2001) reviews particulate matter issues in the Army identifying challenges, data, software, and solutions. Models reviewed include the Industrial Source Complex (ISC3) model, the Climatological Dispersion Model (CDM 2.0), the Gaussian-Plume Multiple Source Air Quality Algorithm (RAM), the Open Burning/Open Detonation Dispersion Model (OBODM), the Second-order Closure Integrated Puff Model (SCIPUFF), and others. The Fort Future development team has adopted SCIPUFF for dispersion modeling associated with the simulation of installations.

### ***RFI***

Before developing spatially explicit RFI prediction software, RFI complaints must be documented and understood. A research effort to collect and analyze this data will help characterize the full nature of the problem, which will lead to efforts necessary to address the challenges. Assuming that RFI problems with local communities are in the VHF and UHF bands, GIS analysis tools that employ traditional line-of-sight tools can be adopted to identify potential interference problems now and in the future.

## **Tools for Predicting Loss of Training/Testing Opportunities Due to Off-Installation Land Development**

### ***Noise***

Urban growth and land-use change occur slowly, but establish relatively permanent patterns that are very difficult to undo. This growth can easily and permanently limit the opportunity on installations to establish future training/testing that is associated with noise generation. Projections of this loss with respect to future urban patterns will be very important pieces of evidence in public regional debates. Software needs to be developed to address this question:

*How will future off-installation land use limit my opportunities to generate noise?*

The R&D proposed here would more specifically address the challenge to generate spatially explicit maps that project the probability of noise complaints from

neighbors. An initial modest approach will involve development of a raster-based GIS analysis tool that generates a noise-complaint functions centered on each residence. Summing these probabilities across the landscape yields a total noise complaint probability surface. Developing this tool should be relatively modest in cost.

A more complete tool can be developed that takes into account the local terrain, land cover and weather conditions to accommodate the ability of the land to focus noise and land-atmosphere potentials to enhance sound levels. Initial tests can involve the use of BNOISE “in reverse.” Except in conditions of strong wind, the intensity of sound at a receiver resulting from a generator will be approximately the same if the receiver and generator switch positions. Therefore, the level of annoyance of a blast at each place on a landscape felt by a resident in a fixed location can be calculated by running BNOISE once for every location, or running BNOISE once with the blast located at the location of the receptor—the resident. Continuing, the annoyance level (and complaint probability) for an entire town can be of a blast located anywhere on an installation can be derived by creating blast input files that locate blast at every residential location. Multiple map layers would be required to evaluate the impact of different types of sources. The results can be calibrated against historic noise complaints to generate future policy designating blast-free areas on installations.

### ***Dust and Smokes***

There is an opportunity to develop models that predict the tolerance of communities to on-installation dust and smoke generation. Existing models predict the concentrations of smokes and chemicals in plumes associated with specific point sources. However, predicting the training and testing capacity far into the future requires analyses in which specific point sources are not known. Using existing models analysis of representative scenarios that involve point locations can be accomplished. However, a model showing where dust and smoke generation would be tolerated would be a useful addition to the long-term planning tools.

Smokes and obscurants research in recent years has focused on their impact on threatened and endangered species. This research is helping to limit the loss of training and testing capacity through detailed understandings of the specific impacts on the species. This information can be used to create software tools to estimate future training and testing capacities in areas that supported threatened and endangered species.



## ***RFI***

RFI analyses in the UHF, VHF, and higher frequency bands for interference potentials on local communities can be conducted using line-of sight analyses from the antennas of the residents. Current raster-GIS based line of sight software for predicting viewsheds can be readily adopted. For the most part, RFI solutions involve negotiations at the local, state, national, and international levels where band allocations are carefully assigned.

## ***Night Vision***

Development of spatially explicit night vision interference analyses associated with both ambient light and encounters with headlights on public roads can be accomplished. Ambient light problems should be addressed through the development of a new GIS-based program that considers the location, intensity, type, spectrum, and positioning (e.g., whether the lights are shining upward) of lights throughout an urbanized area as well as local climate (cloud and humidity) data and generates a map showing the probability of the amount of light energy arriving within training areas.

The problem of encountering headlights during night-vision training exercises primarily requires a case-by-case approach as the distances between an approaching vehicle with headlights and a military vehicle being driven using night-vision equipment is small and is based on the detailed placement of roads, trails, trees, and fences. However, standard GIS analysis may help locate potential problems using road-buffering software. Overlaying training area trail buffers with buffers around public-access roads we can help identify potential problem areas that must then be checked in person.

## 7 Summary and Recommendations

### Summary

Military training and testing will continue to be important in the foreseeable future and will require the management and maintenance of land to accommodate installation requirements. Population growth will continue in the United States. This increase will be accommodated through land-use conversions. In addition, as the population becomes wealthier, the demand for lower density housing increases, which further increases the total acreage occupied by homes. These trends will continue to threaten the training and testing that is done on installations, and to decrease the number and size of locations suitable for training and testing. This occurs because the off-installation lands historically and potentially impacted by smokes, dust, noise, radio interference, and water quality is being converted from natural, range, or agriculture to subdivisions and urbanized areas. Military installations have never formally owned the rights to make these impacts. New problematic land-use incompatibilities can develop when new urban owners of the impacted lands who live on the lands claim to own the rights to silence, clean air, and clean water. Training and testing activities can also change over the decades, resulting in more extensive and more severe off-installation consequences. This can result in new incompatibilities with new (and long-term) neighbors.

Installations have a number of alternatives for dealing with current, planned, projected, and potential land-use conflicts. In the short term, ranges can be moved, training/testing frequency reduced, and times restricted. In the medium term, installations can work with regional planners to locate new roads, schedule road maintenance, establish zoning regulations, create parks, and purchase property rights.

To deal with installation real and potential land-use conflicts, the installation must be able to identify current and future impacts of training/testing across the fence line and to project future training and testing needs. In the short term (1–5 years) we can assume that, in general, the mission of the units on an installation, their equipment, training/testing doctrine, on-installation road networks, and the local climate will remain relatively constant. The current approach for predicting training intensity on the landscape is optimal under these expectations. An installation

land-use impact map can be developed (through a variety of approaches) that depicts the training/testing impact footprint. This shows the pattern and relative intensity of impacts that have occurred in the recent past. By varying the total training, and the specific amount of training per training area/compartments, it is possible to turn the generic footprint into a predicted impact map. In the mid-term (5–20 years) doctrine, weapon systems and installation tenants can change, making it less appropriate to use this approach to generate land-use impact maps based on training. It becomes necessary to capture the rules that are implicitly used by range control and environmental offices to schedule training/testing areas. If these rules could be formalized, then it may be possible to predict mid-term range training/testing land use under alternative management scenarios. In the 20–50 year range it becomes even less tenable to predict weapon systems, warfighting doctrine, political alliances, and installation tenants. For this time period, it may be optimal to seek to guide regional land-use changes in a manner that keeps the military training and testing options open.

## Recommendations

This document set out to address a specific question in order to establish a research direction that will result in new abilities to predict the long term direct and indirect impacts of proposed regional policies and investments on the ability of a local installation to maintain its opportunities and requirements to train and test:

What is the best way to approach analyzing projected urban growth patterns around military installations with respect to changes in community pressure to restrict training and testing, and how might the approaches be different when addressing short (1-5 year), medium (5-15 year) and long (20-50 year) planning issues?

First, it is presumed that installations and/or surrounding regions have projected urban growth patterns. This is only possible after stakeholders: (1) identify their desired future, (2) propose regional and local investments and policies designed to reach that desired future, and (3) have turned these proposals into projections of urban growth. Investments and policies can include land purchases, land ownership rights purchases, land exchanges, relocation of training/testing areas, changes in the timing and frequency of training/testing, regional zoning, direct purchase of some land rights, location of new roads and highways, and conversion of land adjacent to installations into parks, game preserves, and other natural areas that prohibit development.

In the short to medium term, the current basic design of an installation will persist, and changes to training and testing lands will be specifically planned. Impact of training/testing on surrounding communities and the impact of pressure from surrounding communities and local, state, and Federal regulations can be estimated straightforwardly. Therefore, in the short to medium term, predictions of incompatible land use can and should be accomplished with existing software tools and approaches by capturing on and off installation land use change plans.

However, available software tools do not currently address medium- to long-term planning very well. Specifically, the development of installation lands over a span of 10 to 50 years is very difficult, if not impossible to predict. However, the development of urban areas outside installations remains tractable and perhaps easier to predict because, over longer periods of time, the dominant driver of patterns may be dominated more by physiographic features and less by politics. In this time period, installations must switch from seeking to analyze the impact of specific land use training and testing plans on the local community to analyzing the change in training and testing potential. In other words, it makes sense to identify what can be done with installation land over time rather than to identify what is being done or being planned.

The military Land use Evolution and Assessment Model (mLEAM) capabilities adopted by the ERDC Fort Future software development effort currently supports a land use change (LUC) model. Based on the analysis in this report, the following R&D initiatives are recommended to develop approaches for:

- identifying areas on installations that may be under public pressure to limit training or testing due to noise, dust, and smoke
- identifying the percentage of sensitive or important regional habitat (e.g. for TES) on-installation and estimating the level of public and legal pressure to restrict training and testing
- identifying loss of night vision training due to light pollution from urban areas.

The results of such analyses should be integrated into the approaches that estimate the training and testing capacity (e.g., the Army's ATTACC model). The ultimate goal must be to predict how proposed regional policies and investments might affect the medium to long-term training and testing capacity of installations.

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