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Integrated Climate Assessment for Army Enterprise Planning

Effects of Climate Change and Urban Development on Army Training Capabilities

Firing Ranges and Maneuver Areas

Michelle E. Swearingen, Andrew Fulton, Wade Wall,
Rachael Bakaitis, and John W. Weatherly

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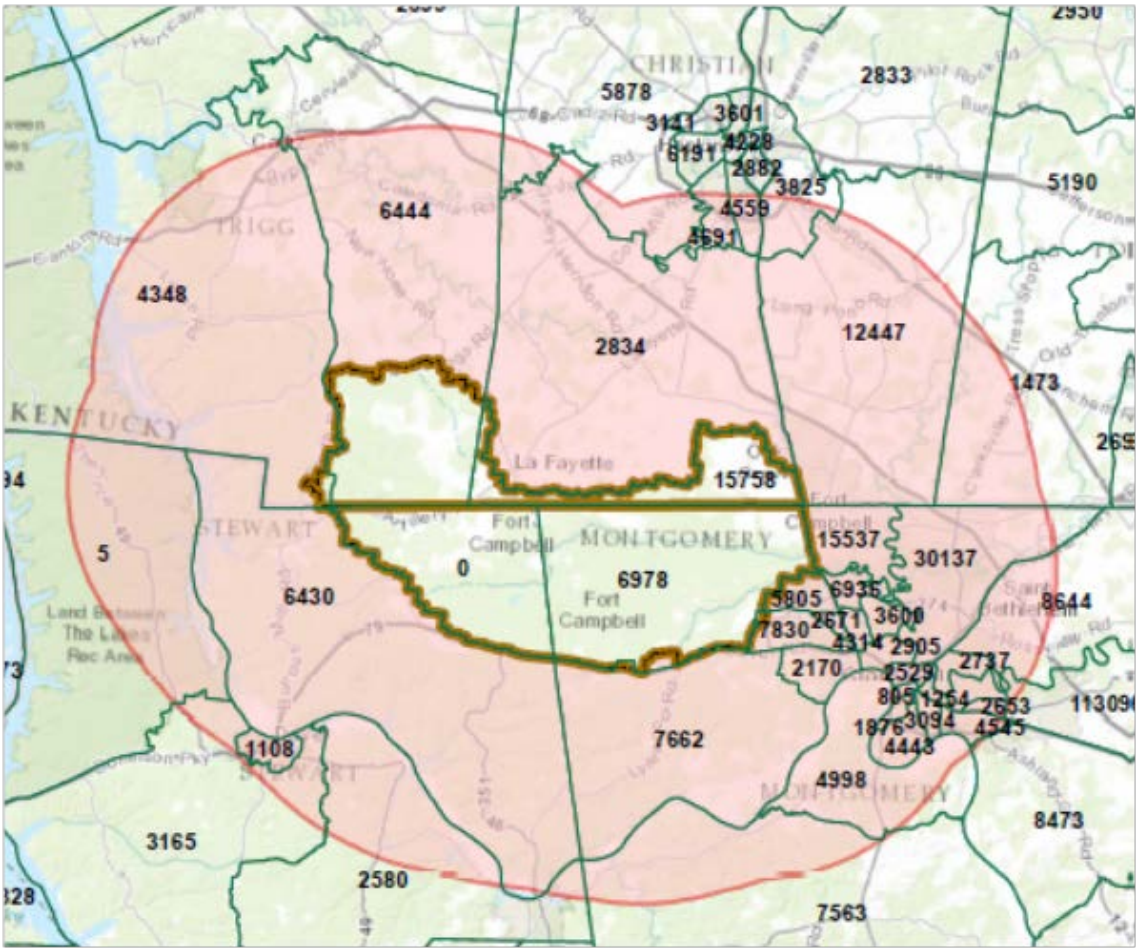

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Effects of Climate Change and Urban Development on Army Training Capabilities

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Abstract

Army stationing analyses have historically been conducted under the assumption that most conditions at and around installations will generally remain static. Previous optimal stationing analyses have resulted in substantial costs associated with moving units, constructing buildings and roads, and local investments in the development of off-post housing, shopping facilities, eating, and other businesses that provide quality of life for soldiers and their families. In reality, the capacity of the natural, social, and built infrastructure changes over time, and, this non-stationarity should be considered in stationing analyses to: (1) avoid premature abandonment of expensive buildings and associated infrastructure, and (2) avoid costly realignments to locations where capacity is being adversely affected by change. This work documents efforts completed in FY14 that began to investigate how potential changes associated with climate and urban development might affect the ability of Army installations to continue to conduct training on firing ranges and in maneuver areas.

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Preface

This study was conducted for Headquarters, U.S. Army Corps of Engineers (HQUSACE) under project 622720A896, "Environmental Quality Guidance," Work Package "Integrated Climate Assessment for Army Enterprise Planning," Work item L4F5G1, "Firing Range Capacity." The technical monitor was Sarah Harrop, Headquarters, Department of the Army (HQDA).

The work was performed by the Ecological Processes Branch (CNN) of the Installations Division (CN), U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, Chris Rewerts was Chief, CEERD-CNN; Michelle J. Hanson was Chief, CEERD-CN; and Alan B. Anderson was the Technical Director for Environmental Quality/Sustainable Lands and Ranges. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

COL Bryan Green was Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

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1 Introduction

1.1 Background

Army stationing analyses have historically been conducted under the assumption that most conditions at and around installations are generally static, or stationary. Army installations rely on surrounding towns, cities, and counties to provide water, energy, a source of labor, and areas that tolerate training by-products such as noise, dust, smoke, and radio interference. Strategic stationing analyses based on this assumption have determined that realignments result in substantial costs associated with moving units, constructing buildings and roads, and local investments in the development of off-post housing, shopping facilities, dining facilities (restaurants), and other businesses that provide quality of life for soldiers and their families.

In reality, conditions at and around installations are not static; the capacity of the natural, social, and built infrastructure changes over time. For example, water availability can dramatically change as aquifers are exhausted at rates that outstrip recharge rates, or as river water is over-partitioned to meet growing city and agricultural demands. Cities nearby to installations that experience population expansion and/or economic development can grow to the point where the economic value of land associated with military activity can become much higher for its potential to support community (residential, industrial, or recreations) purposes than for its perceived value as training land. Shifts in temperature and precipitation patterns can reach the point where the amount of training time available is limited. Finally, listing of threatened and/or endangered species (TES) or their habitats can also result in the reduction of training area footprints and/or the time-periods when the lands are available for training. Stationing analyses must consider this non-stationarity; otherwise, such analyses can result in: (1) the premature abandonment of expensive buildings and associated infrastructure, (2) costly realignments to locations where capacity is being adversely affected by change, or (3) an over dependency on training resources that become further constrained over-time.

Recent changes in Federal policies and guidelines with respect to climate change (discussed in Chapter 2) require the military to consider how these changes might affect the missions at military installations. This work was undertaken to investigate how climate change and urban development may potentially affect the ability of Continental United States (CONUS)

Army installations to continue to conduct training activities, specifically, the ability to support future firing range and maneuver area training.

1.2 Objective

The overall objective of this work was to document efforts completed in FY14 that began to investigate how potential changes associated with climate and urban development might affect the ability of Army installations to continue to conduct training on firing ranges and in maneuver areas. Specific objectives were to:

- develop proposals for estimating how training activities on large weapon firing ranges and maneuver areas will change on Army installations in response to climate change and urban growth.
- list and explore the causal relationships connecting change to future throughput.
- identify the causes likely to result in significant training capacities.
- develop proposals for how anticipated changes can be considered in the Army's future stationing and realignment, specifically by:
  - identifying Military Value Analysis (MVA) attribute(s) associated with maneuver area capacity most likely to be affected by climate change
  - incorporating potential climatic shifts (e.g., changes in temperature and rainfall) into a modified MVA attribute.
- for a subset of installations, estimate climate change impacts on maneuver area capacity.

1.3 Approach

The objectives of this work were met in several steps:

1. Federal government policies and guidance associated with the need to consider non-stationarity, especially with respect to climate change, were reviewed (Chapter 2).
2. Approaches recently used by the Army to conduct strategic stationing studies; for example, past Base Realignment and Closure (BRAC), in which the Army placed a high value on the capacity of installations to support maneuver range and firing range training, were reviewed (Chapter 2). For each of those approaches, the potential for climate and urban development to alter future training activities was investigated.
3. This investigation also focused on how and to what extent training activities might be altered through various cause-effect chains, e.g.:

a. Firing ranges could be affected by how climate might change noise contours outside of installation fence lines (Section 4.2.1).
b. Environmental clean-up costs might change as a consequence of climate change (4.2.2).
c. Heat stress days and fire risk might affect firing range use and throughput (Section 4.2.3).

4. This work also considered the impacts of changing factors on the capacity of maneuver lands to support training (Chapter 5).

1.4 Scope

This work considered the ability of CONUS Army installations to support firing range and maneuver area training into the future by considering traditional current capacities and then by measuring how these capacities are likely to change over the next 50 years. Drivers to those changes are limited to direct and indirect consequences of changes related to climate and urban growth.

This work focuses on Army strategic stationing analyses like BRAC and the European Infrastructure Study (DoD 2015) to provide metrics and context for the impact analysis. The BRAC 2005 Military value (MV) and recent CAA MV analyses were used for metric examples and a baseline for the impact analysis.

1.5 Mode of technology transfer

It is anticipated that the results of this work will provide a foundation for follow-on research in support of Army stationing analyses.

2 Policy Driving Consideration of Climate Change

Executive Order (EO) 13514, "Federal Leadership in Environmental, Energy, and Economic Performance" (White House 2009) declares that all Federal Departments and Agencies are required to evaluate climate change risks and vulnerabilities to manage short- and long-term effects of climate change on the agency's mission and operations, and to include an adaptation planning document as an appendix to its annual Strategic Sustainability Performance Plan (SSPP). EO 13653, "Preparing the United States for the Impacts of Climate Change" (White House 2013) went further by noting that:

> each agency shall develop or continue to develop, implement, and update comprehensive plans that integrate consideration of climate change into agency operations and overall mission objectives and submit those plans to CEQ (Council on Environmental Quality) and OMB (Office of Management and Budget) for review.

The Department of Defense (DoD) recognizes the need for a strategic approach to the challenges posed by global climate change, including potential impacts to missions, built infrastructure, and natural resources on DoD installations. Executive Orders, the CEQ, and the Climate Change Adaptation Work Force prompted DoD elements to enact climate change policy guidance. This was reflected in the 2010 Quadrennial Defense Review (QDR), which required that climate change be taken seriously and directly considered in long-term Army planning. The QDR, the principal means by which the National Defense Strategy is translated into new policies and initiatives, states that "The Department must complete a comprehensive assessment of all installations to assess the potential impacts of climate change on its missions and adapt as required."

To address the QDR, the DoD Strategic Sustainability Performance Plan (2010) defined the need to integrate climate change considerations into existing processes using robust decision-making approaches based on the best available science. In the *DoD 2014 Climate Change Adaptation Roadmap* (DoD 2015), the Army recognized that climate change interacts with stressors that it already considers and manages. In the 2013 Report to Congress on Sustainable Ranges (DoD 2013), the Army reported progress toward fulfilling this policy. The Army's approach is to integrate climate

change issues into existing processes instead of considering it as a separate decision-making process. DoD intends to fully integrate climate change considerations into its extant policies, planning, practices, and programs. More recently, this requirement was described in Secretary of Defense Draft Memo, "Actions Required to Support Defense Mission Readiness in a Changing Climate" (2013), which refers to DoD's deep experience in planning for uncertain futures, and directs the DoD Senior Sustainability Council (SSC) to establish policies and guidance for conducting consistent climate change vulnerability assessments across DoD components. Most recently, *The President's Climate Action Plan* (2013) re-emphasized the development of tools for more effective climate-relevant decision making.

The Office of the Assistant Secretary of the Army for Installations, Energy, and Environment Office of the Assistant Secretary of the Army for Installations, Energy and Environment (OASA[IE&E]) has the lead responsibility for integrating climate change into Army planning processes. This requirement is documented in the *Army Campaign Plan* (HQDA 2011) as Objective 2-7, "Adapt/Execute Climate Strategies." In FY12, OASA(IE&E) tasked ERDC with developing an adaptation planning framework that is consistent with CEQ and the goals of the DoD Climate Change Adaptation Roadmap to integrate climate change planning in existing Army installation planning processes. This effort considered five major Army installation planning processes including: Installation Strategic Plan, Installation Master Plan, Installation Range Complex Master Plan, Installation Integrated Natural Resource Management Plan, and Installation Critical Infrastructure Risk Management Plan. This effort did not address Army enterprise planning processes including BRAC, stationing decisions, and acquisition. The Army currently lacks approaches and tools to incorporate climate change into enterprise-wide decision processes. The objective of this work is to address this Army deficiency.

The Army requirement to consider the impact of climate on long-term enterprise-scale basing and stationing decisions directly results from the fact that weather is inherently intertwined with the Army's ability to successfully complete required training and testing missions, and to perform operation and maintenance (O&M) of both built and natural infrastructure. Future weather, as affected by climate change, will change in short-, mid-, and long-term time-scales. These changes will be reflected not only in long-term trends, but also in the variability and frequency of extreme weather events. There is a need to support the planning decision process

and its associated assessments of enterprise systems and installation functions with regard to their vulnerabilities to future weather impacts.

Unless the Army develops the ability to assess and incorporate changing future conditions into Army planning scenarios, those changing conditions could compromise mission success and the long-term sustainability of the Army enterprise. Current decision processes that support enterprise and installation planning assume that present environmental conditions will remain static and persist as such into the future. Therefore, installation metrics used in long-term enterprise planning (e.g., BRAC, stationing, and land set-asides) are typically fixed values across the planning horizon. The various metrics that are used were created to collectively represent the capabilities, value, and costs incurred by installations meeting mission requirements. At this time, the Army does not have an objective, repeatable, time relevant, and cost appropriate approach to assess how these metrics might change as a consequence of climate-related dynamics.

Addressing these needs requires some ability to forecast the future climate for areas of interest to the Army, typically individual installations. The future climate for any given location is extremely difficult to forecast. At research institutions around the world, there are roughly a couple of dozen different general circulation models, also known as global climate models (GCMs). These typically run for the globe over a century or more with a resolution of approximately 2 degrees. They take as input the current climate, landforms, winds, and currents. Winds and currents are considered for multiple levels on the atmosphere and oceans. An important input is a forecast of greenhouse gas (GHG) concentrations over time, currently called Representative Concentration Pathways (RCPs). There are over 100 combinations of GCMs and RCPs, and each supercomputer-based simulation results in different forecasts. The RCPs are established to represent a suite of possible GHG emission futures, with no probability established. Simulation results are typically not useful for a given location until they are downscaled to resolutions of a few kilometers squared; there are several approaches for accomplishing this. The result of running all of the GCMs for the suite of RCPs and then downscaling those results with a variety of methods leaves a wide range of future climate possibilities for a given location, none of which is associated with any likelihood of occurring. Any application of this data must therefore involve at least analyzing a representative set of results to capture the range of forecasted futures.

Climate has been measurably changing across the globe and, in many cases that change has been accelerating. Changing climate will begin to affect (and in some cases is already affecting) urban development, water resources, and TES habitat — all factors that are relevant to a military installation's long-term viability for mission success and that are conceptually related to current decision metrics. Army-relevant models for various natural and built systems exist, but do not account for cause-effect relationships associated with climate change (from short to long term).

Specific systems that are most pertinent and essential for assessment include: infrastructure and energy, water availability, climate-dependent noise propagation, urban growth and encroachment, threatened and endangered species, and climate-aggravated training impacts. These are outlined as follows:

- *Infrastructure and Energy*. Increased temperatures and increased human residential, commercial, industrial, and agriculture leads to increased demands on energy sources and energy distribution networks, potentially resulting in local or regional brownouts. Temperature changes also impact facility O&M costs.
- *Water Availability*. The availability, quality, and cost of water are crucial to sustaining the military mission. Demands on water for regional agriculture, cities, energy sustainability, and habitat security will change with changing climate, urban patterns, and technologies.
- *Threatened and Endangered Species*. The probability of future species listings may impact the availability of Army training and testing lands and their associated management costs.
- *Climate-Aggravated Training Impacts*. A critical and limiting Army asset is its training and testing areas – especially large maneuver landscapes. Climate may significantly alter the resiliency of natural vegetation on maneuver areas and produce secondary effects that may degrade soil quality. Soil degradation will negatively impact the land's training or carrying-capacity and increase maintenance costs.
- *Climate-Dependent Noise Propagation*. Weather conditions dramatically alter the amount of noise associated with military training and testing activities that propagates beyond installation boundaries into surrounding communities. Since military training and testing activities can be restricted when associated noise impinges on those communities, climate change can potentially impact the number of days ranges can operate without restrictions.

- *Urban Growth and Encroachment*. Urban growth will continue to erode military mission opportunities in several ways, including noise complaints, destruction of habitats suitable for listed species, changes in water demands, and changes in energy demands.

The development of science-based, climate sensitive enterprise decision metrics and associated data and models that enable regional and national scale assessments is critical to meeting Army objectives. The ability to perform informed risk analysis, forecast future scenarios of competing enterprise investment, and assess future facility value and cost will allow the Army to save both time and money over the near and far term.

3 Army Stationing Analysis

3.1 Background

Changing conditions and challenges around the world, changing political situations, and evolving technologies and tactics all work to alter the requirements for maintaining Army readiness. One consequence of such changing conditions is that the Army often finds itself with excess, unwanted, or unneeded facilities. In the 1950s DoD began downsizing its inventory of land and infrastructure. Through the 1960s, DoD was free to make its own divestment decisions. In the 1970s and early 1980s, closures were largely halted, in part to prevent a loss of jobs in areas installations might otherwise have been closed. To meet growing needs to realign installations and bases in the United States, Congress passed PL 100-526, which authorized "BRAC 88." Congress then added language to Section 29 of the *National Defense Authorization Act Year 1991* that authorized future rounds of BRAC. Additional rounds were then conducted in 1991, 1993, 1995, and 2005.

BRAC 2005 was the first such study in 10 years, and the most ambitious. Unlike previous rounds, BRAC 2005 was conducted when the nation and military were in a post 9/11 environment, and when the military structure was not in a drawdown; military transformation was a major emphasis. These conditions required that stationing analyses consider a 20-year time horizon and a 20-year Net Present Value (NPV) cost horizon. Another major change was that, for the first time, seven Joint Cross-Service Groups (JCSGs) were allowed direct input in addition to the three military departments conducting analyses for input into the process.

The Center for Army Analysis (CAA) was tasked with supporting the Total Army Basing Study (TABS), which was responsible for conducting BRAC analyses. Figure 1 shows the TABS Group's methodology. DoD established eight criteria (Wynne 2005) for conducting the BRAC 2005 analyses:

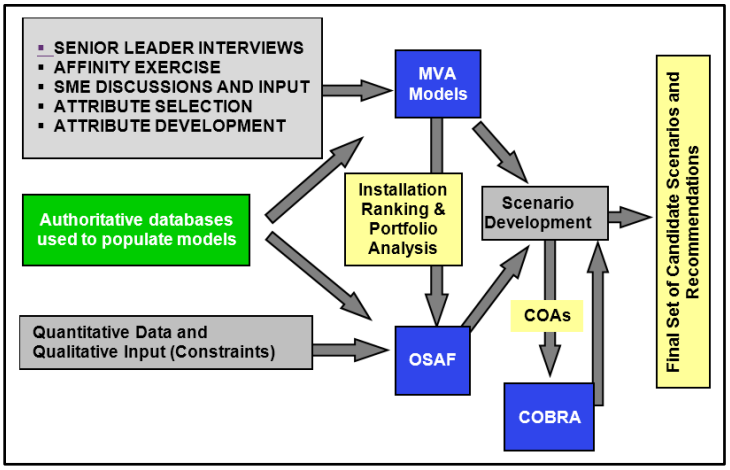
1. *Criterion 1*. The current and future mission capabilities and the impact on operational readiness of the total force of DoD, including the impact on joint warfighting, training, and readiness.
2. *Criterion 2*. The availability and condition of land, facilities and associated airspace (including training areas suitable for maneuver by ground, naval, or air forces throughout a diversity of climate and terrain areas and staging

areas for the use of the Armed Forces in homeland defense missions) at both existing and potential receiving locations.

3. *Criterion 3*. The ability to accommodate contingency, mobilization, and future total force requirements at both existing and potential receiving locations to support operations and training.
4. *Criterion 4*. The cost of operations and the manpower implications.
5. *Criterion 5*. The extent and timing of potential costs and savings, including the number of years, beginning with the date of completion of the closure or realignment, for the savings to exceed the costs (i.e., Cost of Base Realignment Actions [COBRA]).
6. *Criterion 6*. The economic impact on existing communities in the vicinity of military installations.
7. *Criterion 7*. The ability of the infrastructure of both the existing and potential receiving communities to support forces, missions, and personnel.
8. *Criterion 8*. The environmental impact, including the impact of costs related to potential environmental restoration, waste management, and environmental compliance activities.

The first four criteria were considered the "Military Value" (MV) criteria, the last four as "Other." The installation ranking and scores developed through the Military Value Analysis (MVA) process were combined with additional installation quantitative and qualitative data as inputs to the Optimal Stationing of Army Forces (OSAF) model. OSAF prescribed possible optimal portfolios of unit-installation assignments given a budget constraint, resulting in potential courses of action (COAs). These were evaluated using military judgment, COBRA, and environmental and local area models to define the final set of candidate recommendations.

Figure 1. CAA's methodology.



3.2 Military value analysis

The CAA continues to use the referenced MVA process for strategic studies including stationing and realignment analyses and adapts the process to each specific application. It employs a Multi-Objective Decision Analysis (MODA) that involves quantifying qualitative data/information. The understanding and knowledge of senior leaders and subject matter experts are gathered to identify the appropriate considerations, to establish qualitative values for those considerations across installations, and to quantify those values to support combination and integration. For each MVA application, CAA seeks to ensure that the chosen installation attributes meet the Specific, Measurable, Attainable, Realistic, and Timely (SMART) criteria:

- *Specific*. Attributes must be clear and focused to avoid misinterpretation; their assumptions and definitions must be easily interpreted or explained.
- *Measurable*. Acceptable attributes are those that can be quantified and compared to other data. Attributes should allow for meaningful statistical analysis. In determining attributes, avoid binary "yes/no" measures, which become screening criteria.
- *Attainable*. Attributes must be achievable, reasonable, and credible under conditions expected.
- *Realistic*. Attributes must fit into the models and be cost-effective.
- *Timely*. Attributes must be achievable within the given time frame.

The attribute metrics must be combined, resulting in an overall score for each installation. Hence, each attribute must be scaled in some manner and then properly weighted for combination with other attributes. For BRAC 2005, 40 attributes were chosen to represent the value of installations. Each attribute has one of three levels of operational support. Each attribute also has one of three primary levels of "ability to change": (1) mission (very difficult to change), (2) mission support (difficult to change), and (3) mission enablers (changeable with Army dollars). Finally, each attribute was associated with an importance weight on a scale of 1 to 100.

The current CAA MVA methodology uses the following seven steps:

1. Review the most recent application of MVA.
2. Add/delete/update attributes and value conversion curves to reflect the current requirement.
3. Modify the weighting scheme, if needed, using subject matter expert (SME) input.

4. Receive the list of installations for consideration.
5. Collect installation data from designated organizations.
6. Calculate values for installation alternatives and run sensitivity analyses.
7. Work with the customer (G-3) to prepare recommendations for Army senior leadership.

The MVA methodology first developed for BRAC 2005 was vetted, validated, audited, and approved by senior Army and DoD leadership, and has since been applied to many stationing analyses. For a recent operational analysis, it was possible to reduce the relevant attributes for a Brigade Combat Team (BCT) selection study down to a total of 16. Every new analysis always begins with a candidate set of attributes that are reduced to the minimum possible.

3.3 Optimal stationing of Army forces

OSAF uses an integer-programming optimization approach to match units to installations and was the first such model of this type to be used within the BRAC scenario development process Loerch et al. (1996) report an early optimization application that addressed the challenge of stationing across Germany. The original OSAF model was developed for the 2001 QDR to aid in stationing decisions (Dell and Tarantino 2002). Previously, a post-BRAC analysis model that supported the optimal implementation of approved scenarios, called the Base Realignment and Closure Action Scheduler (BRACAS), was developed to support the BRAC 95 implementation (Dell 1998). These efforts had their foundation at the Naval Post Graduate School (NPS). For example, Singleton (1991) and Tarantino (1992) developed early stationing optimization analysis models for their master's theses. These capabilities were further enhanced at NPS into the Optimally Stationing Units to Bases (OSUB) model (Dell et al. 1994). OSUB used an elastic bi-criterion mixed integer-programming model that combined military value with cost objectives to assist the Army with closure and realignment.

After the development of OSAF for the QDR, the model was further developed at CAA for the purpose of supporting future analysis studies (Tarantino and Connors 2001). This early version of OSAF was applied to a Korean stationing study (OSAFK) that optimally stationed 194 units across 51 installations (Gezer 2001), a study to station the 21st Air-Cav (Tarantino 2002) Dell et al. (2008) documented the OSAF application used within BRAC 2005, which uses an integer-programming optimization capability

written within GAMS (General Algebraic Modeling System) (GAMS 2015) and the CPLEX solver (GAMS/CPLEX). The input to the model takes the form of descriptions of the stationing capabilities and limitations of about 70 installations grouped into five types where soldiers can be stationed. Model inputs require descriptions of about 6000 units aggregated into 655 stationing packages. The goal of the optimization model is to prescribe the stationing of unit-packages at the 70 installations in a manner that minimizes the NPV of the solution, subject to the installation capabilities and constraints. (A data update is in progress to consider 100 installations and over 800 stationing packages (CAA 2013). Installation capacities and considerations include:

- infrastructure inventory, condition, and size in square feet
- population
- maneuver land and range days available
- housing inputs include: staffing, percent married, number of units, housing allowances, and on-base costs
- additional inputs include: Base Operating Support, Real Property Maintenance, moving costs and mileage, Military Construction (MILCON) cost factors, and Program costs (program management, mothball, and caretaker)
- Military Value Scores (from the MVA Model).

Installations have fixed costs and variable cost-per-soldier and cost-per-civilian assigned to the installation.

Unit Requirements include buildings, land, and ranges. Unit maneuver and range requirements come from Army Technical Committees (TCs) such as TC 25-1 (Sustainable Range Program 2004). OSAF considers two types of maneuver land: heavy and light, and 18 range types.

While seeking an optimal solution, OSAF uses elastic variables to accommodate shortages by lowering required levels of an asset (universally or at specific installations), or by requiring construction. For a subset of installations, the units stationed there are allowed to train at any installation in the subset. Units realigned are assigned one-time transportation costs for moving; this triggers military construction to meet unit requirements.

The OSAF post-optimization analysis considers model outputs (e.g., NPV and number of units moved) with a number of factors not specifically included in the model's objective function. These include the overall military

value, turbulence caused by the number of units moved, strategic implications given closures and realignments, quality of life, environment, and ease of mobilization/deployment. For BRAC 2005, OSAF informed the scenario development process that recommended closing 13 installations that primarily house active duty soldiers, 176 Army Reserve centers, and 211 National Guard armories; and realigning 56 active component units.

3.4 Opportunities

Every stationing and realignment analysis is a challenge due to changes in mission needs, strategic implications, ability to forecast future needs, and unique unit requirements. The above review of OSAF reveals a substantial capability to help inform a strategic stationing analysis like BRAC. The first BRAC analyses did not use large-scale optimization; however, with the efforts of one professor and a couple of master's degree candidates, optimization techniques were developed, formalized, and proven. By 2003, the OSAF optimization model was used for multiple smaller analyses and for the 2001 QDR. For BRAC 2005, OSAF brought a high level of mathematical modeling to the TABS and became central to informing the scenario analysis process.

OSAF is being maintained to allow efficient use in anticipated future strategic stationing studies. Opportunities to improve OSAF to meet future challenges exist in multiple categories of study, one of which is further discussed here. This report addresses enterprise dynamics that can result in significant changes to an installation's MV over time. Historical versions of MVA rely on installation metrics that represent a snapshot-in-time, with the presumption that the metrics will not significantly change. Such an approach provides an installation's MV and an OSAF input, which is adequate if a strategic study that covers a short period of time, for example 2-5 years; or if the study provides decisions used within an adaptive management approach, in which decisions allow movement toward a desired future without fully committing to that future.

The last Army strategic stationing study, BRAC 2005 was 10 years ago and it is anticipated that the next BRAC may not occur for multiple years. With a decade or more between these strategic analyses, analysts must strive to look farther and more clearly into the future to ensure development of wise realignment recommendations. The primary goal of the research documented in this report is to establish approaches for pulling the curtain of time back to reveal likely futures, their required missions, and changes to

the various costs and constraints associated with missions. While BRAC 2005 considered the implications of their recommendations over a 20-year period with static installation values, future strategic studies including BRAC may need to include forecasts of changing installation metrics, conditions, capabilities, and costs; and then to determine the resulting change in an installation's military value over 30 or 40 years.

4 Firing Range Capacity

Live-fire ranges are critical for fulfilling the training mission at many installations. These firing range areas are typically completely contained within military installations and include firing points (where weapons are fired), impact areas (where the fired projectiles land and can detonate), safety fans (which are evacuated during range activity), and noise zones. Each of these must remain intact for the range to function. Unfettered use of these ranges can be affected by changing conditions, due to climate or encroachment.

For example, the use of firing points can be affected by hot weather that results in restrictions to soldiers' ability to spend the necessary time outside (heat stress days). Impact areas can be affected by requirements to protect designated threatened or endangered species (TES) and by requirements to curtail use due to an increased fire risk. Safety fans often overlap with other land uses that are allowed to take place when the range is not in operation. As pressure to accommodate these diverse uses increases and climate shifts occur, the potential throughput of the range can be limited. Finally, development of urban patterns within noise zones can eventually lead to limitations on the use of a range and even the complete abandonment of the range due to strong negative community response.

The range of potential climate futures for any given area as forecasted by the many GCMs based on GHG scenarios defined by the several RCPs can result in a variety and range of consequences. These changing climate forecasts are associated with multiple unknown repercussions although it is known that it can alter the potential for range fires, the listing of endangered species, and the times that soldiers are allowed to train under heat stress. Urban growth can alter the response of local communities to noise and other encroachment factors. Understanding the implications of climate change and urban growth on the long-term viability of installation firing ranges is critical to making informed restationing decisions that will be valid over a long time horizon.

The Firing Range Capacity project within the Integrated Climate Assessment for Army Enterprise Planning program has two primary goals: (1) to determine the factors related to firing ranges that are influenced by climate change and temporal change, and (2) to estimate the magnitude of the factor's influence on restationing analyses. Firing range capacities have been included within BRAC MVA models and in the OSAF model. The

MVA attributes considered in firing range capacity are Range Sustainability, Population Impact (Urban Sprawl in BRAC 2005), Indirect-Fire Capability, and Direct-Fire Capability. Of these, Range Sustainability and Population Impact currently have known potential to change over time, due to climate change and related factors. Indirect-Fire Capability and Direct-Fire Capability only consider the geometry associated with the ability to safely fire various weapons systems. The current version of OSAF considers the capacity of 18 different range types. Of those, this work considers the impact of change on only those ranges supporting the largest weapons. It is assumed that small arms ranges are far less impacted by local urban growth and climate change.

In the first year of this investigation of the potential for climate change and other temporal changes to impact installation firing range capacity, work focused on determining the relevant factors. Noise contours, urban growth, and environmental clean-up were considered (Sections 4.1.2, 4.2.1, and 4.2.2). Section 4.2.3 discusses fire risk and heat stress days, which were also noted as potential factors. The presence of and impacts on TES were noted as a potential factor of interest and will be addressed in a follow-on report.

4.1 MVA and OSAF attributes considered

This project initially focused on the potential to incorporate the temporal influence of climate change on firing ranges into definitions of several selected applicable BRAC 2005 MVA attributes: Range Sustainability, Population Impact, and Indirect and Direct-Fire Capability. Based on other MVA attributes used in the 2005 BRAC analysis, an MVA attribute, Noise Contours, was also examined.

The following sections describe the MVA attributes considered in this study and propose potential modifications that will enable the inclusion of the possible effects of climate change. Appendix A to this report includes descriptions of record for each attribute as provided by CAA in November 2014.

4.1.1 Range sustainability

The Range Sustainability attribute determines the amount of training area available without restrictions and includes a factor denoting land resiliency. This attribute was originally considered as a potential vehicle for in-

corporating climate change factors on live-fire ranges into the MVA. However, the most recent CAA MV attribute listing for BCT analysis (July 2014) version of the attribute definition explicitly ties this attribute to maneuver areas (see Appendix A). The addition of live-fire ranges to this attribute would require significant additions to the attribute definition due to the different environmental impacts on these two different types of ranges. Adding live-fire ranges to the attribute could dilute the value of the attribute to the overall analysis.

4.1.2 Population impact

According to the May 2014 draft (included in Appendix A), the Population Impact (titled Urban Sprawl in the BRAC 2005 analysis) MVA attribute examines the population density within a 10-mile buffer zone around the installation and uses a growth factor based on the change in population over the 20 years between 1990 and 2010. The population density is assumed to be evenly distributed within the entire buffer zone. The intent is for this attribute to serve as an indicator of potential encroachment issues.

Population data are gathered using the most recent decennial census geospatial data at the census block level. Growth factors are derived from the change in census block level data from the most current decennial census and the one immediately previous to it. For example, an assessment performed in 2014 would use the 2010 data as the current set, and 1990 as the previous set. The method then imports the data into a Geographic Information System (GIS) tool and finds a 10-mile buffer zone just outside the Installation boundary. Installation boundary data are gathered from Army Mapper, the Army's geospatial dataset of record for installations. Note that those boundaries are notional; the legal boundaries are maintained by the U.S. Army Corps of Engineers. Averaged population density and population growth rates are then calculated. These values are normalized across the entire set of installations in the study set so that the population impact score (normalized population density + normalized percent change in population) can be calculated.

The methodology presented in the MVA attribute definition provides a generalized indicator of the potential for future encroachment issues. For the scale required in a restationing analysis, this may be sufficient. However, while it is useful to have information regarding population densities around military installations as an encroachment indicator, the methods used fall short of relating significance to the locations and projected

growth rates of the population centers. Encroachment factors include noise, dust, radio frequency availability, light pollution, and others. Noise, dust, and light pollution encroachment all depend on the locations of the residential centers. Synchronizing the encroachment factors and projected urban growth would result in a more meaningful assessment of the impact of urban sprawl.

A linear, uniform model for population growth fails to capture the areas in which growth is projected to occur. The locations of growth are quite important from an encroachment standpoint. For example, growth in an already-densely populated area near the cantonment area is a lesser impact on training ranges than the introduction or rapid growth of a lightly-populated area near the training ranges. For time periods greater than 10-20 years, a linear growth model may not be appropriate.

There is an opportunity to significantly improve the underlying analysis for this attribute. While the current methodology for calculating population impact may be sufficient at a screening level, the use of a more-refined attribute would be of value, particularly in cases where the population impact is not obviously a large or an insignificant factor in the analysis.

4.1.3 Indirect-fire capability and direct-fire capability

The Indirect-Fire Capability and Direct-Fire Capability MVA factors measure the ability of the installation's ranges and impact areas to support indirect-fire/non-line-of-sight and direct-fire weapons training. The score is based on the largest weapon fired on the installation and the distance from the firing point to the impact area. Discussions with CAA noted that the Direct-Fire Capability attribute has not been used since the 2005 BRAC and that as of July 2014, the Indirect-Fire Capability attribute has been replaced by Dudded Impact Area. The Dudded Impact Area attribute provides a measure of an installation's ranges and impact areas to support indirect-fire/non-line-of sight weapons training. The score is based on the number of impact areas and the size of the largest impact area. The Indirect-Fire Capability attribute assigned a score corresponding to the largest weapons system that could fire on an installation, based on required distances.

All of the attributes considered in the above paragraph are purely geometrical in form. They do not consider the availability of the firing ranges and impact areas for live-fire training. If the analysis of potential influences such as fire risk, TES impacts, and clean-up present significant constraints

on range training activities, it may be necessary to develop an attribute that takes the availability of firing ranges and impact areas into account. This attribute could be in addition to the Dudded Impact Area attribute.

4.1.4 Noise contours (2005 BRAC MVA attribute)

During the 2005 BRAC process, noise contours were considered as an attribute in the MVA analysis. The area outside of the fenceline impacted by Noise Zones II and III (as defined by AR 200-1, Chapter 14) was summed, weighted by installation size, and converted into a reference value. It is not clear that any consideration regarding current or projected land use of these areas was taken into consideration. The most relevant method for incorporating noise contours into an MVA analysis could be to include the noise zones in the Population Impact attribute. This concept is described more fully in Section 4.4.1.2.

4.1.5 Firing range capacity (OSAF)

The OSAF model includes information about range throughput in its input set. Because this model is highly flexible and constantly evolving, it should be possible to include in the model estimates of restrictions on range training activities. These restrictions can include curfews due to noise, days or hours lost due to heat stress, days lost to high fire risk, areas/times lost to Endangered Species management, and other range uses that restrict training. Further work in this area is recommended.

4.2 Environmental factors considered – Criterion 8

Three factors considered in this study that align more strongly with the category of Environmental Factors, BRAC Criterion 8, than the MVA analysis are: Noise, Environmental Clean-up, and Heat Stress and Fire Risk days. This section describes the investigations into each of these factors and presents results.

4.2.1 Noise

Noise produced during live-fire training operations, particularly from heavy weaponry and demolitions, is often the most persistent reminder to communities that they are located near a military training installation. These noises are sudden, infrequent, and at times loud enough to rattle windows. Sound propagation is strongly influenced by the meteorological conditions present during the noise event (Valente et al. 2012). However, it is unknown

whether the aggregate combination of propagation conditions has a significant influence on the annual long-term average noise levels that are used for land use planning purposes. Because of this, it was determined necessary to investigate the influence of the current local climate on annual average noise contours, and to determine the impact, if possible, of climate change on these contours. This work examined predicted noise levels using multiple methods and metrics to address these questions by:

1. Examining the relative influences of combinations of wind speed, wind direction, and atmospheric stability.
2. Developing a method for creating an "acoustic climate" simulation (see Section 4.2.1.2 for the definition), enabling the use of location-specific climate data to create an annual average noise contour.
3. Investigating the importance of using location-specific simulation sets.

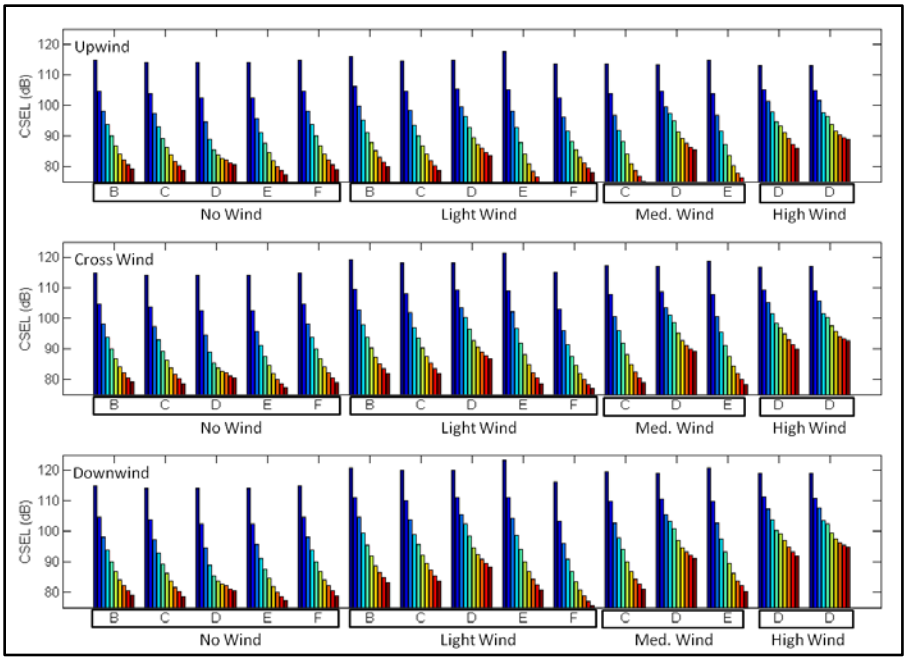
Each of these steps is described in more detail below.

4.2.1.1 Individual propagation condition effects

The influence of instantaneous meteorological conditions on sound propagation is well-known (Valente et al. 2012). To begin developing an intuitive sense of how a changing climate could impact the long-term noise assessment contours, this work investigated individual propagation conditions. This portion of the study used a set of sound propagation simulations that vary the wind speed and Pasquill Stability Class (Pasquill 1974). Wind speeds were set to only cover values that occur frequently with each Pasquill class. Upwind, downwind, and crosswind conditions relative to the propagation direction were calculated for distances out to 10 km, using a simulated source equivalent to 5 lbs of Composition C4 plastic explosive. The results are presented as C-Weighted Sound Exposure Levels (CSEL), in decibels.

Several interesting observations were made during the data analysis. First, the well-mixed atmosphere (Pasquill Class D) had the slowest attenuation rates by far. In other words, during this condition, the sound levels will persist at a higher level for much longer distances than during other conditions (Figure 2). Second, it was then noted that light wind cases (i.e., wind speed of ~2 m/s [~5 mph] at a height of 10 m) depended most strongly on the stability class, with the more stable conditions (E and F) attenuating much more quickly than the well-mixed (B-D) conditions.

Figure 2. Decay vs. distance under different atmospheric stability conditions. Letters correspond to the Pasquill Stability Class. Light wind (~ 5 mph), Medium wind (~10 mph), and high wind (15 and 20 mph, left to right). Upwind corresponds to sound propagation into the wind, downwind corresponds to sound propagation with the wind, and crosswind corresponds to sound propagation perpendicular to the wind direction.



Third, decay rates, with the notable exception of Class D, were found to be nearly identical for the no wind and the medium wind cases. Finally, once the wind speed exceeded 6 m/s (~15 mph), higher wind speeds had little impact on the propagation. As expected, levels are higher in the downwind direction.

These observations highlight the fact that sound propagation is highly dependent on meteorological conditions. This work postulated that areas with a preponderance of light winds will result in annual average noise contours that are sensitive to the frequency of occurrence of different stability classes. It can also be postulated that, in cases where high winds are common, levels will be higher overall. Other than these very broad observations, it is difficult to discern what the impact may be over the course of a year at a location. To further investigate this, an "acoustic climate" was developed and then construct was this used to predict annual average noise levels.

4.2.1.2 The acoustic climate

The second task in this activity was to develop a method for creating a location-specific "acoustic climate" scenario. First, the "acoustic climate" was defined as the set of individual acoustic propagation cases that occur and

their frequencies of occurrence, over the course of a year at a unique location. This set of conditions is then used to create the aggregate model used to calculate an annual average noise contour using the CDNL (C-weighted Day-Night Sound Level) metric. To achieve this, climate data were obtained from the Air Force Combat Climatology Center (AFCCC) for the seven test locations as defined in Section 4.3.1. The climate data were presented such that the frequency of occurrence for each combination of 6-hour time window, Pasquill Stability Class, wind speed category, and wind direction (every 22.5 degrees) were available. Because using this data in their raw form would generate an unwieldy set of conditions to consider for noise contour simulations (BNoise2), the data were consolidated into day and night (0600-1800, 1800-0600), Pasquill class, wind speed category, and quartile wind direction (every 90 degrees). This resulted in a much more usable number of conditions for calculation. The number of conditions considered is important as the noise simulation software performs one calculation for each condition and each source, and then performs a weighted sum to find the aggregate result. Therefore, the runtime is linearly connected to the number of conditions considered. Time was divided nominally into day and night to accommodate the nighttime penalty that is applied to the noise attribute (CDNL) that is used in military noise assessments.

4.2.1.3 Location-specific noise contours

Once the acoustic climate cases were built, an analysis was done to investigate the impact of using these cases. The specific intention was to examine how much change would occur in the levels at different distances and in different directions. To accomplish this task, noise levels in CDNL were calculated for a 5 lb charge of Composition C4 for distances out to 10 km in the four cardinal directions (North, East, South, and West). Calculations were performed for each of the seven acoustic climates developed by performing a weighted sum of the levels produced by each of the occurring propagation conditions shown in Section 4.2.1.1.

The results of these calculations produced an interesting result (Figure 3). In all seven diverse locations, the predicted levels at 10 km were all within 5 dB. This is quite a small difference, considering the propagation distance of 10 km, and is well within the typical error associate with propagation calculations. If the decay plots are related to the wind roses shown in Figure 4, one can see that the frequency of occurrence of winds coming from a direction has a noticeable impact on the decay when the frequency of occurrence is high.

Figure 3. Annual average noise levels for all seven test locations, calculated using the acoustic climates.

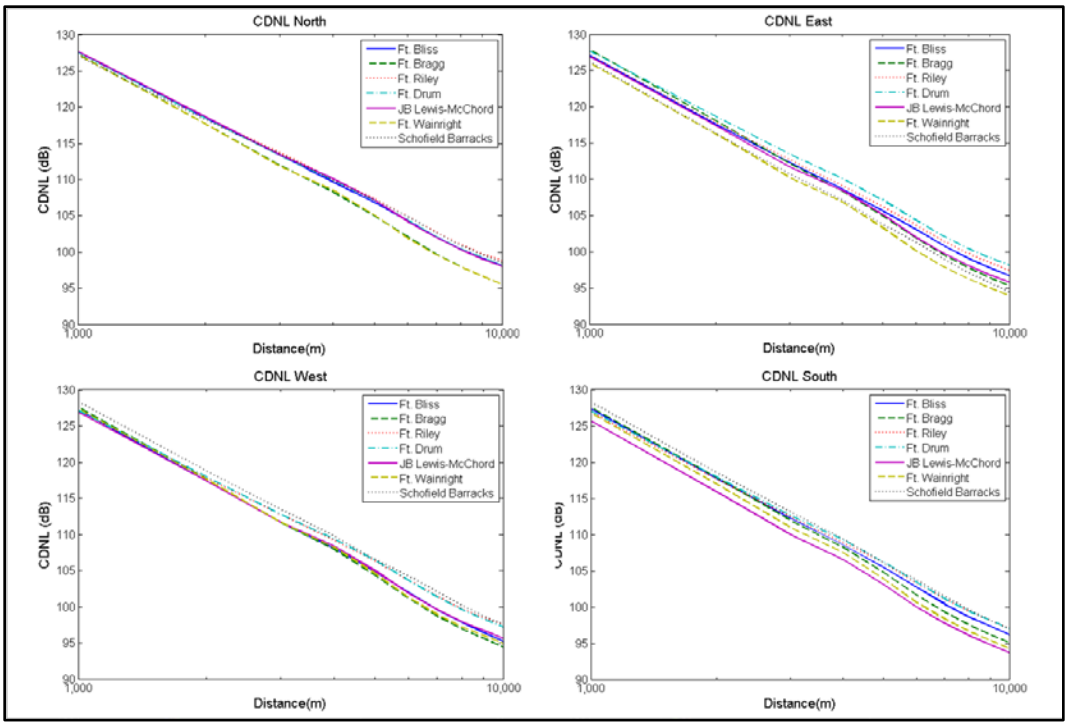
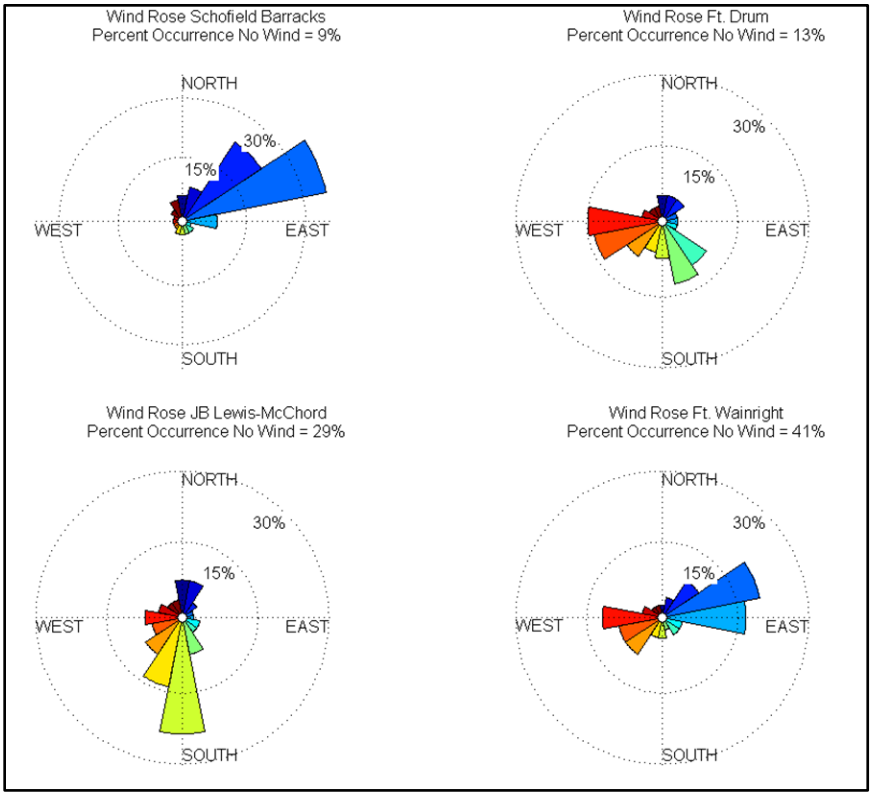


Figure 4. Wind roses showing frequency of occurrence of wind in each direction. Wind speed is not represented in this representation.



For example, Joint Base Lewis-McChord has predominant winds out of the south. The levels to the north are higher than those to the south by nearly 5 dB at 10 km, and nearly 3 dB at 1 km. In another example, Schofield Barracks has winds predominantly out of the east, and levels to the west are higher than in other directions.

In conclusion, in some cases, such as those with a preponderance of wind from a specific direction, the local climate plays a significant role in the directionality of the noise contours. Conversely, for cases with highly variable winds, the inclusion of local climate does not significantly impact the shape of the noise contour. Overall, the differences are not large in an acoustic sense. However, a small change in predicted level can correspond to a large change in area within a restricted use noise zone. Therefore, consideration of the local climate can lead to more accurate assessments of the noise impacts on a local community. A more detailed investigation, using realistic training data, is needed to fully determine the necessity of using local climate data for long-term noise assessments.

4.2.1.4 Climate change influence on noise contours

This project considered the feasibility of using future climate projections from climate models to predict the changes in noise contours. While the atmospheric variables that most strongly influence noise propagation, wind direction and low-level stability, are simulated in climate models, the accuracy and reliability of these variables on the local scale in the global models is limited. In addition, there is little direct correlation between large-scale climate changes and wind direction for most locations. There is low reliability (and a large degree of random scatter) in projected changes in low-level stability in climate models. This limits confidence in the feasibility of using climate projections to assessing changes in noise contours of changing winds and stability profiles.

4.2.2 Environmental clean-up

Changes to the fate and transport of military-specific contaminants due to climate change induced biome shifts was the topic of a separate ERDC research program, “Climate Change-Induce Biome Shifts and Contaminant Management for DoD Lands.” This research effort developed a web-based, spatially-explicit tool that allows managers to inform responsive and sustainable DoD land management and stewardship by examining the impacts of various management actions and potential changes in climate.

Consultations with the lead researcher on this project led to the conclusion that the methods being developed would require extensive additional effort to produce results that would be directly applicable to the Firing Range Capacity project. However, these efforts are developing a new model that will lead to the ability to calculate an estimate of the change in environmental clean-up costs in cases of climate change induced biome shift. This cost estimate is currently planned for FY16, pending the outcome of the current work.

4.2.3 Heat stress days and fire risk

Two indices have the potential to affect the metrics of available training days on ranges: the number of days with heat-related training restrictions and the number of days with high fire risk for live-fire training. These two indices are both computed from daily temperature and other observed data for installations, and can also be readily computed from the projections of temperatures and precipitation from climate models for future climate scenarios.

The heat stress days are computed from the maximum daily wet bulb-black globe temperature (WBGT), which combines the maximum wet bulb temperature (T_{wb}), ambient air temperature (T_{air}), and temperature measured inside a black globe in the incident sunlight (T_g):

$$WBGT = T_{wbgt} = 0.7\ T_{wb} + 0.2\ T_g + 0.1\ T_{air} \quad (4\text{-}1)$$

While WBGT can be measured on site at installations, this work computed WBGT from the separate temperatures above as functions of the daily maximum temperature, humidity, wind speed, and solar radiation for the location of interest. Brown et al. (2014) describes the full set of equations used for estimating the wet bulb T_{wb} and the globe temperature T_g.

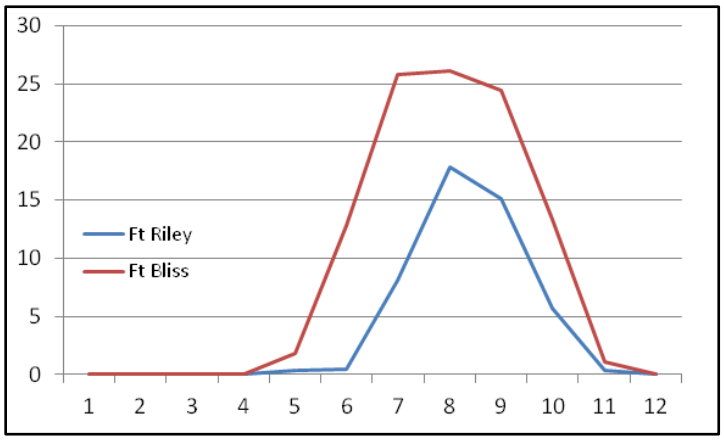
The WBGT is used in determining when soldiers are potentially at risk of heat-related illness in training based on the guidance of Army Technical Bulletin Medical 507 (HQDA and Air Force 2003). The increasing heat category 1 through 5 corresponds to the WBGT increasing from 78 °F (Cat 1) to > 90 °F (Cat 5).

The numbers of days with the WBGT within each heat category in Table 1 were computed for the seven example installations (see Section 4.3.1) using the observed weather records for the period of 1970-1999. The example in Figure 5 shows the average days each month with WBGT above 90 °F (Heat Category 5) for Fort Riley, KS and Fort Bliss, TX.

Table 1. Heat Category table using WBGT for training work-rest times and water intake based on Dept of the Army Technical Bulletin (TB) Med 507 (2003).

Heat Category	WBGT Index, F°	Easy Work		Moderate Work		Hard Work	
		Work/Rest	*Water Intake (Qt/H)*	*Work/Rest*	*Water Intake (Qt/H)*	*Work/Rest*	*Water Intake (Qt/H)*
1	78° - 81.9°	NL	½	NL	¾	40/20 min	¾
2 (GREEN)	82° - 84.9°	NL	½	50/10 min	¾	30/30 min	1
3 (YELLOW)	85° - 87.9°	NL	¾	40/20 min	¾	30/30 min	1
4 (RED)	88° - 89.9°	NL	¾	30/30 min	¾	20/40 min	1
5 (BLACK)	> 90°	50/10 min	1	20/40 min	1	10/50 min	1

Figure 5. Average number of days per month with WBGT above 90 °F (Heat Category 5) from daily maximum temperatures for Fort Riley KS and Fort Bliss, TX over 1970-1999.



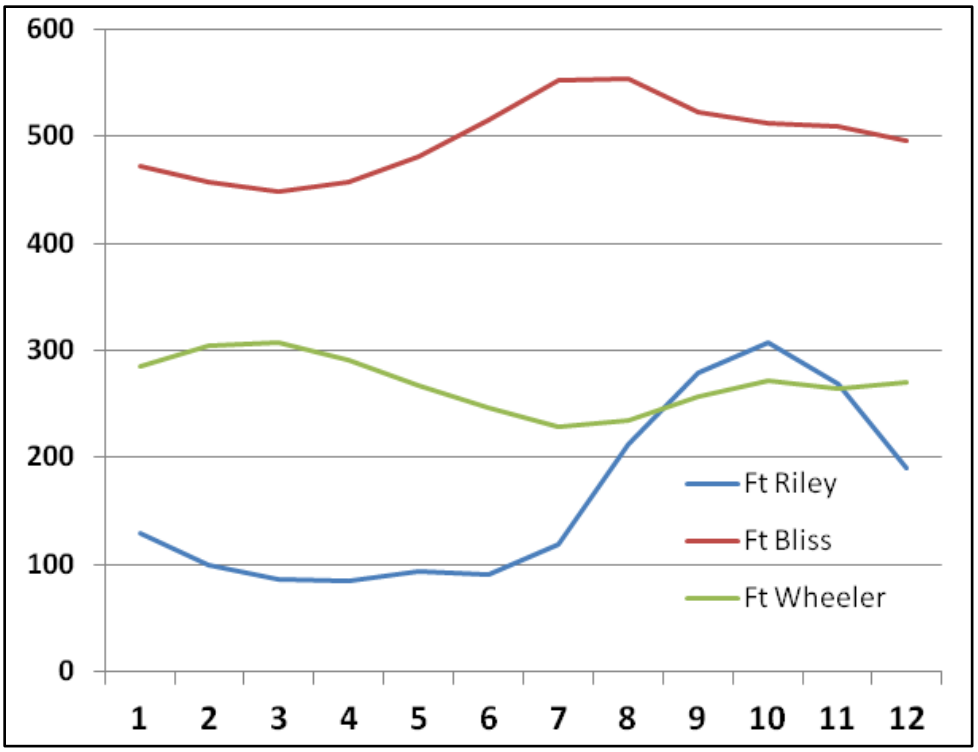
Similar to the heat stress, the days with high fire risk that might impact live-fire training are computed using the Keetch-Byram Drought Index (KBDI), designated Q, by incrementing the index dQ using the daily maximum air temperature (T_{max}) and daily precipitation, P. The formulation follows the revised and corrected English units equation of Alexander (1990) and Crane (1982) of the original Keetch and Byram (1968) index:

$$dQ = \frac{[800-Q][0.968\exp(0.0486Tmax)-8.30]dt\ x\ 10^{-3}}{1+10.88\exp(-0.0441R)} \quad (4\text{-}2)$$

The minimum Q value is kept at zero, the maximum at 800, which indicates an 8-in. deficit in precipitation.

The KBDI was computed for the seven example installation from their daily observed records for 1970-1999. The example in Figure 6 shows the average monthly KBDI for Fort Riley, Fort Bliss, and Fort Wheeler.

Figure 6. Monthly average values of the KBDI from daily observations for Fort Riley, KS, Wheeler Air Force Base (AFB), HI, and Fort Bliss, TX over 1979-1999.



The risk of igniting fires on training ranges through live-fire training potentially increases with greater KBDI, that is, with greater maximum daily temperatures, with little or no precipitation, and where KBDI increases with each additional day that the conditions persist. For any particular training range there are other potential factors to consider in the risk of igniting fires through live-fire training, such as the presence or abundance of dry vegetation and persistent wetlands that may not be high risk for ignition. Therefore the on-site determination of fire risk by firing range managers, and restrictions on live-fire training, are determined locally, and not based on a single factor such as KBDI.

For ranges with significant risk, Table 2 lists the types of restrictions in live-fire training that can be implemented based on the KBDI. The increasing risk is denoted by the green-to-black color scale, with increasing requirements for fire-fighting detail on hand.

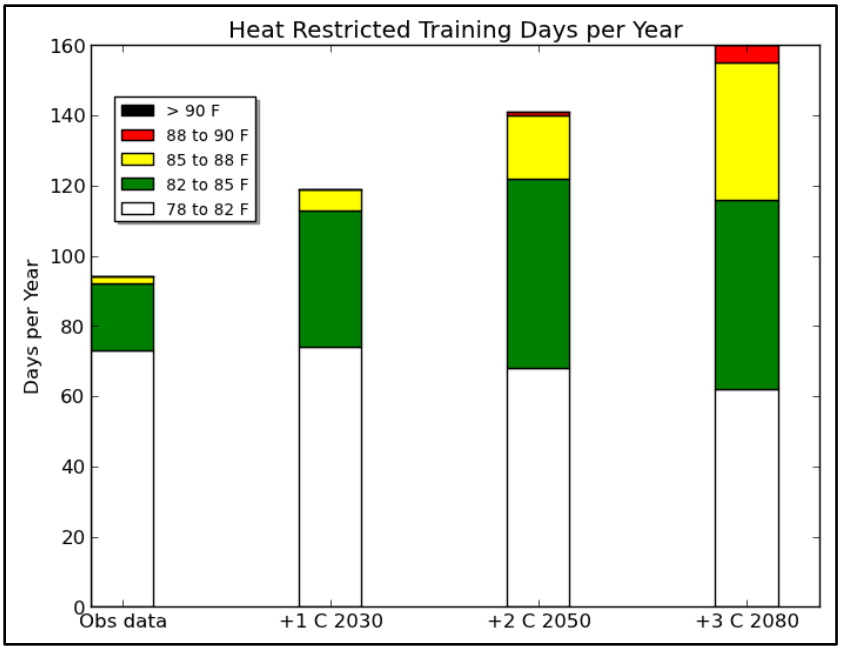
Table 2. Fire danger categories with live-fire training restrictions and fire-fighting requirements, with the KBDI range used in this study for each category.

Category	Fire Danger Condition	Expected Fire Behavior	Training Restrictions	Fire-Fighting Detail Requirements	Derived KBDI*
1	GREEN	Fires are difficult to start and do not burn with vigor. Fires can easily be controlled using direct attack.	None.	None.	0-300
2	AMBER	Fires start easily and may burn quickly through grass and shrub fuels. Fires can be controlled using direct attack, but in some circumstances may require indirect attack methods.	No aerial flares outside the live-fire training areas. Pyrotechnics must be used on roadways, tank trails, or barren areas.	None.	300-600
3	RED	Fires start easily, move quickly, burn intensely, and may be difficult to control.	No pyrotechnics, incendiary munitions, tracers.	10-person fire-fighting detail required. On-call helicopter required on 20-minute standby.	600-750
4	BLACK	Fires start very easily and are impossible to control.	No live-fire training. No pyrotechnics. Non-live-fire training must be authorized by the Senior Mission Commander.	None.	750-800

Projected future changes in temperature and precipitation have been used to calculate these two climate-related indices, WBGT and KBDI, for the sample installations in the first year of this study. See examples of these projections below. Increases in air temperature by 1.8 °F (1 °C), 3.6 °F (2 °C) and 5.4 °F (3 °C) have been added to the air temperature used in the formula for WBGT to calculate the number of days with heat stress restrictions. For these projections of WBGT, relative humidity, wind, and solar inputs are left unchanged. The temperature increases are average changes for the central United States across multiple GCMs, corresponding to 10-years centered around 2030, 2050, and 2080. Weatherly et al. (2014) provides specific information on the climate change scenarios and the GCM used here.

Figure 7 shows the numbers of days per year with WBGT in each heat category (1-5) for Fort Bliss TX, with the projected future days. The total days with any level of heat categories increase from 155 in the observed data to 192 days per year in 2080. The number of observed “black flag” category-5 days for Fort Bliss increases the most, from about 30 days in the observations to nearly 90 days in 2080.

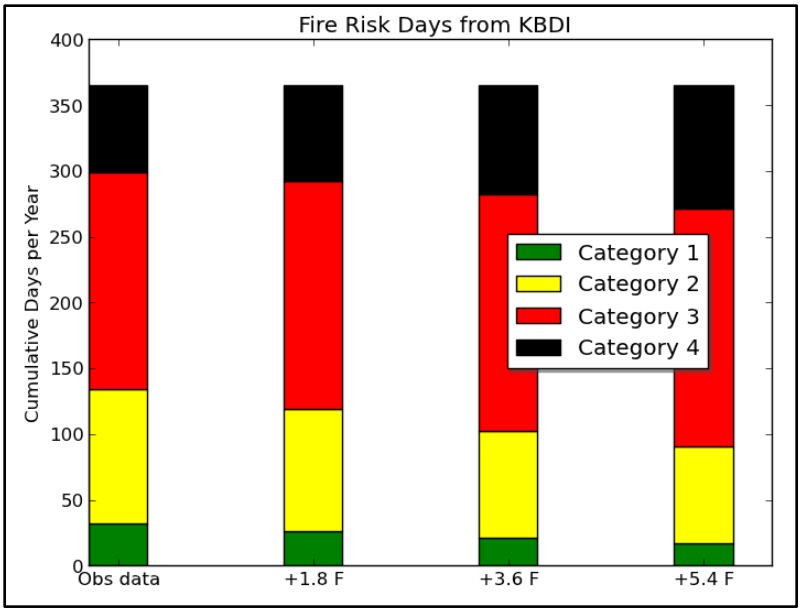
Figure 7. Average number of days per year with calculated WBGT in the five heat categories (with temperatures shown) for Fort Bliss, TX. The observed data column (left) use the daily temperatures, dewpoint, and wind speeds over 1979-1999. The projected columns (right three) used added temperature changes from climate models centered on years 2030, 2050, and 2080.



These projections of future WBGT reflect a potential for increasing risk of heat-related injury and restrictions on training activities during the maximum daytime heat. This graph does not reflect the potential impacts on nighttime or early-morning training, which are less affected by the solar input, but which can be affected by temperature and humidity. Both day and night training impacts are included in this set of climate-related impacts for installations.

Table 2 lists the numbers of days with fire risk in each category (green to black) with the associated KBDI values for each category. Figure 8 shows the average number of days per year with calculated KBDI in those four categories for Fort Bliss, TX. The KBDI using the daily recorded temperature and precipitation are shown for the observed data. The same increases in temperature (1 °C, 2 °C, 3 °C) are added to the observed temperatures centered on the years 2030, 2050 and 2080. The number of "black" Category 4 days (highest KBDI) increases from 60 in the observed to 85 days in 2080, while number of the "red" Category 3 days also increase slightly from 160 to 180 days, and the number of lower-risk "yellow" and "green" (Categories 2 and 1, respectively) days decrease accordingly.

Figure 8. Average number of days per year with calculated KBDI in the four categories from Tbl. 2 for Fort Bliss, TX. The observed data column (left) uses the daily recorded temperatures and precipitation over 1979-1999. The projected columns (right three) used added temperature changes from climate models centered on years 2030, 2050, and 2080.



These projections reflect the potential for increased fire risks on installations, restrictions on live-fire training or fire-fighting requirements on site for longer durations.

4.3 Projected impact of climate change on Environmental factors

4.3.1 Test cases

A set of seven installations was selected to serve as an initial set of test cases. These installations were selected to cover unique ecoregions that would be susceptible to different types of climate change. Table 3 lists the installations and their associated geographical regions.

Table 3. Listing of test case installations and geographical region

Installation	Geographical Region
Fort Drum	Northeastern United States
Fort Bragg	Southeastern United States
Fort Bliss	Southwestern United States
Joint Base Lewis-McCord	Northwestern United States
Fort Riley	Midwestern/Central United States
Schofield Barracks	OCONUS – Hawaii
Fort Wainwright	OCONUS - Alaska

4.3.2 Projected impacts

Projected impacts were investigated for noise, urban growth, heat stress days, and fire risk days. This section summarizes the findings for each of these areas.

It was found that changes in climate would have potentially little impact on the noise contours if the predominant wind directions remain approximately the same as they are now. Climate change projections are not able to predict atmospheric stability and wind vectors reliably, making noise contour projections that incorporate climate change impossible.

The current method for projecting urban growth patterns and the potential impact on the installation was found to be acceptable for screening purposes, but fails to account for many of the details that will be critical in cases where the urban growth patterns are either non-existent (i.e., where there are no issues) or where the urban areas are so large that the installation is irrecoverably impacted for a training mission. Section 4.4.1.2 provides recommendations for improving this MVA attribute. Future work will consider the impacts of climate change on urban growth patterns.

Heat stress days are anticipated to increase as temperature increases, as is increased fire risk. This will lead to a reduction in full days available for training. Weatherly (2014) includes a more detailed analysis of the implications of climate change on the number of heat stress days.

4.4 Recommended work

The analysis of current assessment methods and the investigations into the magnitude of potential impacts on firing area capacity due to temporal and climate changes has revealed multiple opportunities for improvements to stationing analyses and future research and development.

4.4.1 Recommendations for updated or new MVA attributes

Based on this analysis, it is recommended to develop one new attribute and to revise one existing attribute.

4.4.1.1 New attribute: Firing range capacity

The current attribute associated with live-fire ranges, Dudded Impact Area, does not account for range throughput. As the attribute is written, it

depends solely on the number of impact areas available and the maximum distance that a weapons system can fire within the installation's geographical constraints. The current attribute captures the important feature of whether an installation has the physical capacity to conduct live-fire training. However, it does assume that because there is capacity, it will be used to its maximum possible level. In reality, various restrictions, such as noise curfews, TES habitat areas, and protected cultural sites, impact the actual availability of these ranges for training.

This work proposes the development of a new MVA attribute that would take the availability of firing ranges and impact areas into account in a way similar to the Range Sustainability attribute for maneuver areas. The attribute could be either a change in the actual number of days available for training vs. maximum ideal days available, or it could be a percent change. Fixed constraining factors could include current noise, TES, cultural site, KBDI, and heat stress restrictions. Dynamic constraining factors could include climate change induced changes in KBDI, heat stress, and changes to TES restrictions due to either new listings or population migrations. This attribute will be developed in FY15, pending approval from CAA.

4.4.1.2 Revised attribute: Population impact

Installations that are neither obviously burdened (already surrounded by dense urban populations) nor unburdened (rural and remote) by urban growth will require a more robust analysis of population impact than is provided by the current (May 2014) Population Impact attribute. A significant improvement to the current attribute would be to include an assessment of the locations that are likely to experience growth, synchronized with encroachment factors, and using a more robust method for estimating growth. This alternate attribute will be developed in spring 2015. The strategy for development is included below.

Development of this alternate attribute will need to consider the three areas identified in the previous paragraph: (1) localized growth, (2) synchronization with encroachment factors, and (3) a more robust, location-specific growth model. In addition to these three areas, the current attribute does not take the installation mission into account. For example, an installation with an administrative mission is impacted differently by population growth than a live-fire training installation. The following paragraphs describe each of these areas more fully, highlight the drawbacks of the current method, and propose a path forward.

The current Population Impact attribute assumes that the growth rate for the 10-mile buffer area is the average of the growth rates of each sector within the buffer. This assumption could lead to erroneous or deceptive predictions of where growth will occur. For example, the area just outside of the main gate of an installation could be growing rapidly, while areas closer to the training ranges are not growing at such a high rate. By averaging the growth rates over the entire buffer area and assuming that the rates are now the average for every location, a potential problem area could be erroneously identified. Conversely, if the areas near the training ranges grow rapidly, but growth in the more densely populated areas has slowed significantly, a potential problem area could be missed entirely. Identifying the growth rate in each sector of the 10-mile buffer will greatly improve the assessment of the impact of the growth on the installation.

The current attribute does not couple population location or growth to encroachment factors such as noise, dust, TES habitat, and light pollution. It is also proposed that noise contours could be used as a "worst case" encroachment factor, due to the distances to which noise can propagate beyond the fenceline. Noise contours could be overlaid on the population map and areas of greater impact identified. Locations experiencing high growth rates that are also within the high impact region of a noise contour would indicate a stronger potential impact on the installation training mission. Conversely, if population and growth areas are not within the high impact region of the noise contour, this would indicate a lesser potential impact on the installation. It is important to note, however, that this analysis must make assumptions regarding range usage.

Using a linear growth model, based on the previous 20 years of growth, does not adequately portray the potential urban growth in an area. Multiple factors, such as availability of space for housing, economic resiliency, and desirability of a location all influence the actual growth in an area. Additionally, long-term growth tends to level off when an area reaches a saturation point, an effect not captured in a linear growth model. A linear model also fails to capture the effects of a significant influx or outflow of population due to external drivers, such as a major restationing decision. Finally, if a significant population event occurred within or just after the timeframe, the growth rate could be skewed. There are multiple methods and tools available for creating more detailed projections of future population densities over variable time periods. These include the ERDC-CERL-maintained Regional Urban Growth model (RUG) (Westervelt 2011), the

Landuse Evolution and Impact Assessment Model (LEAM) (Deal 2004), and the U.S. Environmental Protection Agency's (USEPA's) Integrated Climate and Land Use Scenarios (ICLUS) model (USEPA 2010). Using any of these methods presents a significant improvement to the growth rate model. Because RUG is DoD-owned and managed software, it has the greatest potential for reliable access and adaptability.

4.4.2 Recommendations for future research and development

Items identified as requiring additional research and/or development to either: (1) determine the potential impact of climate change on a given factor, or (2) enhance the capability of an existing method/system to incorporate climate change effects and influences, are:

1. Evaluation of training restrictions due to the presence of TES
2. Cost analysis of changes in environmental clean-up costs due to climate change induced biome shift
3. Incorporation of climate change factors, such as changes to flood plains and water hazard, into the ERDC-CERL RUG Model.

The evaluation of training restrictions due to the presence of TES will include multiple phases. The first phase will determine the areas currently containing critical habitat, which in turn create restrictions on training. Next, existing literature will be reviewed to determine the types of live-fire-induced impacts (noise, dust, fire, projectiles, etc.) that have a negative impact on TES. These impacts will be mapped to areas of influence, creating a map of potentially restricted areas that include temporal aspects. For example, a nesting area for a migratory species may only be restricted during certain times of the year. Finally, the influence of climate change will be incorporated. This could be a migration of a listed species into or out of a new area, a biome shift that creates or destroys critical habitat, or new species listings (although new species listings may not be directly related to climate change).

Environmental clean-up costs are a reality for live-fire training ranges. A cost analysis of changes in clean-up costs due to a climate change induced biome shift will be performed. Clean-up costs could change if the soil properties, such as ph, change, or if there is a vegetation change that either improves or reduces natural clean-up means.

It is anticipated that the ERDC-CERL RUG model can be updated to include such major impacts of climate change as changes to flood plains due to changes in precipitation, and water availability.

5 Maneuver Area Capacity

5.1 Consideration of maneuver capacities in stationing

One of the highest rated factors in past MVA analyses and one of the more binding constraints in OSAF has been the consistent availability of maneuver / training lands. These are defined as those areas on an installation designated for impact and detonation of all ordnance or those areas required for land-intensive training at the installation (HQDA 2013). Sub-categories of interest for estimating maneuver area capacity include training areas designated for light forces and heavy forces. Light force areas are those areas that are set aside for small units or units that have only wheeled vehicles, and that cannot be used by heavy forces. Heavy force areas are those areas where use is unrestricted in terms of vehicle or equipment type, and can be used by both heavy and light forces.

Currently, two MVA metrics directly address maneuver area capacity. The Maneuver Land MVA metric represents the sum of heavy and light maneuver lands for an installation. The purpose of this metric is to quantify the ability of an installation to support both heavy and light maneuver training. During BRAC 2005, the maneuver area capacity metric was scaled by the number of available training days. Currently (as of 5 May 2014), maneuver land is simply the total area available for training. As currently estimated, the maneuver land metric will not be sensitive to climate change because it is simply an aerial calculation; it is recommended to use a metric that includes sensitivity to climate in the calculation.

The second MVA metric that directly addresses maneuver area capacity is Range Sustainability, which represents available training lands without restrictions, scaled by a multiplicative factor (range 0-1) that reflects the resiliency value of an installation (see Range Sustainability Metric in Appendix). Restrictions include wetlands (as defined by the National Wetland Inventory) and areas with slopes greater than 30%. The resiliency value for an installation is currently derived by determining the ecoregion, as defined by Bailey (1980) in which the installation resides, and by applying the appropriate value based on the ecosystem (WES 1960). Resiliency values reflect the number of passes from an M1A1 tank over the course of a year that an area can withstand before it is considered to be at a critical level. Resiliency values range from 2 to 12; possible values are 2, 3, 4, 6, and 12. Resiliency

values are converted into multiplicative factors that scale the aerial estimates of the installation. For example, if an installation's resiliency value is 12, the multiplicative value would be 1; if an installation's resiliency value is 6, its multiplicative value would be 0.5 (Appendix A).

Unlike the Maneuver Land MVA attribute, the Range Sustainability attribute is likely to be affected by climate change since predicted changes in precipitation and temperature would impact the amount of vehicular disturbance both to the soil and the vegetation because as soil moisture increases, vehicle impacts generally increase for most soil types (Ayers 1994). In its current iteration, the Range Sustainability MVA attribute is not responsive to predicted shifts in precipitation and temperature at any temporal scales. New range maps outlining future Bailey's Ecoregions might be updated based on new climate and vegetation data, but this is unlikely to occur and would not be sensitive enough to expected climatic change for certain areas of the United States. Secondly, these ecoregions are relatively gross and do not take specific local conditions into account. Training capacity can vary dramatically within an ecoregion based on soil types, elevation, and slope.

This work proposes a modification of the Range Sustainability metric to replace Bailey's Ecoregions with an objective and easily quantifiable formula that incorporates temperature, precipitation, vegetation, soil attributes, and expected impacts from training into a revised metric. The proposed modification of the current Range Sustainability metric would yield the following positive steps:

1. The metric would be more objective compared with the current metric as it would not be based on expert opinion.
2. The metric would be temporally explicit and thus able to reflect seasonally-adjusted impacts of training.
3. The metric would be responsive to predicted changes in precipitation and temperature
4. The model would contain the potential to link with other models (e.g., the Army Training and Testing Area Carrying Capacity [ATTACC]).

The modified Range Sustainability metric would be based on the Universal Soil Classification System (USCS) value (WES 1960) for each soil map unit on an installation, and on predicted responses in soil strength due to shifts in soil moisture on a monthly time scale.

5.2 Background

Determining the land required at an installation to support required maneuver training is complicated and involves many factors. TC 25-1 documents the land area and shape required to support all maneuver exercises, and the frequency of training required for specified types of military units. That information allows for the calculation of kilometer-squared-days (km^2-days) that training area can provide in a year and the km^2-days required each year by the units that need maneuver training. Each training area contains unique attributes that can dramatically affect the training. For example, parts of a training area may need to be avoided because of gullies, high slopes, swamps, and deep forest, which can collectively limit maneuver options. Endangered species can be associated with requirements to avoid maneuvering in specific areas, sometimes at specific times of the year.

A balance must be found between training that disturbs plant biomass above- and below-ground, and land recovery and maintenance. A desert system can take many decades to recover from a maneuver exercise, while a temperate moist climate can support grasses that are resilient to maneuver training and can often recover quickly. Training areas can be more or less intensively managed. Management activities can include removal of trees and shrubs to support realistic training, reinforcement of heavily traveled trails, reseeding of destroyed areas, and placement of moveable barriers that keep vehicles from overusing trails. Trainers also must decide how realistic the training needs to be. In some cases, a plantless mudhole or sandpit can perhaps provide sufficient training, in which case maneuver area recover can be less important. But even in these cases, significant rainfall events coupled with intensive training can dramatically create gullies in the landscape resulting in land conditions that are inadequate or dangerous for training.

Finally, the increased soil moisture at the time of maneuver training increases the soil disturbance. The longer trainers can delay training during and after severe rain events, the greater the overall annual sustainable training throughput. This is in conflict with meeting mission and requirements and for the sake of training realism, training at these times must not be postponed. Therefore, increased soil moisture is likely to lead to increased ground disturbance without either changes in the training times or increased maintenance.

The bottom line question remains: "What is the total throughput of maneuver training that a training area can sustainably support?" The following general equation captures many of the above noted factors that contribute to the available maneuver km^2-days for maneuver area factors:

$$A = (AT - AU - AS) * SR * VR * M \quad (5\text{-}1)$$
$$A = (AT - AU - AS) * (SR + VR) * M$$

where:

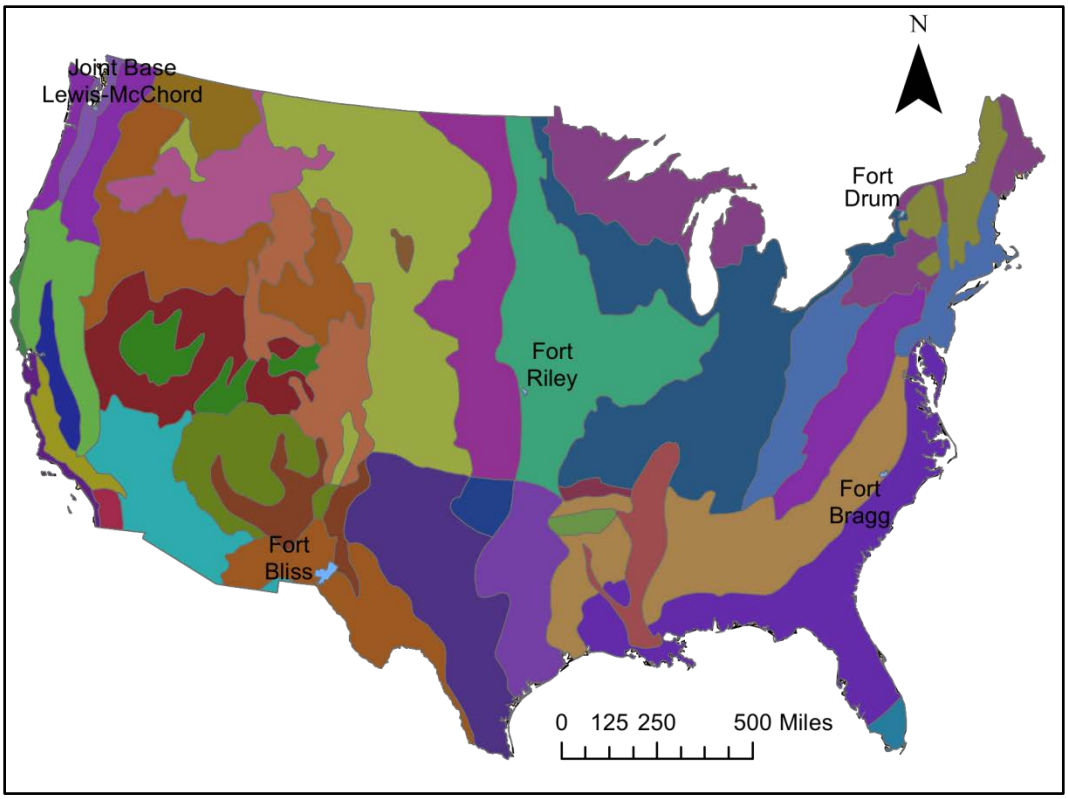
A = the area available for maneuver training
AT = the total area
AU = the area inside the total area that is unusable
AS = the area dedicated to TES and cultural areas
SR = a soil resilience factor (0-0.5)
VR = a vegetation recovery factor (0-0.5)
M = a management factor (>1).

5.3 Proposed approach and test application

The proposed approach addresses many of the factors in Equation 5-1: total area (AT), unusable areas (AU) such as high slope and wetlands, and soil resilience (SR). This work does not address management (M). Areas lost through dedication to TES and cultural resources are also left for future consideration. SR is calculated on a monthly basis and considers soil type and moisture from estimated precipitation and temperature values. The soil and vegetation factors are directly responsive to climate, allowing changes to maneuver throughput to be calculated into the future.

Five installations were selected to capture the range of ecoregions and possible future climatic scenarios (Figure 9): Fort Riley, KS, Fort Lewis-McCord, WA, Fort Bliss, TX, Fort Bragg, NC, and Fort Drum, NY (Table 3). The areal extent of maneuver area was estimated by obtaining data layers for maneuver area, National Wetland Inventory, and digital elevation maps. The maneuver area spatial data layer; the National Wetland Inventory data layer (USFWS 2014); and digital elevation maps were obtained. Available training land was estimated by subtracting areas designated as wetlands and areas with slopes greater than 30%.

Figure 9. CONUS installations considered in the present study. Color-coded regions represent ecological provinces as defined by Bailey (1980).



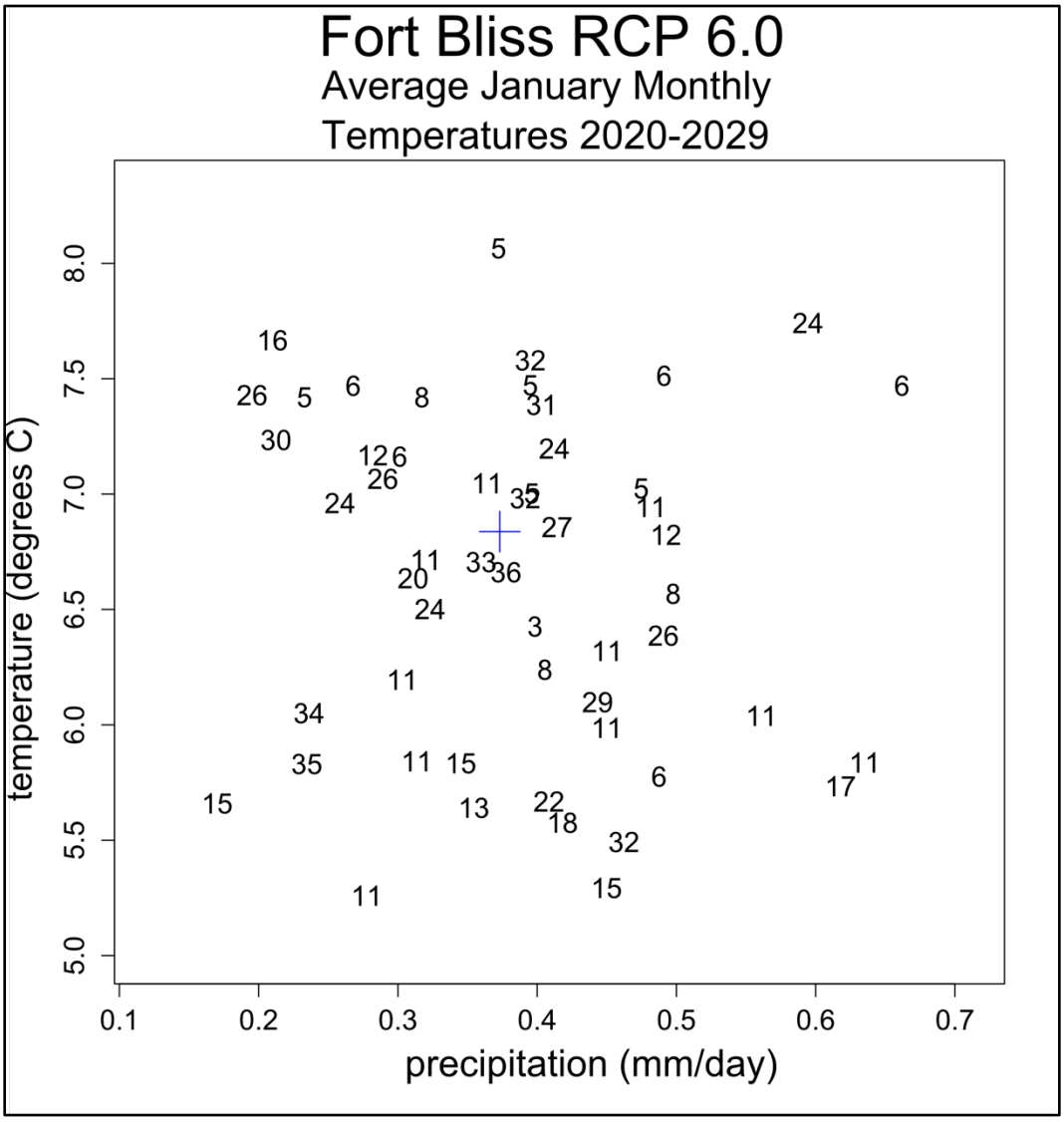
Training land lost to TES or to the protection of cultural resources was not estimated because, at the current time, these areas are not removed when calculating maneuver area. Often cultural resources involve very small sites that can be protected with barriers or other no-go indicators in a manner that does not significantly detract from maneuver opportunities. The loss of maneuver areas to the protection of TES habitat will be considered in the future based on ongoing research into the threat of new listings and the potential impact of the level of required protection. The final area represents a subset of the available training land.

Climate data were downloaded from the Bureau of Reclamation (2014). These data represent biased corrected, downscaled data from 37 general circulation models (Bureau of Reclamation 2014, Table 2) for the years 2006 to 2100. For each GCM, the predicted monthly precipitation and temperature was estimated for four 10-year time periods (2020-2030, 2030-2040, 2040-2050, and 2050-2060), representing 10, 20, 30, and 40 years from the current date, by calculating the mean monthly value across the 10-year time period. For each of the five installations, the range of precipitation and temperature scenarios across the different GCMs for each

month and time period was identified (Figure 10). The extreme values (either negative or positive) represent a possible "bounding box" for future possible climate scenarios. These values can easily be updated by adding in addition GCMs and/or GCM runs as the data become available.

County level spatial soil data were downloaded from the Soil Survey Geographic (SSURGO) database (USDA 2014). For the five installations, individual county level data were merged into a single spatial data layer. The percentage area of each installation with map units classified according to the USCS (WES 1960, Table 1) was calculated.

Figure 10. Predicted mean January changes in temperature and precipitation at Fort Bliss for the years 2020-2029. Each number represents a separate GCM run. The blue cross represents historical average temperature and precipitation for the years 1970-1999, as measured at El Paso International Airport (El Paso, TX, USA).



Predicted climate data were used to estimate soil moisture (Huang, van den Dool, and Georgarakos 1996) on a monthly basis using the following equation:

$$\frac{dW(t)}{dt} = P(t) - E(t) - R(t) - G(t) \quad (5\text{-}2)$$

where:

$W(t)$ = the soil moisture content at time t
$P(t)$ = the mean precipitation
$E(t)$ = the mean evapotranspiration
$R(t)$the net stream flow divergence from the area
$G(t)$ = the net loss of water through deep percolation.

$R(t)$ was evaluated to estimate actual runoff (NRCS 2004) in the following formula:

$$Q = \frac{(I - 0.2S)^2}{I + 0.8\,S} \quad (5\text{-}3)$$

where:

Q = the direct surface runoff depth (mm)
I = the storm rainfall depth (mm)
S = equivalent to the maximum potential difference between runoff and rainfall (mm).

Estimation of $S = \frac{25400}{CN} - 254$, with CN derived from curve numbers was provided via an ArcGIS (ESRI 2011, Redlands CA) tool (Zhan and Huang 2004).

Monthly soil moisture values were used to estimate the USCS soil type-specific rating cone index (RCI) values (Sullivan et al. 1997) for each possible USCS soil type within an installation. The average RCI values were weighted by percentage of USCS soil type on the installation to provide an installation-wide RCI value that is dependent on estimated temperature and precipitation. An installation's average RCI value was used to estimate resiliency (SR in Equation 5-1) by first calculating a resiliency value (Table 4), then by scaling by half the multiplicative factor.

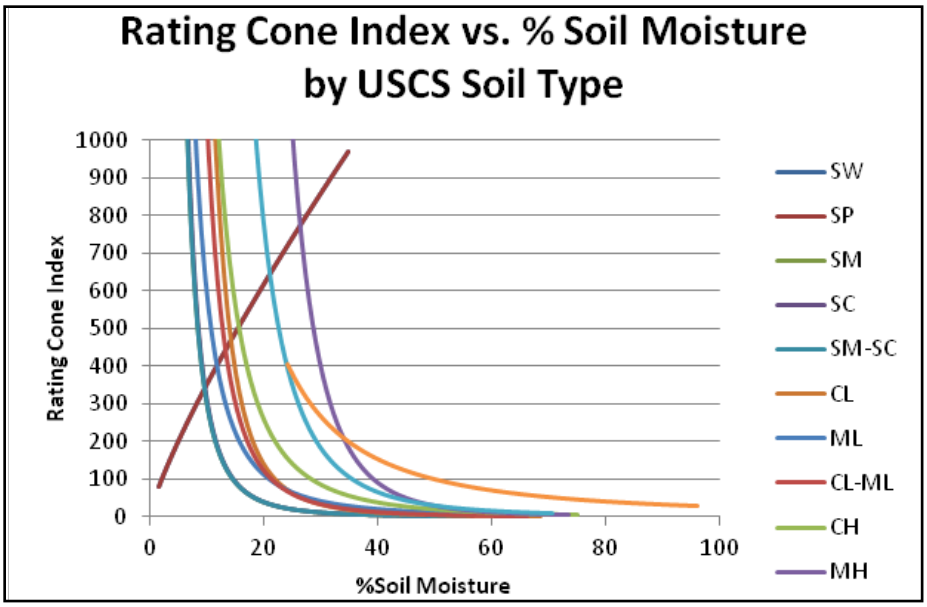
Table 4. Crosswalk table relating original resiliency values ranges (as specified in the Range Sustainability metric), and the proposed resiliency metric. RCI range refers to range of possible RCI values.

Original Resiliency Value	Multiplicative Factor	Proposed Resiliency Value	RCI Range
2	0.17	1	0-5
3	0.25	2	5-10
4	0.33	3	10-20
6	0.5	4	20-40
12	1	5	> 40

Table 5. USCS codes and definitions.

USCS Soil Type Code*	Description
SW	This group comprises well-graded gravelly and sandy soils having little or no-non-plastic fines.
SP	This group comprises poorly graded gravel and sands containing little or no-non-plastic fines.
SM	This group comprises gravel or sands with fines having low or no plasticity.
SC	This group comprises sandy soils with fines that have either low or high plasticity. The gradation of the materials is not considered significant and both well- and poorly- graded materials are included.
SM-SC	A borderline soil that exhibits characteristics of both SM and SC soil groups. The SM soil group comprises silty sands while the SC group comprises clayey sands.
CL	Primarily inorganic clays with low liquid limit (i.e., less than 50).
ML	This group comprises predominantly silty materials and micaceous or diatomaceous soils with low liquid limits.
CLML	This group comprises a borderline soil that exhibits characteristics of both CL and ML soil groups. The CL soil comprises low plasticity clays and the ML soil group comprises silts with low plasticity.
CH	This group comprises predominantly primarily inorganic clays with high liquid limit (i.e., greater than 50).
MH	This group comprises predominantly silty materials and micaceous or diatomaceous soils with high liquid limits.
GC	This group comprises gravelly soils with fines that have either low or high plasticity. The gradation of the materials is not considered significant and both well- and poorly graded materials are included.
Pt	This group is comprised of highly organic soils that are very compressible, frequently have fibrous vegetable matter.
OL	This group is characterized by the presence of organic matter. Organic silts and clays are classified in this group if they have materials with low plasticity.
OH	This group is characterized by the presence of organic matter. Organic silts and clays are classified in this group if they have materials with high plasticity.
*Adapted from ASTM D 2487-06 (ASTM 2006).	

Figure 11. RCI as a function of soil moisture across 10 USCS soil types. For most soil types, RCI values decrease as a function of soil moisture, while SP (poorly graded gravel and sands containing little non-plastic fines) increases.



Vegetation recovery was estimated by using net primary productivity as a surrogate for recovery. Several net primary productivity (NPP) models exist, many of which are quite complex and require input variables as specific as carbon dioxide concentration, soil water content, photosynthetically active radiation, soil fertility, leaf area index, potential and actual evapotranspiration to name a few (Cramer et al. 1999). Studies comparing NPP estimates derived from up to 17 different models have been conducted and the results indicated that seasonal variation among the models was high, both locally and globally (Cramer et al. 1999). However, the broad global pattern of NPP and the relationship of annual NPP to the major climatic variables coincided across most major ecoregions (Adams, White, and Lenton 2004) indicating their utility to operate simply and without requirements for significant plant community input variables to drive the models.

There are potential opportunities to modify simpler models. Candidates include: the CENTURY (Parton et al. 1993), National Center for Ecological Analysis (NCEAS) (Del Grosso et al. 2008), and Miami (Leith and Whittaker 1975). These models may be used to account for vegetation attributes like plant functional type (C3, C4, CAM), for plant community type that would improve estimates of NPP, and for the subsequent development of plant cover and plant cover effectiveness that could be used to infer plant community resilience to mechanized training in Maneuver Area Capacity (MAC) predictions.

All of these models predict NPP based on precipitation and temperature, with NPP positively correlated with precipitation in a curvilinear fashion. NPP tends to be over-estimated in non-tree dominated systems. However, the magnitude of the estimates is similar across different grassland types (Del Grosso et al. 2008).

The NCEAS modeling effort used 5600 global data points (0.5 degree latitude/longitude cells) obtained from the central and eastern United States and Australia with observed NPP, land cover class, precipitation, and temperature, representing the largest global NPP dataset collected to date. Using these data, NCEAS developed a simple regression model to estimate NPP that can be used as a starting point for developing installation specific NPP estimates for use in the MAC model. For grassland and shrubland systems, the regression model for estimating NPP is:

$$NPP = 0.2819x + 170$$

where NPP is expressed in g C/m^2/year and x is the mean annual precipitation (mm). The coefficient of determination for the grassland/shrubland model is 0.68.

For forested systems, the regression model for NPP is:

$$NPP = 0.3835x + 192$$

where the coefficient of determination for the forested systems model is 0.40.

Plant basal cover can be estimated by dividing NPP by 100. Across several ecoregions, the cover value obtained by NPP/100 is a close approximation to those obtained in other plant and community ecology studies (Barbour et al. 1980, Brady et al. 1995, Jonasson 1988, Smith 2001). The basal cover value can then be used as an input into EQ1 to determine plant cover effectiveness. As explained above, when used in conjunction with the soil erosivity, texture, deformation, moisture content, and durability factors (discussed in the following section), a value for vegetation resilience to mechanized disturbance could be developed in FY15 based on published research relating soil texture to plant community resilience to disturbance.

Soil resiliency and vegetation recovery values were estimated in the same manner as the estimated RCI values for an installation (Table 6). First, total net primary productivity (TNPP) was estimated for an installation. The values were then rescaled to a multiplicative factor and divided by 2 to obtain a value between 0-.5.

Table 6. Crosswalk table relating original resiliency values ranges (as specified in the Range Sustainability metric), and the proposed resiliency metric. Total net primary productivity range refers to range of possible TNPP values for an installation.

Original Resiliency Value	Multiplicative Factor	Modified Resiliency Value	TNPP Range
2	0.17	1	0-50
3	0.25	2	50-150
4	0.33	3	150-250
6	0.5	4	250-350
12	1	5	>350

5.4 Projected impact of climate change on Range sustainability

Modified SR values indicated little change in soil moisture at the installations included in this study (Fort Bliss, Fort Bragg, Fort Drum, Fort Lewis, and Fort Riley) across the four decades of predicted precipitation and temperature (Figure 12). Even though there are predicted changes in temperature and precipitation across most of the United States, it may be the case that soil moisture is less sensitive to changes in air temperature, perhaps because it is stabilized by ground temperatures. Results from other continent-scale soil moisture estimations indicate similar soil moisture estimates across areas with varying temperature and precipitation.

The minimal changes in soil moisture resulted in nonsignificant shifts in RCI values (Figure 13). This is not unexpected, as RCI is directly related to soil type and soil moisture. In addition, TNPP, as estimated based on the NCEAS model, was surprisingly stable across the 4 decades observed for the five installations (Figure 14) even with changes in precipitation and temperature. Mean TNPP values across the 4 decades ranged from 100.06 at Fort Bliss to 465.88 at Fort Bragg, NC (Table 7).

The estimated RCI values and TNPP resulted in proposed multiplicative values ranging from 0.6-0.7 (Table 8). This represents a collapse of the multiplicative value toward the mean, mainly due to the negative correlation between the soil resiliency value and the vegetation recovery value. As soil resiliency decreases, vegetation recovery increases, and vice versa.

Figure 12. Estimated soil moisture at Fort Bliss Military Reservation, TX by USCS soil type across four decades. Temperature and precipitation inputs were mean monthly predictions for the 36 included general circulation models. Seasonality is evident, with decreasing moisture during the summer, but no evidence of decreasing soil moisture with predicted climate change.

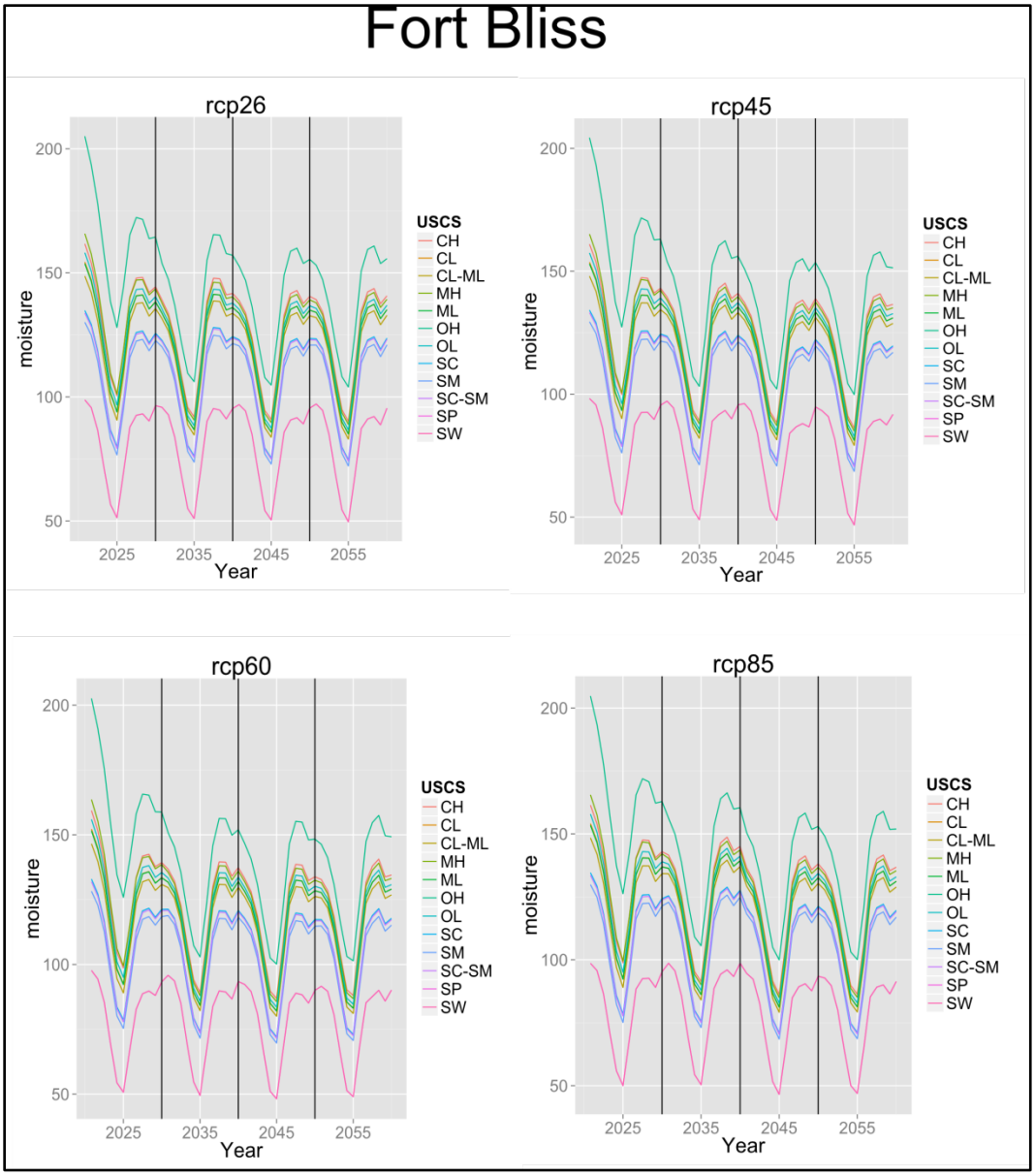


Figure 13. Boxplot of average RCI values for Fort Bragg Military Reservation, NC, across four decades and four different emissions scenarios. In the boxplot, the horizontal line represents the median value, the top and bottom of the boxplot represents the 75th and 25th percentiles, and the lines represent 1.5 times the standard deviation. Outliers are represented as points. As with the predicted soil moisture values, RCI values do not exhibit statistically significant (α = 0.05) shift in values.

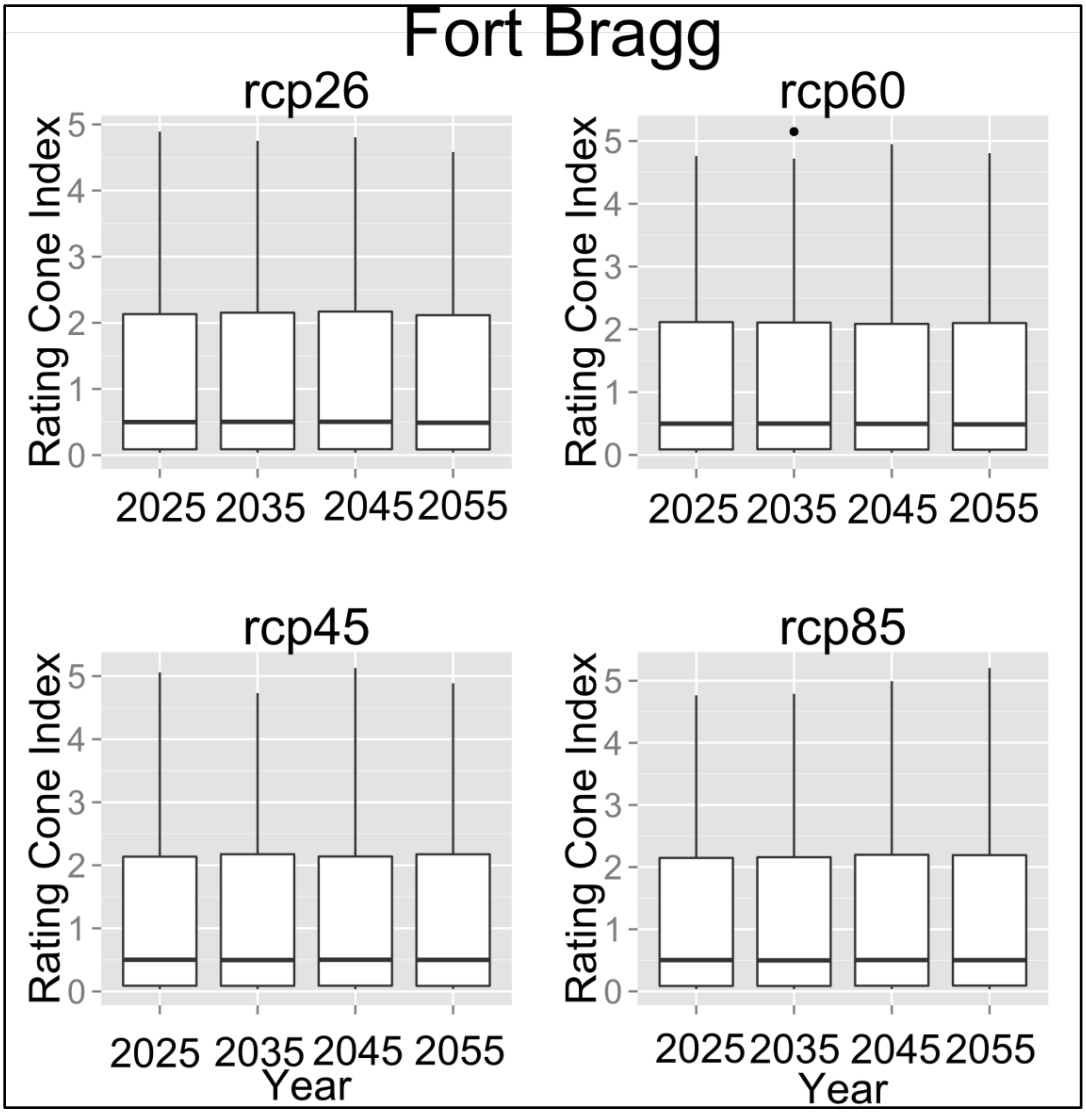


Figure 14. TNPP: g C m-2 y-1) across four emissions scenarios for Fort Riley, KS under 36 general circulation models. TNPP estimates are the result of differing combinations of annual temperature and precipitation across the GCMs, leading to decreases in estimated TNPP under some climate scenarios.

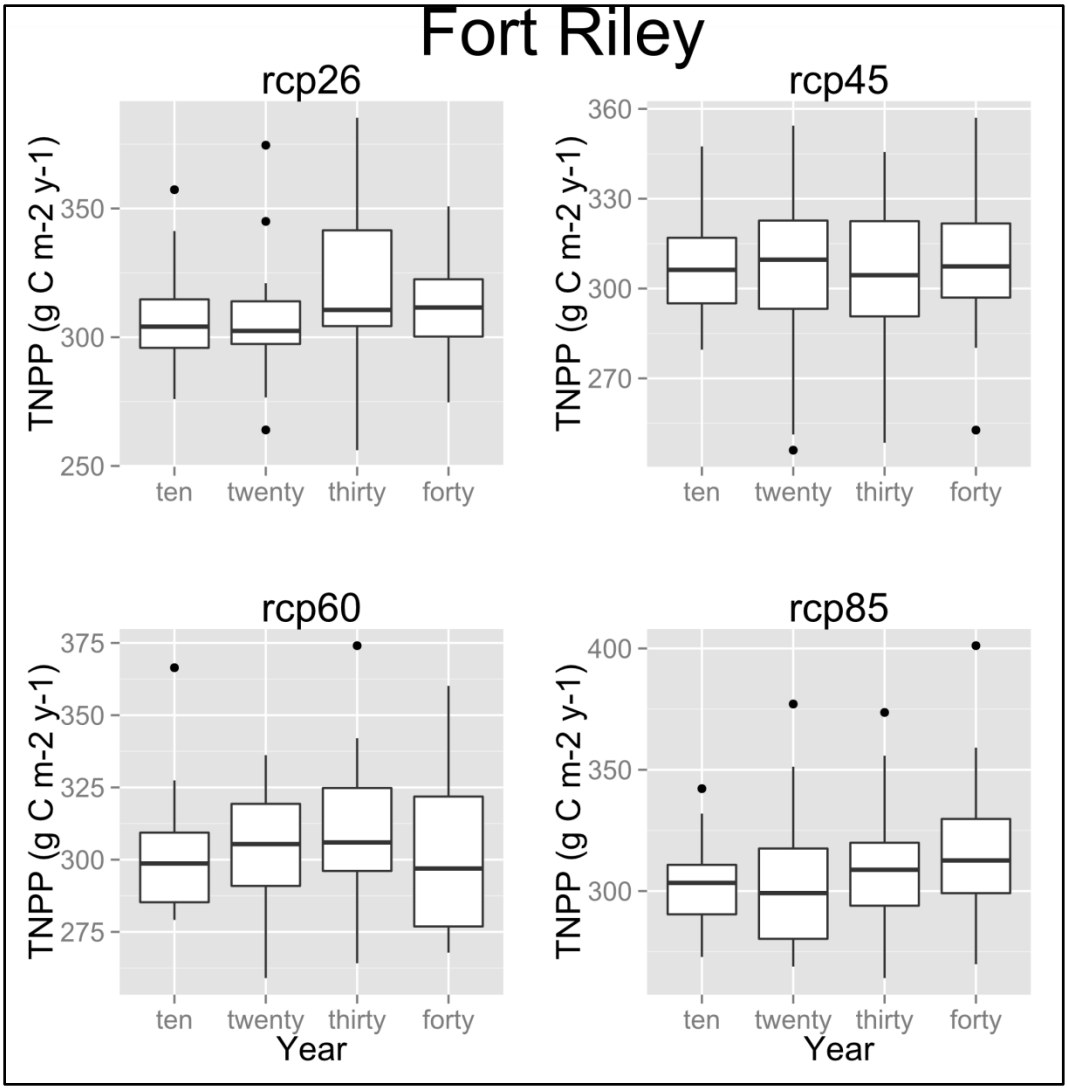


Table 7. TNPP g C m-2 y-1) for five installations. Mean TNPP represents the mean across 36 general circulation model outputs.

Installation	Time	Mean TNPP	Standard Deviation
Fort Bliss	2025	100.67	10.33
Fort Bliss	2035	101.92	11.74
Fort Bliss	2045	100.06	11.67
Fort Bliss	2055	101.05	12.91
Fort Bragg	2025	456.26	25.10
Fort Bragg	2035	457.21	24.72
Fort Bragg	2045	460.09	28.32
Fort Bragg	2055	465.88	29.63
Fort Drum	2025	367.13	12.61
Fort Drum	2035	369.38	12.00
Fort Drum	2045	373.65	13.95
Fort Drum	2055	377.75	14.66
Fort Lewis	2025	425.60	18.09
Fort Lewis	2035	429.04	21.37
Fort Lewis	2045	435.57	21.55
Fort Lewis	2055	434.54	24.12
Fort Riley	2025	305.66	18.61
Fort Riley	2035	304.51	23.73
Fort Riley	2045	309.75	25.87
Fort Riley	2055	309.96	23.43

Table 8. Soil resiliency and vegetation recovery values for five CONUS installations. The proposed multiplicative value is calculated dividing the sum of the soil resiliency and vegetation recovery values by 10.

Installation	Soil Resiliency Value	Vegetation Recovery Value	Proposed Multiplicative Value
Fort Bliss	5	1	0.6
Fort Bragg	1	5	0.6
Fort Drum	1	5	0.6
Fort Lewis	1	5	0.6
Fort Riley	3	4	0.7

5.5 Recommendations for future research and development

The preliminary results presented here, based on previously used empirical and process-based models, indicate that soil moisture is not likely to dramatically shift because of expected changes in temperature and precipitation across the included five installations. These minimal shifts in soil moisture in turn lead to minimal shifts in RCI values for the different soil types. Furthermore, the expected shifts in precipitation appear to not drastically alter total net primary productivity, as calculated using an empirical model. The overall preliminary results indicate that the predicted changes

in temperature and precipitation anticipated under multiple global climate models will not drastically alter maneuver area capacity. However, these preliminary results come with several caveats:

- First, the results are dependent, to some extent, on the selected models. Net primary productivity can be estimated in several different ways, for example, using empirical models, remotely-sensed data, and process-based models. The method used in this document relied on an empirical model that simply may not be sensitive enough to changes in precipitation to detect moderate changes in net primary productivity. In addition, model variance is quite high in the NCEAS TNPP model.
- Another source of error is the fact that the current model does not include several feedbacks and interactions that are likely to be important. For example, small changes in temperature, precipitation, and soil moisture may interact with soil properties to create vastly different growing conditions for plant species, which affect net primary productivity and above- and below- ground biomass. Presently, these possible interactions are not included in the analysis. Another interaction that is not currently included is disturbance in the form of training. While changes in RCI were included, the direct and indirect impacts of training and the possible interactions with climate were not included in the analyses.
- Finally, the current approach does not capture extreme weather events. The current analysis utilized monthly time steps; these will likely not be sensitive to extreme precipitation events and extreme temperatures may be somewhat muted with monthly averaging of the climate data.

Future analyses will: (1) explore the use of process-based models, (2) incorporate vegetation and training interactions into the analysis, and (3) attempt to incorporate daily GCM outputs in the model to capture projected extreme weather events. It is predicted that these incorporation will provide a more realistic outlook for military installation training areas under projected climate scenarios.

6 Conclusions

This work has documented all of the different paths taken in these investigations of the influence of climate change on firing range capacity, and concludes that:

- The Army needs an MV attribute that accounts for the temporal aspects of climate change.
- Population Impact attributes can be improved if they include the synergies between local regions of growth and encroachment factors. Linking encroachment factors, such as noise contours, with projected localized urban growth would greatly improve the fidelity and utility of this attribute, particularly in cases where the encroachment is neither nonexistent, nor complete. Recommendations for improving this attribute have been provided and will be further developed in future work.
- The development of an MV attribute similar to the Maneuver Area's Range Sustainability attribute, but tailored to firing ranges, is recommended. This will be further developed in future work.
- Location-specific noise contours do add additional fidelity to land use planning applications. However, the full utility will be unknown until further investigations using realistic training tempo scenarios are conducted. Current methods for climate projections cannot reliably infer changes to wind directions and speeds, two of the critical aspects for noise contour generation. Therefore, it is not possible to include climate change features in noise contours.
- The impact of current and future listings of endangered species has been identified as a potential restriction to range throughput. This will be further investigated in future work.
- An assessment of the change in clean-up costs due to climate change-induced biome shifts will be produced in future work.

Acronyms and Abbreviations

Term	Definition
AEC	Army Environmental Command
AFB	Air Force Base
AFCCC	Air Force Combat Climatology Center
AR	Army Regulation
ATTACC	Army Training and Testing Area Carrying Capacity
BRAC	Base Realignment and Closure
BRACAS	Base Realignment and Closure Action Scheduler
CAA	Center for Army Analysis
CDNL	C-weighted Day-Night Sound Level
CEERD	US Army Corps of Engineers, Engineer Research and Development Center
CEQ	Council on Environmental Quality
CERL	Construction Engineering Research Laboratory
COA	Course of Action
COBRA	Cost of Base Realignment Actions
CONUS	Continental United States
CRREL	Cold Regions Research and Engineering Laboratory
CSEL	C-weighted Sound Exposure Level
DoD	U.S. Department of Defense
EO	Executive Order
ERDC	Engineer Research and Development Center
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
ESRI	Environmental Systems Research Institute, Inc.
GAMS	General Algebraic Modeling System
GCM	Global Climate Model
GIS	Geographic Information System
HQDA	Headquarters, Department of the Army
HQIIS	[Army] Headquarters Installation Information System
ICLUS	Integrated Climate and Land Use Scenarios
JCSG	Joint Cross-Service Group
KBDI	Keetch-Byram Drought Index
LEAM	Land-use Evolution and impact Assessment Model
MAC	Maneuver Area Capacity
MILCON	Military Construction
MODA	Multi-Objective Decision Analysis
MVA	Military Value Analysis
NCEAS	National Center for Ecological Analysis
NPP	Net Primary Productivity
NPS	Naval Post Graduate School

Term	Definition
NPV	Net Present Value
NRCS	Natural Resources Conservation Service
OASA(IE&E)	Office of the Assistant Secretary of the Army for Installations, Energy and Environment
OCONUS	Outside Continental United States
OMB	Office of Management and Budget
OSAF	Optimal Stationing of Army Forces
OSAFK	OSAF, Korea
OSUB	Optimally Stationing Units to Bases
PL	Public Law
POC	Point of Contact
QDR	Quadrennial Defense Review
RCI	Rating Cone Index
RCP	Representative Concentration Pathway
RUG	Regional Urban Growth (model)
SMART	Specific, Measurable, Attainable, Realistic, Timely
SME	Subject Matter Expert
SSC	DoD Senior Sustainability Council (SSC)
SSPP	Strategic Sustainability Performance Plan
SSURGO	(USDA-NRCS) Soil Survey Geographical Database
TB	Technical Bulletin
TC	Technical Committee
TES	Threatened or Endangered Species
TNPP	Total Net Primary Productivity
TR	Technical Report
USA	United States of America
USCS	Unified Soils Classification System
USDA	US Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USFWS	US Fish and Wildlife Service
WBGT	Wet Bulb-Black Globe Temperature
WES	Waterways Experiment Station
WGBT	

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Appendix A: MVA Attributes

This appendix contains the most recent versions, as of November 2014, of MVA attributes described in this report. These attribute definitions were obtained from CAA in November 2014.

The latest available versions of MVA Attributes described in this report are:

1. Range Sustainability (8 July 2014)
2. Population Impact (1 May 2014)
3. Dudded Impact Area (16 May 2014)
4. Indirect-Fire Capability (04 April 2004)
5. Direct-Fire Capability (29 June 2004)
6. Noise Contours (09 June 2004).

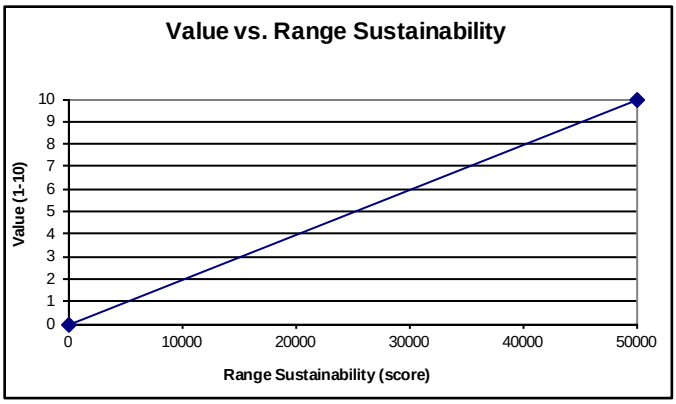
A.1 Range sustainability (as of 8 July 2014)

1. **Definition:** The amount of training area without restrictions, combined with a factor denoting land resiliency.
2. **Purpose:** Measures the amount of training land on an installation that is usable and its ability to sustain maneuver training. Specifically, measures this by identifying land that is not usable and considers the land's ability to withstand maneuver activities.
3. **POC:** G 3/5/7 DAMO-TRS
4. **Data Source:**
   a. Headquarters Installation Information System (HQIIS)
   b. Sustainable Range Program, Geospatial Support Center
   c. Bailey's Ecoregions study.
5. **Methodology:**
   a. Determine the operational land area. This is an aggregate of light and heavy operational range inventory (Facility Category codes 17710 & 17720), as used in the maneuver land attribute.
   b. Determine restricted, or unusable, acres based on safety, regulatory, and stewardship restriction. Restrictions are derived from GIS analysis performed at the Sustainable Range Program, Geospatial Support Center.
   c. Determine a land resiliency factor by applying Bailey's Ecoregions study values to installations. Using the same resiliency values used to determine land repair requirements, provide an increasingly greater value for resilient ecological types.
      (1) The resiliency value is a single number ranging 2-12, with possible values including 2, 3, 4, 6, and 12.
      (2) The value for resiliency represents number of "passes," or passes from a M1A1 in tactical mode, over a year until the soil reaches a critical level.
      (3) The resiliency value is converted into a multiplicative factor using the values listed below:

Resiliency Value	Multiplicative Factor
2	0.17
3	0.25
4	0.33
6	0.50
12	1.0

      (4) Combine data and calculate range sustainability.

6. **Equation:** Range sustainability = (Operational land – unusable land) * resiliency factor.
7. **Model requirements:**
8. **Model Input:** The operational land available, restricted acres, and land resiliency are the primary inputs.
9. **Value function:**
   a. The value function converts the range sustainability measure into military value.
   b. The value function is a linear increasing function.
   c. The maximum value of 10 is given for a score of ***x***, which indicates a large amount of usable land and high soil resiliency. ***Note: actual upper bound will be determined when data are collected.***
   d. The minimum value of 0 is given for a score of 0, which indicates no usable land, as shown below:



A.2 Population impact (as of 1 May 2014)

1. **Definition:** The impact of population density and growth rate in a 10-mile buffer outside the installation.
2. **Purpose:** The Population Impact attribute attempts to address potentially negative impacts on an installation and the nearby communities created by changes in population in the surrounding area over time. It also serves as an indicator of potential encroachment issues relating to noise complaints, reduction of natural buffer land surrounding installation boundaries, light pollution effects on nighttime training operations and other potential impacts to operations on installations.
3. **POC:** U.S. Army Environmental Command (AEC): Ms. Janet Kim (janet.kim1.civ@mail.mil)
4. **Data Source:** U.S. Census, Army Mapper
5. **Methodology:**
   a. Obtain the most recent decennial census geospatial data (with population statistics at the census block level) and the decennial data from 20 years before the most recent dataset. Decennial census data is used because it is more accurate than population estimates developed in the interim years and because it is collected down to the census block level.
   b. Use the buffer tool in ArcGIS software to create a 10-mile buffer area around the installation. See Figure A-1.
      (1) A standardized set of geospatial data for installation boundaries is required. Currently, AEC uses installation boundaries from Army Mapper, the Army's geospatial dataset of record for installations.
      (2) The installation boundaries maintained in Army Mapper are the notional site boundaries, not the legal boundaries that are maintained by the U.S. Army Corps of Engineers.
      (3) Ten miles was chosen as the buffer area by subject matter experts, based on factors such as noise, road infrastructure, and a comparison of the population densities around the installations.
   c. Add decennial census block data to the project. See Figure A-2.
   d. Select census block polygons where the polygon centroid of the census blocks is within the polygon representing the 10-mile buffer of the installation. See Figure A-3.
      (1) The location of the centroid of the census block polygon is used to determine if the census block is included in the population total for the 10-mile buffer. If the census block polygon centroid lies outside of the 10-mile buffer, the entire polygon is excluded from the analysis.
      (2) Create a new data layer with the census blocks selected from the overlay analysis.
   e. Determine the total population for all of the census blocks that were selected from the overlay analysis. The best way to do this is by opening

the attribute table for the census blocks data layer and summarizing the population data field for the total population.

f. Determine the square miles of the 10-mile buffer zone surrounding the installation being analyzed. The best way to do this is by adding a new field to the attribute table for the buffer data layer and using the "calculate geometry function" to determine the total square mileage and automatically add that information to the new data field.

g. Divide the total population of the selected census blocks by the square mileage of the buffer area (step f) to calculate the current population density per square mile.

h. Normalize the current population density and scale the range of values to a score that ranges from 0 to 9.

i. Calculate the percentage change in population between the most current census population (i.e., 2010) by the census population from 20 years prior (i.e., 1990) to determine the rate of population change over the 20 year span.

j. Normalize the percentage changes in population and scale the range of values to a score that ranges from 0 to 1.

6. **Equations:**

a. Population density = population / 10-mile buffer area (in sq. mi.)

b. Percentage change = (2010 population – 1990 population) / 1990 population

c. Population impact score = Normalized population density + Normalized percentage change in population [10 is the maximum score for any installation and 0 is the minimum score.]

d. Normalization = $b + [(X - X_{min})\ (a-b) / (X_{max} - X_{min})]$, where *a* represents the highest score for the dataset, *b* represents the lowest score for the dataset, and *X* is either population density per square mile or percentage change in population. For the population density, $a = 9$, and for percentage change, $a = 1$; $b = 0$ for both.

7. **Model requirements:**

a. **Model Inputs:** The primary model inputs are the most recent decennial census geospatial data (with population statistics at the census block level), the decennial data from 20 years before the most recent dataset and the 10 mile buffer area.

b. **Value Function:**

(1) The value function converts the score/category into military value.

(2) The value function is linear increasing.

(3) The conversion is direct; i.e., a label of 1 gets a value of 1, a label of 10 gets a value of 10, etc.

Figure A-1. Ten-mile buffer with census tracts overlaid.

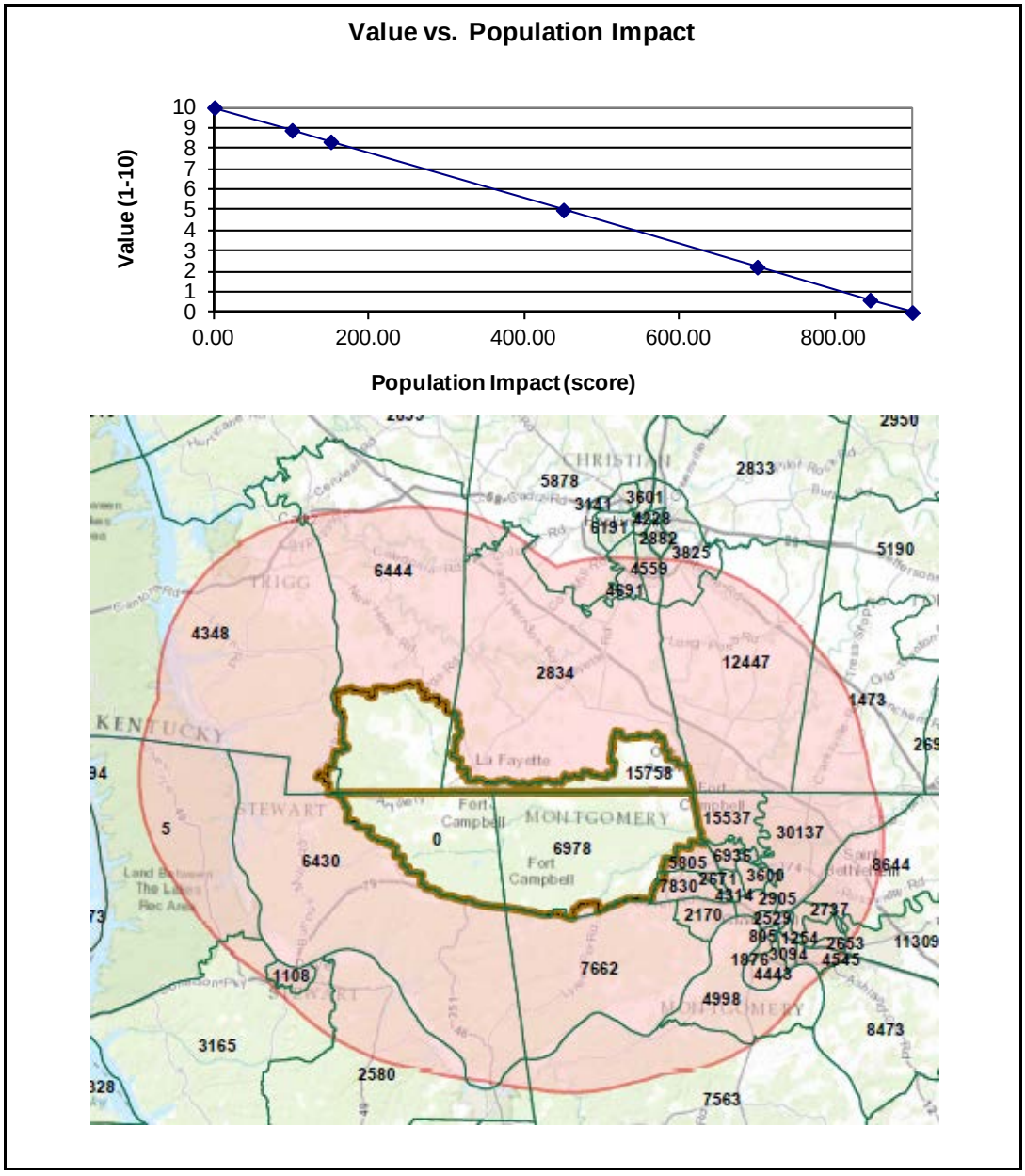


Figure A-2. Ten-mile buffer with census blocks overlaid.

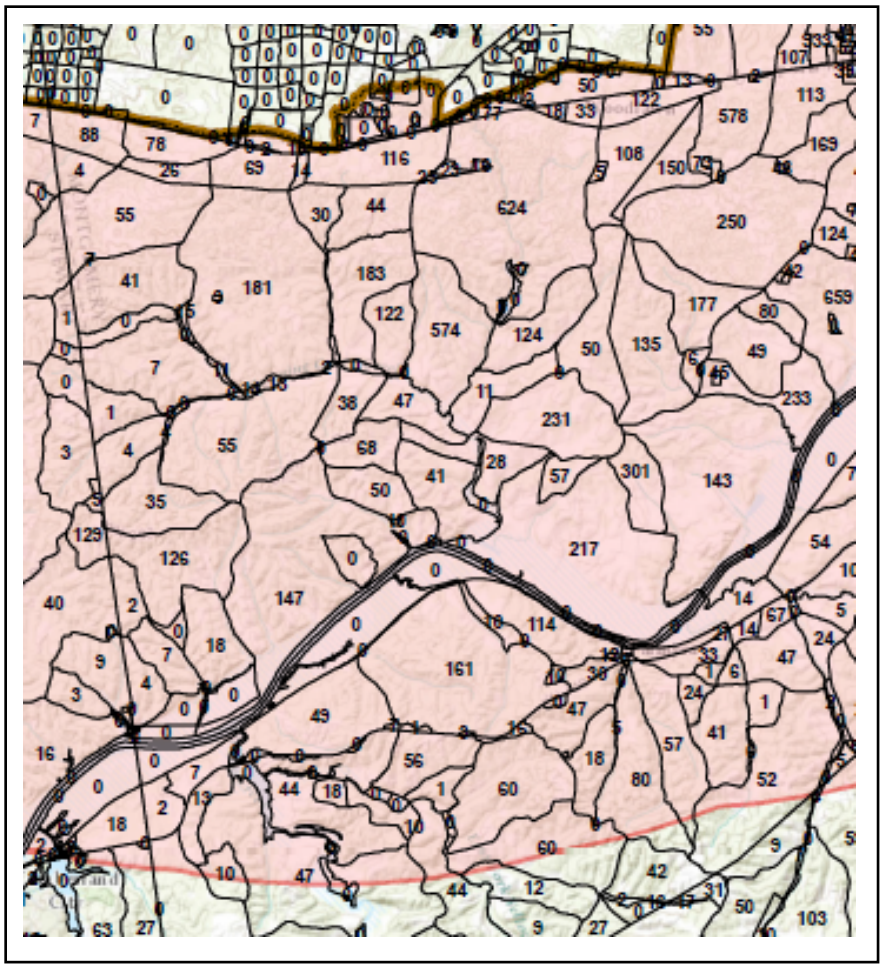


Figure A-2 shows a snapshot of a 10-mile buffer (red) surrounding Fort Campbell with **census tract** geography (green polygons) overlaid. Census tract geography is too large to obtain accurate population statistics for the area within the 10-mile buffer area alone.

Figure A-2 also shows a snapshot of a 10-mile buffer (red) surrounding Fort Campbell with **census block** geography (black polygons) overlaid. Census block geography is nested within census tracts and block groups. It is the lowest level of census geography available. Geospatial analysis at this level of census geography provides for the most accurate population statistics.

Figure A-3. Ten-mile buffer with census blocks and census block centroids overlaid.

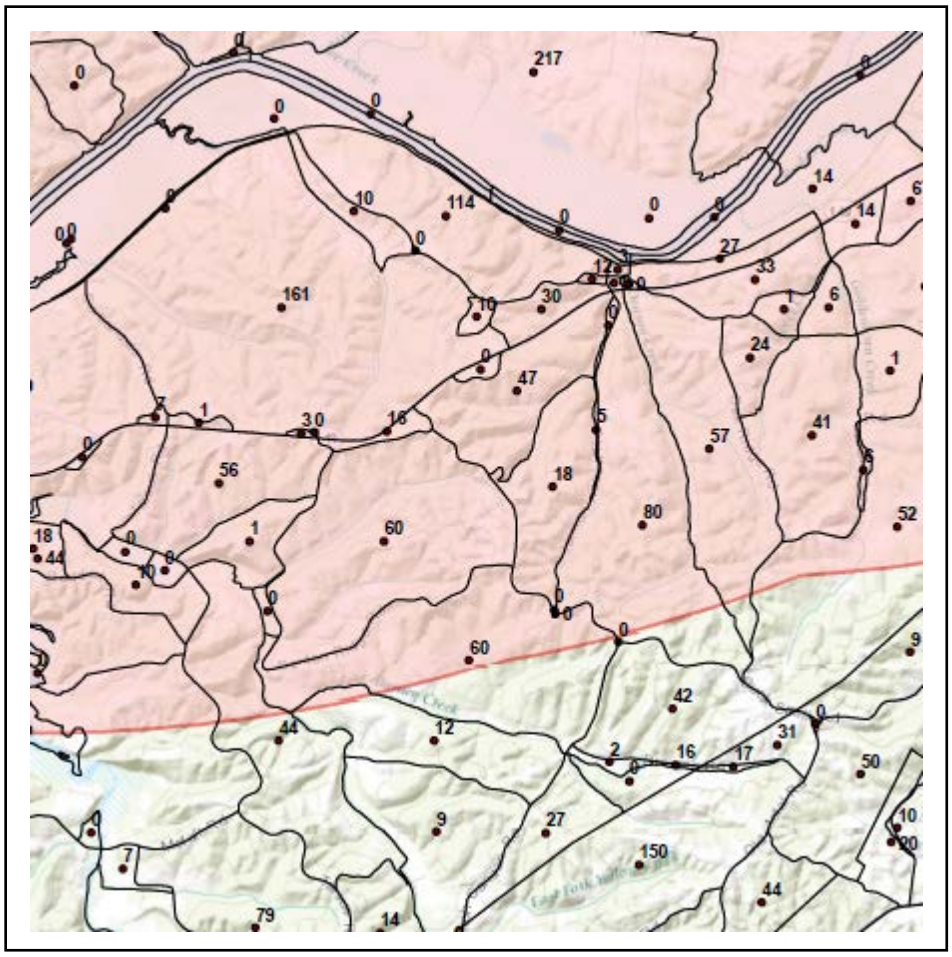


Figure A-3 shows a snapshot of a 10-mile buffer (red) surrounding Fort Campbell with **census block** geography (black polygons) and **census block centroids** (points) overlaid. ArcGIS software is used to geospatially select only the census blocks with their centroids within the 10-mile buffer. Census blocks with their centroids outside of the buffer area are entirely eliminated from the selection and not included in the population statistics.

A.3 Dudded impact area (as of 16 May 2014)

1. **Definition:** A score based on whether an installation has an impact area, how many impact areas the installation has, and the size of the largest impact area.
2. **Purpose:** Measures the ability of the installation's ranges and impact areas to support indirect-fire/non-line-of-sight weapons training.
3. **POC:** G-3/5/7 DAMO-TRS
4. **Data Source:** Headquarters Installation Information System (HQIIS)
5. **Methodology:**
   a. Determine, as a screening criterion, whether the installation has an impact area. (Note: all BCT installations do have at least one impact area.)
   b. Determine the number of impact areas on the installation and the size of the largest impact area. Data are collected from the Real Property Inventory (RPI) as reported in HQIIS.
   c. Use the table below to determine the score for the installation.
      (1) Thresholds for area sizes were developed using Army Training Circulars.
      (2) Training Circular 25-8, *Army Ranges* (HQDA 2004a), describes a Mortar Range on page D-31 and states that "A common impact area is used for all types of mortars. It is at least 2,000 m wide and 6,000 m deep. Firing at maximum and minimum range is obtained by using different firing points." A 2,000 x 6,000 m is 12 km^2, which equals 2,965.2645776 acres; this figure was rounded to 3,000 acres.
      (3) Training Circular 25-1, *Training Land* (HQDA 2004b, p A-17), describes Mechanized Infantry and Armor Division Maneuver/Training Area Requirements, and states that "When artillery units use munitions not approved for overhead firing, the maneuver space in the "Deliver Fires" block apply. With munitions approved for overhead firing, the maneuver space in the "Move" block applies, plus an impact area of 6 x 8 km." Note that 48 km^2 equals 11,861.05831 acres; this figure was rounded to 12,000 acres.
6. **Equation:** NA
7. **Model Requirements:**
   a. **Model Inputs:**
      (1) The number of impact areas on an installation and the size of the largest impact area are the model's primary inputs.
      (2) The maximum value will be given to the installation with the most number of impact areas and the largest-sized impact area.
      (3) The installation receives no value if no impact areas exist.

(4) Labels for any combination size and number of impact areas possible are listed below:

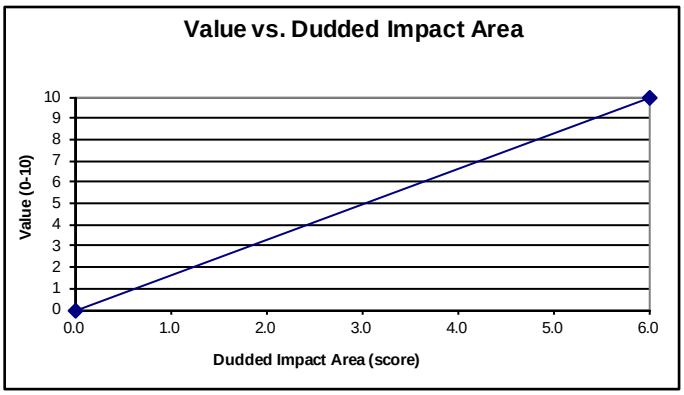
	Number of Impact Areas	
Largest Impact Area (1000s of Acres)	1	2
< = 3	Label 1	Label 2
> 3 and <= 12	Label 3	Label 4
> 12	Label 5	Label 6

b. **Value Function:**

(1) The value function converts the label into military value.

(2) The value function is increases linearly (Figure A-4)

Figure A-4. Linear increase in value function.



A.4 Indirect-fire capability (as of 16 Apr 04)

1. **DEFINITION:** A combination of standoff distance and the largest weapon system capability supported for indirect-fire/non-line-of-sight weapons training.
2. **PURPOSE:** Measures the ability of the installation's ranges and impact areas to support indirect-fire/non-line-of-sight weapons training.
3. **SOURCE:** Installation Capacity Data Call, MVA Data Call
4. **METHODOLOGY:**
   a. The installation, using currently approved range diagrams and regulations, reports its indirect-fire weapons/non-line-of-sight systems that can fire on specified ranges.
   b. The installation reports the maximum distance (standoff) that each indirect-fire weapon system can fire into the installation's impact area as defined in the current training area regulations.
   c. TABS combines the data that are defined in 4a-b and calculates military value.
5. **QUESTIONS THAT DEFINE DATA:**
   a. Additional Live-Fire Capacity – Does the installation have the land capacity to accommodate firing of the listed weapon systems? Thes systems include: 60mm Mortar, 81mm Mortar, 105mm Howitzer, 155mm Howitzer, 120mm Mortar, Multiple Launched Rocket System (MLRS), SMAW, AT-4, Javelin AT, TOW AT, 2.75 Rocket, Hellfire Missile, 20mm Helicopter Cannon, 30mm Helicopter Cannon, 105mm Tank Main Gun, 120mm Tank Main Gun, 25mm Ground Cannon, 30mm Ground Cannon, Mk 19 40mm Grenade Launcher, 50 cal MG, 7.62 MG, 5.56mm MG, Patriot ADA missile, Stinger ADA missile (OSD #154)
   b. What is the maximum standoff distance for each indirect-fire weapon system that can fire in the installation's impact area? Indicate by weapon system: 81mm Mortar 120mm Mortar; 105mm Howitzer; 155mm Howitzer; MLRS; and Patriot ADA Missile. (MVA Data Call)
6. **REFERENCES:** Installation Range Regulations, Army Range Inventory.
7. **UNIT OF MEASURE:** Maximum distance a given weapon system can fire into the impact area (standoff) in kilometers, caliber, or type of weapon system.
8. **EQUATION: N/A**
9. **MODEL REQUIREMENTS:**
   a. Model Inputs:
      (1) The installation's indirect-fire capability, as measured by standoff and weapon's capability, is the model's primary input.

(2) The maximum value of 10 will be given to the installations with the largest standoff (>30 KM) and ability to fire the Patriot Missile.

(3) The installation receives no value if indirect-fire capability does not exist.

(4) Labels for any combination of standoff and weapon system capability that exists on an installation are listed below:

	WEAPON SYSTEM CAPABILITY			
STANDOFF (KM)	<= 120 mm	> 120 mm	MLRS	Patriot
< = 10	Label 1	Label 2	Label 3	X
> 10 and <= 30	Label 4	Label 5	Label 6	Label 7
> 30	Label 8	Label 9	Label 10	Label 11

b. Value Function

(1) The value function is a representation of the military value of an installation's standoff and weapon system capability and converts the raw data that TABS plots into the above matrix to determine a military value for the installation.

(2) The assessment of the function is determined by TABS and coordinated with G3-TR.

(3) Assessment Results.

(a) The table below illustrates the assessment's values, which consists of a series of paired comparisons between the Labels, based on a range from 1 to 9 where a comparison of "1" indicates that preferences between the Labels are the same, and where a comparison of "9" indicates that the preference of one Label to another is extreme.

C.R. = 0.032	Label 0	Label 1	Label 2	Label 3	Label 4	Label 5	Label 6	Label 7	Label 8	Label 9	Label 10	Label 11
Label 0	0	0.50	0.33	0.25	0.50	0.33	0.25	0.20	0.33	0.25	0.20	0.17
Label 1	2	0.08	0.50	0.25	0.50	0.33	0.25	0.17	0.33	0.25	0.17	0.14
Label 2	3	2	1	0.50	2	0.50	1	0.25	0.50	0.33	0.25	0.20
Label 3	4	4	2	2.22	2	1	0.50	0.33	3	1	0.333	0.25
Label 4	2	2	0.5	0.50	0.50	0.5	0.33	0.25	0.5	0.33	0.25	0.17
Label 5	3	3	2	1	2	1.70	0.50	0.33	2	0.5	0.333	0.20
Label 6	4	4	1	2	3	2	3.03	0.50	3	1	0.5	0.33
Label 7	5	6	4	3	4	3	2	5.42	3	2	1	0.33
Label 8	3	3	2	0.33	2	0.50	0.33	0.33	1.25	0.50	0.33	0.25
Label 9	4	4	3	1	3	2	1	0.5	2	2.92	0.5	0.33
Label 10	5	6	4	3	4	3	2	1	3	2	5.42	0.33
Label 11	6	7	5	4	6	5	3	3	4	3	3	10

(b) For example (refer to the above matrix), the SME indicates that Label 11 (scores a 7) is near *extremely* preferred over Label 1, and Label 6 is *moderately* preferred over Label 1 (scores a 4).

(c) This has a consistency ratio (CR) of 0.032 that indicates that the paired comparisons are *consistent* across all Labels. A CR 0.1 is considered adequate. For example, a consistent ranking between Labels would mean that if A > B and B > C then A > C. However, if A < C, then the ranking would be considered inconsistent.

(d) The values associated with each Label are obtained from the previous AHP assessment matrix by recording the values along the diagonal of the matrix. For ease of exposition, Table A-1 lists values for each Label.

Table A-1. Values for each Label obtained from previous AHP assessment matrix.

	WEAPON SYSTEM CAPABILITY			
STANDOFF (KM)	<= 120 mm	> 120 mm	MLRS	Patriot
< = 10	0.08	1.00	2.22	N/A
> 10 and <= 30	0.50	1.70	3.03	5.42
> 30	1.25	2.92	5.42	10.00

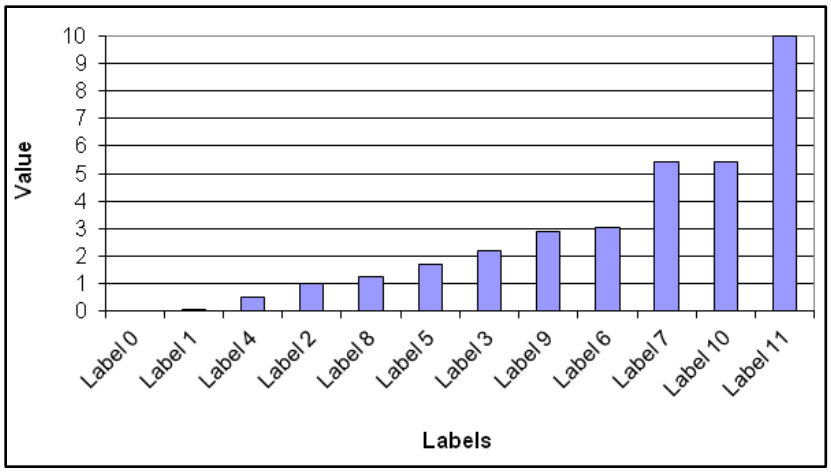
c. Model output

(1) The above matrix represents the model's results (the diagonal of the assessment matrix). Most installations will have standoff and weapon systems capability characteristics that will fit into this matrix. If the installation's values do not fall on the matrix, it receives "0" value for this attribute.

(2) Raw scores are normalized on a scale of zero to 10 based on assessment results shown in the previous matrix.

(3) The histogram for the Value Function provides a graphical representation of the previous matrix. The military values shown in Figure A-5 are ordered according to increasing value based on the assessment. The values show that there are several combinations for this attribute that have nearly the same military value.

Figure A-5. Military values ordered according to increasing value based on the assessment.



A.5 Direct-fire capability (as of 29 Jun 04)

1. **DEFINITION:** A combination of the size of the installation's impact area and the largest direct-fire weapon system capability of an installation range complex.
2. **PURPOSE:** Measures the ability of an installation's ranges and impact areas to support direct-fire weapons training. This measure places added military value to the ranges and impact areas that can be used to train larger direct-fire weapon systems.
3. **SOURCE:** Installation Capacity Data Call
4. **METHODOLOGY:**
   a. The installation calculates the acreage of its impact area as noted in the current training area regulations.
   b. Using currently approved surface danger-zone diagrams; the installation reports the direct-fire weapon systems that can fire on specified ranges.
   c. TABS combines the data that are defined in 4a-b and calculates military value.
5. **QUESTIONS THAT DEFINE DATA:**
   a. Dudded Impact Area – What is the size of the installations dudded impact area(s)? (DoD #156: Dudded Impact Area Acres)
   b. Additional Live-Fire Capacity – Does the installation have the land capacity to accommodate firing of the following weapon systems? These systems include: 60mm Mortar, 81mm Mortar, 105mm Howitzer, 155mm Howitzer, 120mm Mortar, MLRS, SMAW, AT-4, Javelin AT, TOW AT, 2.75 Rocket, Hellfire Missile, 20mm Helicopter Cannon, 30mm Helicopter Cannon, 105mm Tank Main Gun, 120mm Tank Main Gun, 25mm Ground Cannon, 30mm Ground Cannon, Mk 19 40mm Grenade Launcher, 50 cal MG, 7.62 MG, 5.56mm MG, Patriot ADA missile, Stinger ADA missile (DoD #154)
6. **REFERENCES:** Installation Range Regulations, Army Range Inventory.
7. **UNIT OF MEASURE:** Thousands of acres, Type of weapon system.
8. **EQUATION:** N/A
9. **MODEL REQUIREMENTS:**
   a. Model Inputs:
      (1) The size of the installation's impact area and maximum weapon system capability are the model's two primary inputs.
      (2) The largest value of 10 will be given to the installations with the largest contiguous impact area (>=30,000 acres) and the largest weapon system capability (>=120mm).

(3) The minimum value of "0" will be given to an installation if it does not have an impact area and firing capability.

(4) Labels for any combination that can exist for the value measure and an X if the combination cannot exist on an installation are listed below:

	WEAPON SYSTEM CAPABILITY		
IMPACT AREA (1000s ACRES)	<= 50 Cal	> 50 Cal <120mm	>= 120mm
< = 10	Label 1	Label 2	Label 3
>10 and <= 30	Label 4	Label 5	Label 6
> = 30	Label 7	Label 8	Label 9

b. Value Function

(1) The value function measures the returns to scale of the installation's largest contiguous impact area and weapon system capability and converts the raw data that TABS plots into the above matrix to determine military value for the installation.

(2) The assessment of the function is determined by TABS and coordinated with G3-TR.

(3) Assessment Results.

(a) The table below illustrates the assessment's values, which consists of a series of paired comparisons between the Labels, based on a range from 1 to 9, where a comparison of "1" indicates that preferences between the Labels are the same, and where a comparison of "9" indicates that the preference of one Label to another is extreme.

C.R. = 0.016	Label 0	Label 1	Label 2	Label 3	Label 4	Label 5	Label 6	Label 7	Label 8	Label 9
Label 0	0	0.50	0.33	0.25	0.33	0.25	0.17	0.20	0.14	0.11
Label 1	2	0.30	0.50	0.25	0.50	0.33	0.20	0.33	0.17	0.11
Label 2	3	2	1.03	0.50	1	0.50	0.25	0.50	0.25	0.17
Label 3	4	4	2	3.30	2	1	0.50	2	1	0.33
Label 4	3	2	1	0.50	1.17	0.50	0.33	0.50	0.33	0.20
Label 5	4	3	2	1	2	2.83	0.50	2	0.50	0.25
Label 6	6	5	4	2	3	2	5.95	2	2	0.50
Label 7	5	3	2	0.50	2	0.50	0.50	2.31	0.50	0.33
Label 8	7	6	4	1	3	2	0.50	2	4.85	0.50
Label 9	9	9	6	3	5	4	2	3	2	10

(b) For example (refer to column 2 of the above matrix), the SME indicates that Label 9 (scores a 9) is *extremely* preferred over Label 1, and Label 6 (scores a 5) is *moderately* preferred over Label 1.

(c) This has a CR of 0.016 that indicates that the paired comparisons are *consistent* across all Labels. A CR 0.1 is considered adequate. For example, a consistent ranking between Labels would mean that if A > B and B > C then A > C. However, if A < C, then the ranking would be considered inconsistent.

(d) The values associated with each Label are obtained from the previous assessment matrix by recording the values along the diagonal of the matrix. For ease of exposition, the following matrix shows values for each Label:

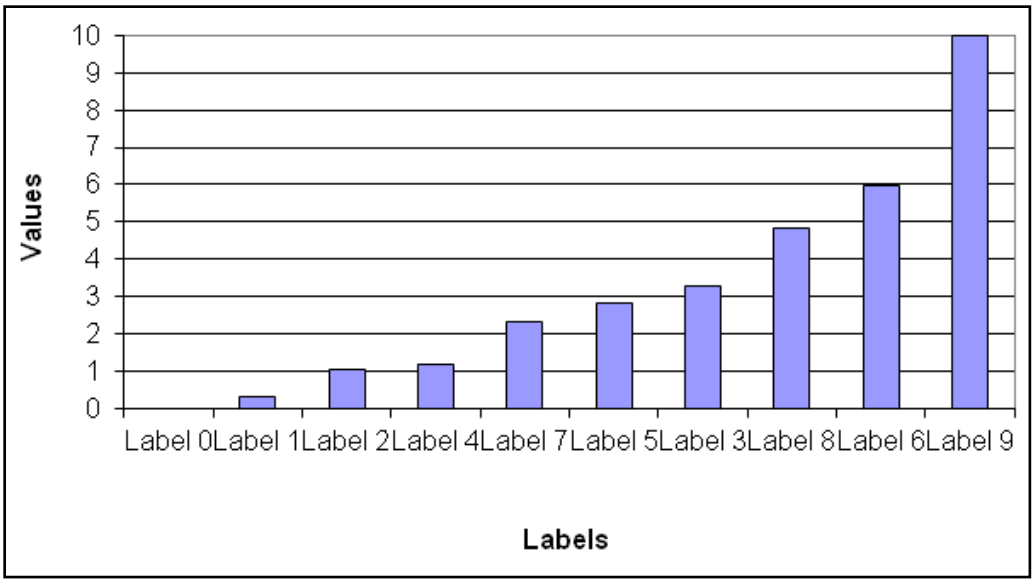
	WEAPON SYSTEM CAPABILITY		
IMPACT AREA (1000s ACRES)	<= 50 Cal	> 50 Cal <120mm	>= 120mm
< = 10	0.30	1.03	3.30
>10 and <= 30	1.17	2.83	5.95
> = 30	2.31	4.85	10.00

c. Model output

(1) The above matrix represents the model's results (the diagonal of the assessment matrix). Most installations will have contiguous impact area and weapon system capability characteristics that fit into this matrix. If the installation's values do not fall on the matrix, it receives a "0" value for this attribute.

(2) Raw scores are normalized on a scale of zero to 10 based on AHP assessment results shown in the previous matrix.

(3) The histogram for the Value Function provides a graphical representation of the previous matrix. The military values shown in the following graph are ordered according to increasing value based on the assessment. The values show that there are several combinations for this attribute that have nearly the same military value.



A.5.1 DoD #154: Live-Fire Ranges Used

Question: Additional Live-Fire Capacity:

Does the activity/installation (e.g., base) have the land capacity to accommodate firing of the listed weapon systems?

Check here if this question is not applicable (N/A): ☐

Please fill in the following table(s), adding rows as necessary

60mm Mortar (Yes/No)	81mm Mortar (Yes/No)	105mm Howitzer (Yes/No)	107mm Mortar (Yes/No)	155mm Howitzer (Yes/No)	MLRS (Yes/No)	SMAW (Yes/No)	AT-4 (Yes/No)	Javelin AT Missile (Yes/No)

60mm Mortar (Yes/No)	TOW AT Missile (Yes/No)	2.75″ Rocket (Yes/No)	Hellfire Missile (Yes/No)	20mm Helicopter Mounted Cannon (Yes/No)	30mm Helicopter Cannon (Yes/No)	105mm Tank Main Gun (Yes/No)	120mm Tank Main Gun (Yes/No)	25mm Ground Mounted Cannon (Yes/No)

60mm Mortar (Yes/No)	30mm Ground Mounted Cannon (Yes/No)	MK19 40mm Grenade Launcher (Yes/No)	50 Cal MG or Rifle (Yes/No)	7.62mm MG or Rifle (Yes/No)	5.56mm MG or Rifle (Yes/No)	Patriot ADA Missile (Yes/No)	Stinger ADA Missile (Yes/No)	120mm Mortar (Yes/No)

A.6 Noise Contours (as of 9 Jun 04)

1. **DEFINITION:** The number of acres off the installation that are incompatible with current land use practices due to Noise Contour Levels II and III.
2. **PURPOSE:** Measures the degree of external encroachment placed on a given installation as a result of noise contours extending off-installation. Primarily identifies areas where noise levels from military sound sources are high enough to be incompatible with "noise sensitive" areas such as housing, schools, churches, and hospitals. Attribute demonstrates the potential for military training to be adversely impacted because of incompatible land use practices.
3. **SOURCE:** Installation Capacity Data Call-1, DoD Questions #198, and #239.
4. **METHODOLOGY:**
   a. *Background*
      (1) The Noise Control Act of 1972 (Public Law 92-574 1972) states "... that it is the policy of the United States to promote an environment for all Americans free from noise that jeopardizes their health or welfare and that Federal agencies (1) having jurisdiction over any property or facility, or (2) engaged in any activity resulting, or which may result, in the emission of noise, shall comply with Federal, State, interstate and local requirements ..."
      (2) Army Regulation 200-1, Environmental Protection and Enhancement (U.S. Army 1997), regulates noise management in the Army. The primary intent of the regulation is to avoid restrictions on training through cooperative land use agreements with the communities controlling zoning in the vicinity of the installations.
      (3) The installation will report Noise Contour II as defined by the noise exposure that would be expected to result in 15–39% of the population describing themselves as "highly annoyed." Also, it is defined physically as 65-75 ADNL, or 62-70 CDNL.
      (4) The installation will report Noise Contour III (Incompatible Use) as defined by the noise exposure that would be expected to result in greater than 39% of the population describing themselves as "highly annoyed." Also, it is defined physically as > 75 ADNL, or > 70 CDNL.
   b. *Method*
      (1) TABS will determine the installation's Gross Acres of noise contours extending off-installation by adding results from paragraphs 4.a.iii and 4.a.iv.

5. **QUESTIONS THAT DEFINE DATA:**
   a. Fill in the following table for the property outside of your main installation, auxiliary airfield, training range and/or Research, Development, Test and Evaluation (RDT&E) range using local zoning and/or community land use plans. Report Noise Zones (Army). When totaling, do not double count overlapping incompatible acres. Also, consider all structures or activities incompatible unless there is specific knowledge (such as visual surveys) that the structure is considered compatible. (DoD #239)
   b. Complete the table for all land owned/controlled by the installation. Report total acreage. "Controlled" includes land/property used by the service under lease, license, permit, etc. DO NOT include easements as either owned or controlled. Include the main installation, ranges, auxiliary airfields, withdrawn land and all outlying sites. Designate ranges, auxiliary airfields, and outlying sites separately by name and real property (four letter) nomenclature. (DoD #198)
6. **REFERENCES:** Installation Environmental Noise Management Plan (IENMP) and/or Technical Manual 5-803-7, 1 May 1997
7. **UNIT OF MEASURE:** Acres
8. **EQUATION: N/A**
9. **MODEL REQUIREMENTS:**
   a. Model Inputs:
      (1) The model's primary inputs are the number of acres of noise contours extending off-installation, and the installation's size.
   b. Model Value Function
      (1) The value function is a representation of the military value of the extent of noise contours extending off-installation. TABS plots the sum of Noise Zones II and III (gross acres) against installation size into the below matrix resulting in a military value for the installation.
      (2) The maximum value of 10 will be given to the largest installations with the fewest number acres of Noise Zones II and III off the installation.
      (3) The Minimum value of 0 will be given to the smallest installations with the greatest number acres of Noise Zones II and III off the installation
      (4) The assessment of the function is determined by TABS and coordinated with the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM.)

	Noise Zones II & III (Gross Acres)			
Installation Size (ACRES)	> 10K	<=10K	<=100	0
<= 75K	Label 1	Label 2	Label 3	Label 10
<=200K	Label 4	Label 5	Label 6	Label 10
>200K	Label 7	Label 8	Label 9	Label 10

c. Assessment Results.

(1) The table below illustrates the assessment's values, which consist of a series of paired comparisons between the different Labels (range from 1 to 7, where a comparison of "1" indicates that the preferences are equal between the Labels, and where a comparison of "9" indicates that the preference of one Label to another is extreme).

C.R. = 0.028	Label 1	Label 2	Label 3	Label 4	Label 5	Label 6	Label 7	Label 8	Label 9	Label 10
Label 1	0	0.25	0.143	0.5	0.2	0.125	0.25	0.167	0.111	0.111
Label 2	4	1.496	0.5	2	0.5	0.5	1	0.5	0.333	0.25
Label 3	7	2	3.389	3	2	0.5	2	2	0.333	0.333
Label 4	2	0.5	0.333	0.644	0.333	0.25	0.5	0.333	0.25	0.2
Label 5	5	2	0.5	3	2.227	0.5	2	0.5	0.333	0.25
Label 6	8	2	2	4	2	4.534	3	2	0.5	0.333
Label 7	4	1	0.5	2	0.5	0.333	1.413	0.5	0.333	0.25
Label 8	6	2	0.5	3	2	0.5	2	2.675	0.333	0.2
Label 9	9	3	3	4	3	2	3	3	6.82	0.5
Label 10	9	4	3	5	4	3	4	5	2	10

(2) The assessment converts the paired comparisons into the value that an installation will receive for meeting the requirements at a given label.

(3) For example (refer to the gray cells in column 2 of the above matrix), the SME indicates that Label 7 is extremely (scores a 7) preferred over Label 1, and Label 4 is moderately (scores a 5) over Label 1.

(4) The above matrix has a CR of 0.020 that indicates that the paired comparisons are consistent across all Labels. A CR < 0.1 is considered adequate. For example, a consistent ranking between Labels would mean that if A > B and B > C then A > C. However, if A < C, then the ranking would be considered inconsistent.

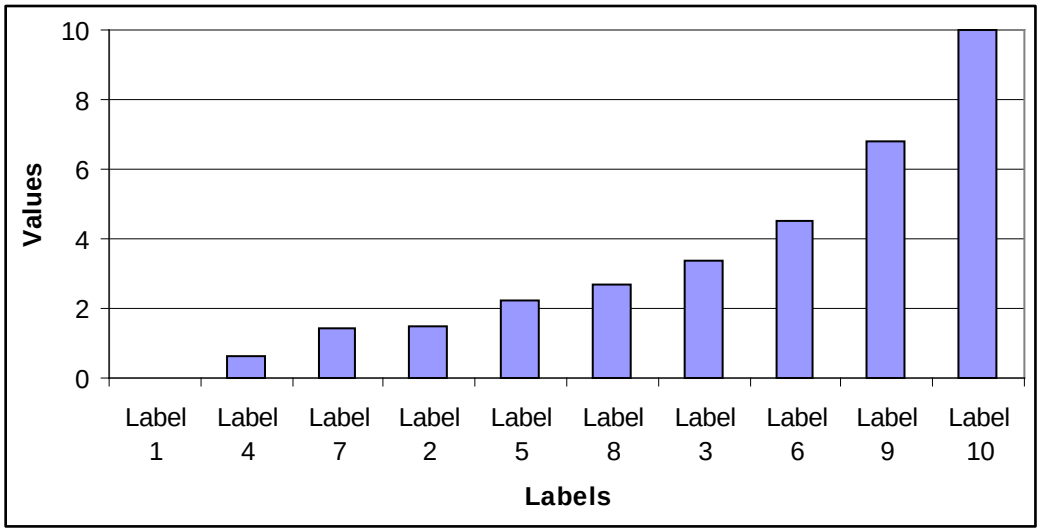
d. Model outputs

Installation Size (ACRES)	Noise Zones II & III (Gross Acres)			
	> 10K	<=10K	<=100	0
<= 75K	0	1.496	3.389	10
<=200K	0.644	2.227	4.534	10
>200K	1.413	2.675	6.82	10

(1) The above matrix represents the model's results (the diagonal of the assessment matrix). Each installation will have 0 or greater gross acres zoned as Noise Zones II and III off the installation, and installation size (acres) that fit into this matrix.

(2) The raw scores were normalized on a scale of zero to 10 based on the paired assessment results.

(3) The histogram for the Value Function provides a graphical representation of the previous matrix. The military values shown in the following graph are ordered according to increasing value based on the assessment. The values show that there are several combinations for this attribute that have the same military value.



Appendix B: Estimated Soil Moisture at Five U.S. Army Installations

This appendix includes results of soil moisture estimations for five military installations (Fort Bliss, Fort Bragg, Fort Drum, Fort Lewis, and Fort Riley) under differing global climate model climate predictions. Soil Moisture estimation based on the methodology of Huang, van den Dool, and Georgarakos (1996).

Figure B-1. Soil moisture estimations for Fort Bliss, TX.

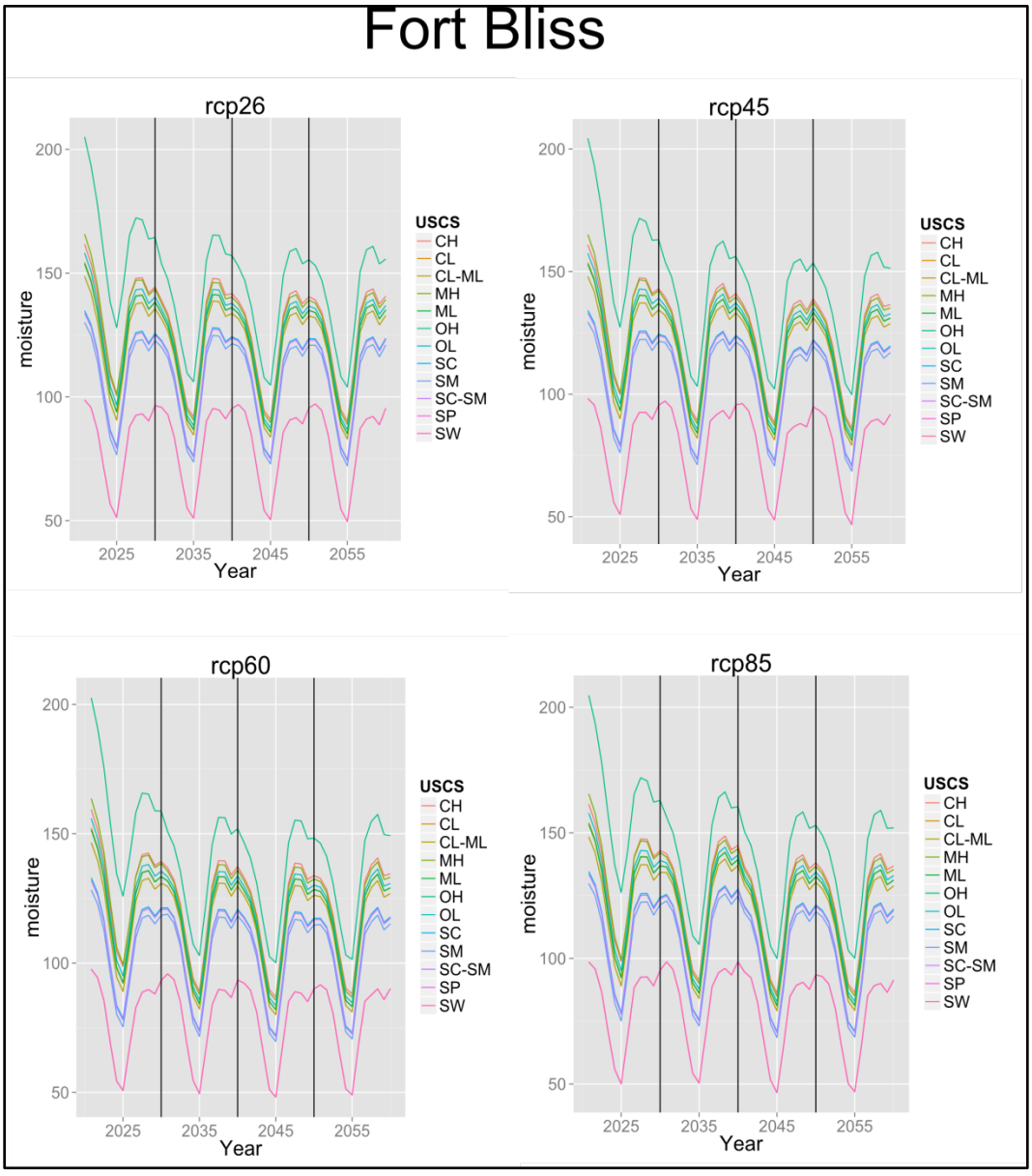


Figure B-2. Soil moisture estimations for Fort Bragg, NC.

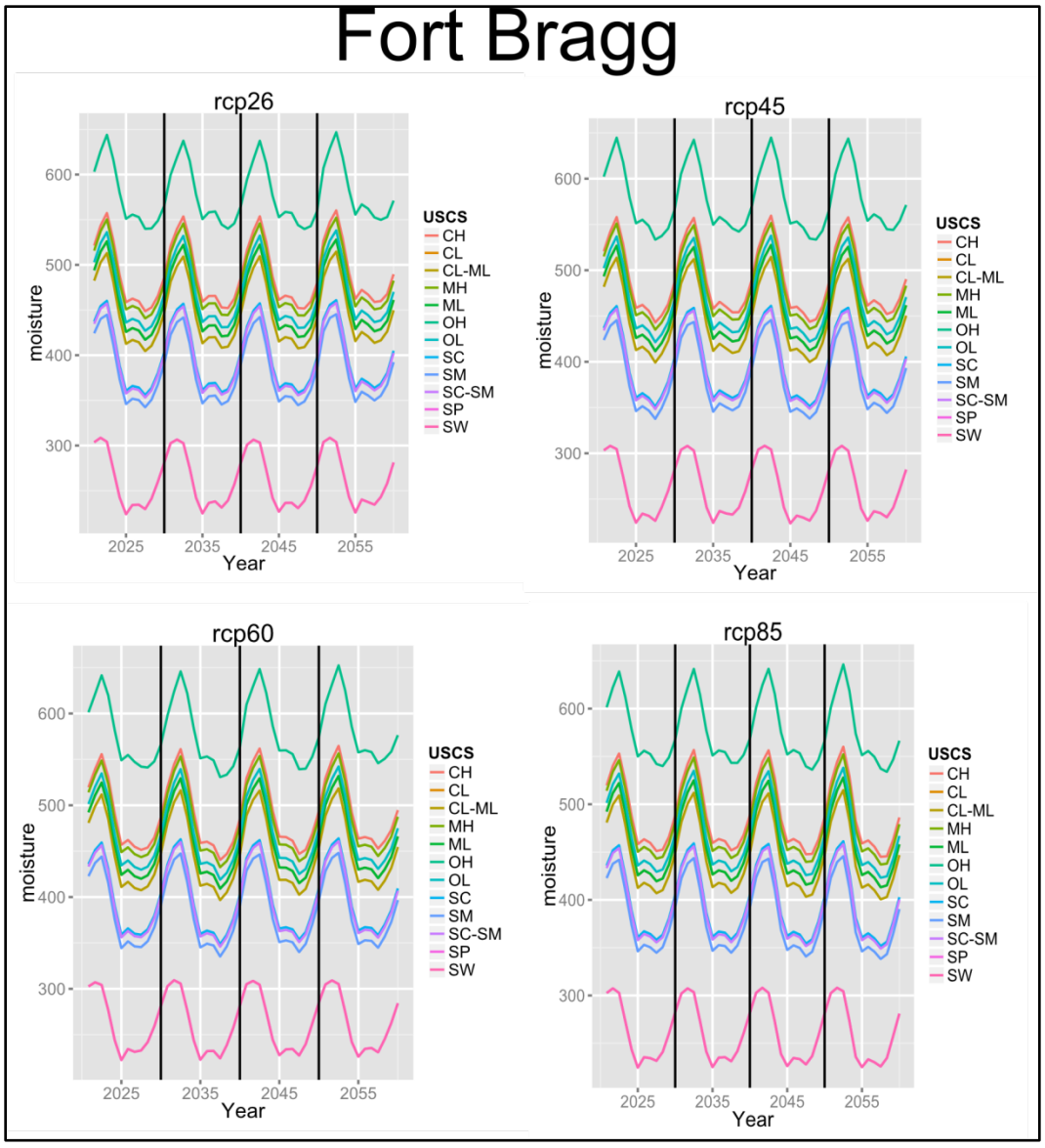


Figure B-3. Soil moisture estimations for Fort Drum, NY.

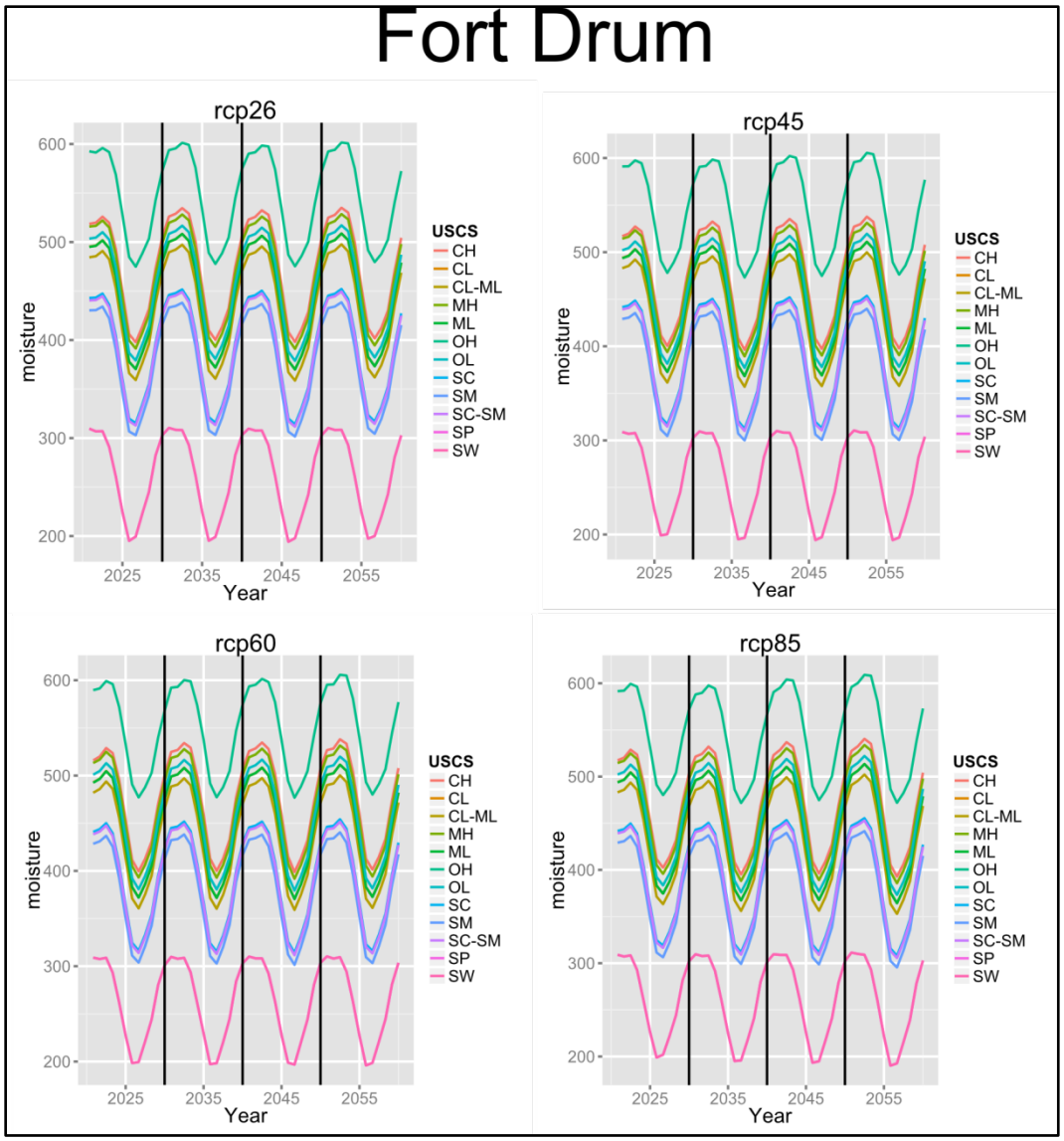


Figure B-4. Soil moisture estimations for Fort Lewis, WA.

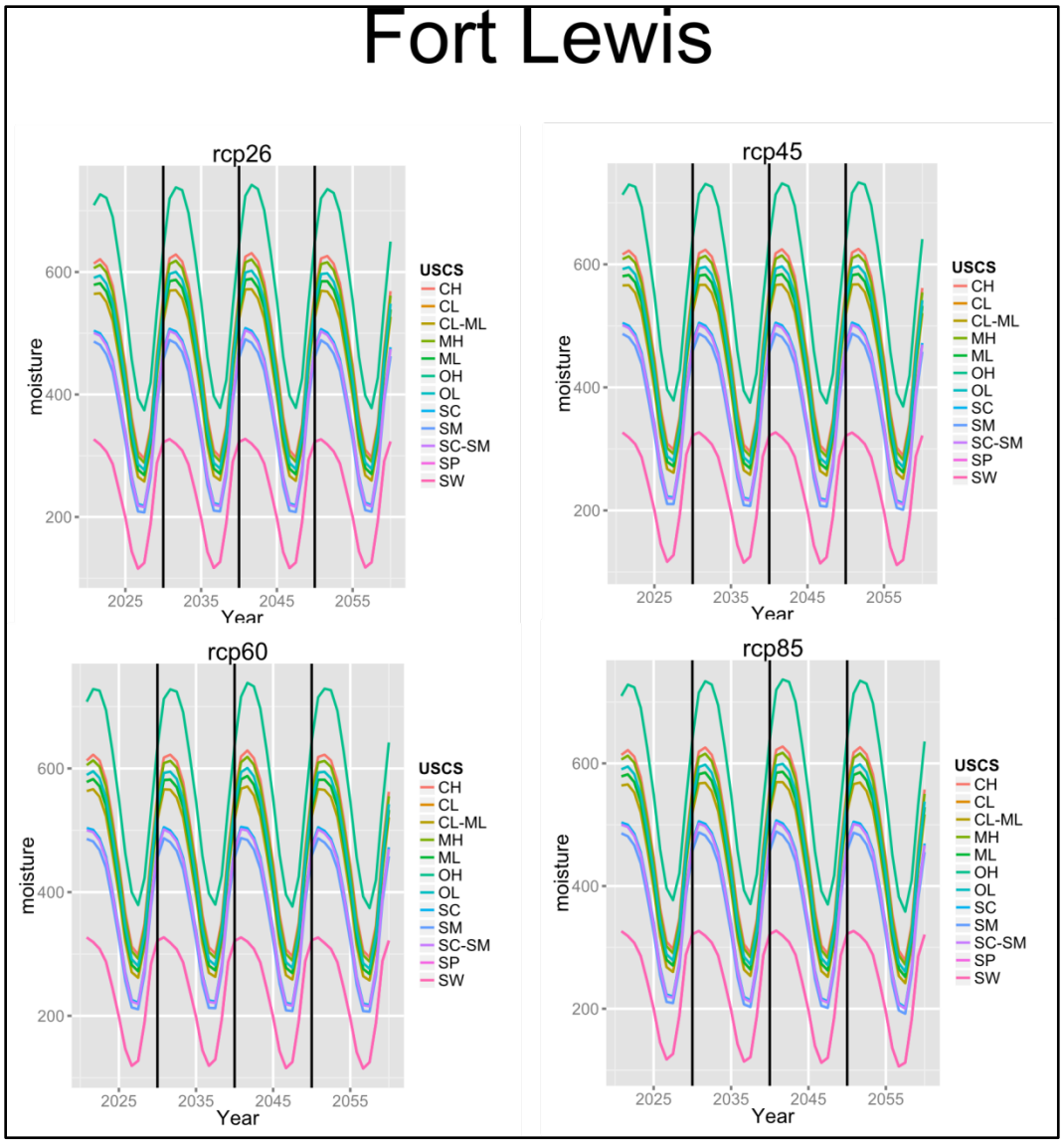
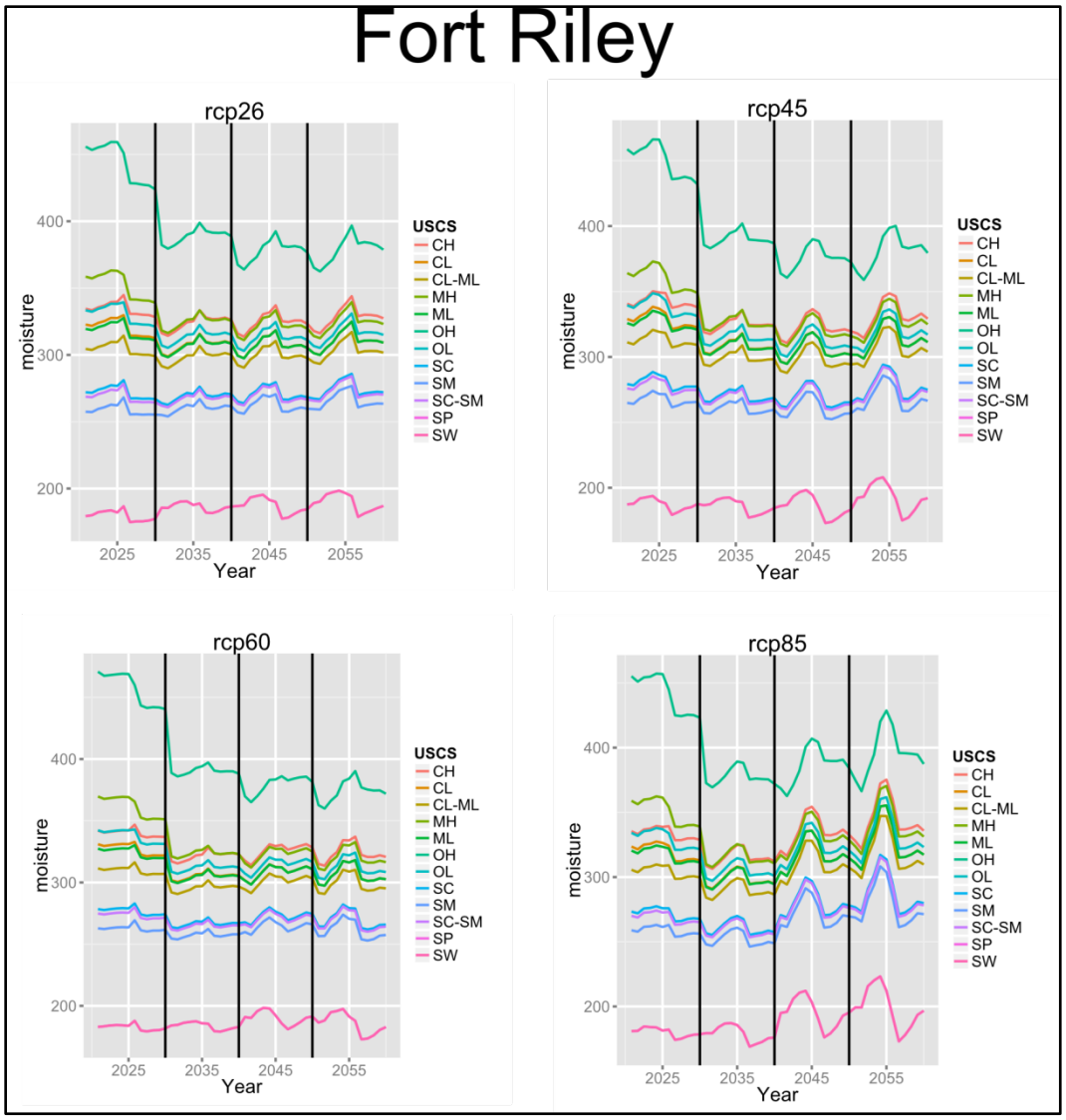


Figure B-5. Soil moisture estimations for Fort Riley, KS.



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14. ABSTRACT

Army stationing analyses have historically been conducted under the assumption that most conditions at and around installations will generally remain static. Previous optimal stationing analyses have resulted in substantial costs associated with moving units, constructing buildings and roads, and local investments in the development of off-post housing, shopping facilities, eating, and other businesses that provide quality of life for soldiers and their families. In reality, the capacity of the natural, social, and built infrastructure changes over time, and, this non-stationarity should be considered in stationing analyses to: (1) avoid premature abandonment of expensive buildings and associated infrastructure, and (2) avoid costly realignments to locations where capacity is being adversely affected by change. This work documents efforts completed in FY14 that began to investigate how potential changes associated with climate and urban development might affect the ability of Army installations to continue to conduct training on firing ranges and in maneuver areas.

15. SUBJECT TERMS
Land use planning, Urban growth, Climate change, Training, Firing ranges, Maneuver areas

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