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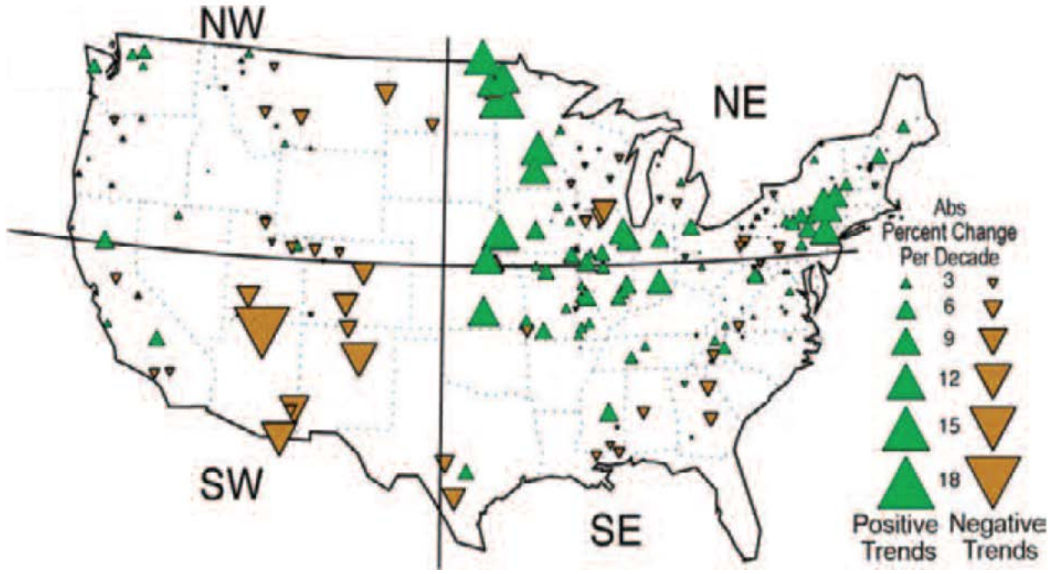
Integrated Climate Assessment for Army Enterprise Planning

Water Stress Projection Modeling

Juliana M. Wilhoit, Grace M. Díaz-Estrada, James P. Miller,
and James Westervelt

September 2016



Magnitude of annual floods from the 1920's to 2008 shown with magnitude (size) and direction (color)

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Abstract

U.S. Army stationing is a constant multi-scale process. Large scale stationing, which is identified with strategic realignments, requires some level of modeling to determine whether the movement of tactical equipment and large numbers of personnel is both economical and continues to meet future long-term strategic requirements. This work explored how climate change implications on water resources may affect military installations in the future, and used that information to outline the WAter Stress Projection (WASP) model, which serves as a decision support system tool that integrates water stressors resulting from global climate change and regional growth to assess the availability of water to an installation in the future. WASP is a tool that provides a scalable solution to incorporate water into the U.S. Army stationing process and to generate a maximum number of personnel at an installation. To test the impact of climate change on the United States Army, the model was applied to five case study installations located across the continental United States in a variety of climate zones.

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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 8D07G1, “Ability to Expand.” The technical monitor was Sarah Harrop, Headquarters, Department of the Army (HQDA).

The work was performed by the Energy Branch (CFE), U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). The CERL Principal Investigators were Juliana Wilhoit and James Miller. At the time of publication, Andrew Nelson was Chief, CEERD-CFE, and Donald K. Hicks was Chief, CEERD-CF. At the time of publication, Alan Anderson, CEERD-CZT, was the Technical Director for Military Ranges and Lands. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

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1 Introduction

1.1 Background

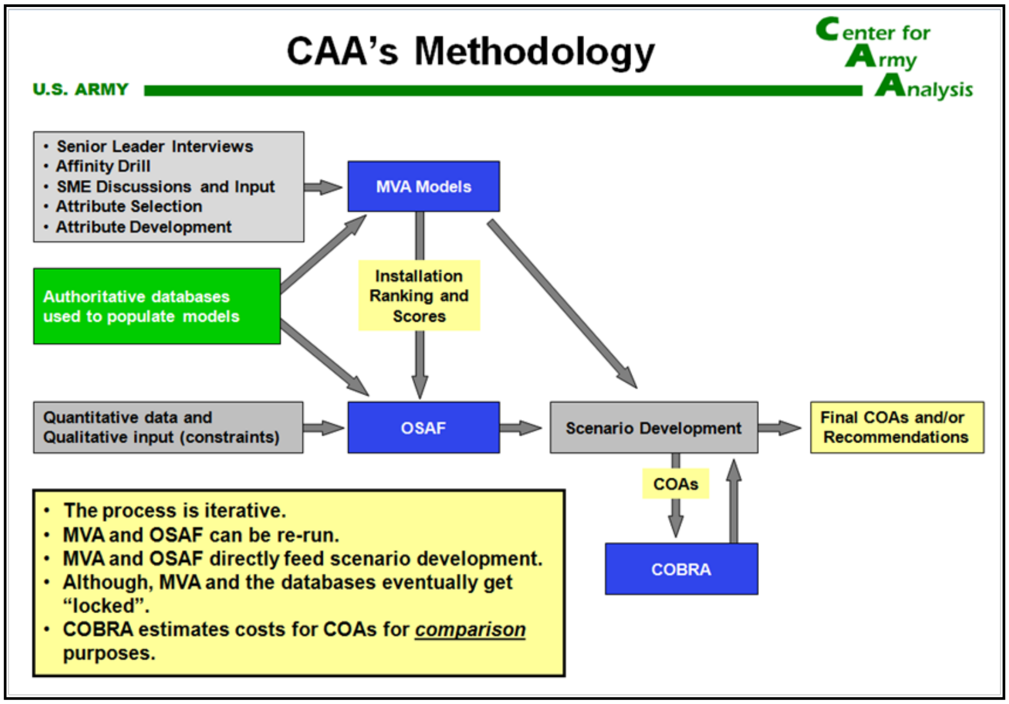
U.S. Army stationing is a constant multi-scale process. Army personnel are in a constant state of flux and changing stations. Army Regulation (AR) AR 10-5, *Organization and Functions* (HQDA 1992) guides most stationing processes. However, large scale stationing, which is identified with strategic realignments, also requires some level of modeling to determine whether the movement of tactical equipment and large numbers of personnel continues to meet future long-term strategic requirements written in the Army Campaign Plan, and to save money. The Center for Army Analysis (CAA) researchers are the experts on large scale modeling and analysis and are often requested to participate in large scale personnel realignments as part of the AR 10-5 process. The largest stationing efforts conducted in the Department of Defense in which CAA participates is the congressionally approved Base Realignment and Closure (BRAC). Smaller stationing exercises are also performed.

To address the scope of stationing analysis required for BRACs and other major stationing exercises, CAA has developed and regularly updates analytical processes that optimize stationing decisions based on costs and military value. These processes are maintained by the Center for Army Analysis (CAA). The most recent process for BRAC (Figure 1-1) was composed of four sub-processes:

1. Military Value Analysis (MVA) modeling
2. Evaluation of the Optimal Stationing of Army Forces (OSAF)
3. Evaluation of the Cost of Base Realignment Actions (COBRA)
4. Formulation of final Courses of Action (COAs) and/or recommendations.

This iterative process builds on MVA models that are based on a set of attributes that define the military value of installations. The MVA models result in installation rankings and scores that provide input to the OSAF model. OSAF and MVA outputs are combined to produce potential scenarios, which are then input to the COBRA tool, which ultimately narrows the potential scenarios to yield final COAs and recommendations.

Figure 1-1. Current CAA stationing decision analysis process.



- The process is iterative.
- MVA and OSAF can be re-run.
- MVA and OSAF directly feed scenario development.
- Although, MVA and the databases eventually get "locked".
- COBRA estimates costs for COAs for *comparison* purposes.

The analysis outlined above is not limited to a BRAC. Many of these tools are used in other large stationing processes, depending on the scope and budget of the process in question. Opportunities for process improvement are available as new technologies are adopted and as data formats evolve that will allow more efficient modeling and improved data standards.

Although this stationing decision analysis process has worked well in the past, the organization has expressed a desire to improve the methods for use in future stationing analyses. Climate change can be expected to have an impact on the Army's costs and ability to fulfill its missions. Therefore inserting environmental analysis into stationing decisions is in the interest of the U.S. Army so that it will be better able to predict and prepare for a changing climate. Army installations will be affected by climate change. It behooves the Army to understand how major military realignments may further exacerbate or may be affected by existing and potential future climate-related problems on any one facility. Stationing analysis done with climate forecasting in mind recognizes an unpredictable future, while striving to best prepare for the consequences of climate change on installations through holistic consideration of various climate factors. The inclusion of these factors will result in a stationing analysis process that will allow for more informed MVA modeling and cost analysis.

This work was undertaken to explore how climate change implications on water resources may affect military installations in the future, and to use that information to outline a model that integrates water stressors resulting from Global Climate Change (GCC) and regional growth to assess the availability of water in the future, and to serve as a decision support system to answer such questions as:

1. Assuming installation populations remain unchanged, which installations will be water stressed by 2050?
2. What is the maximum number of troops that an installation can gain before becoming water stressed?

1.2 Objectives

The objective of this work was to outline a model that integrates water stressors resulting from GCC and regional growth to assess future water availability at DoD installations.

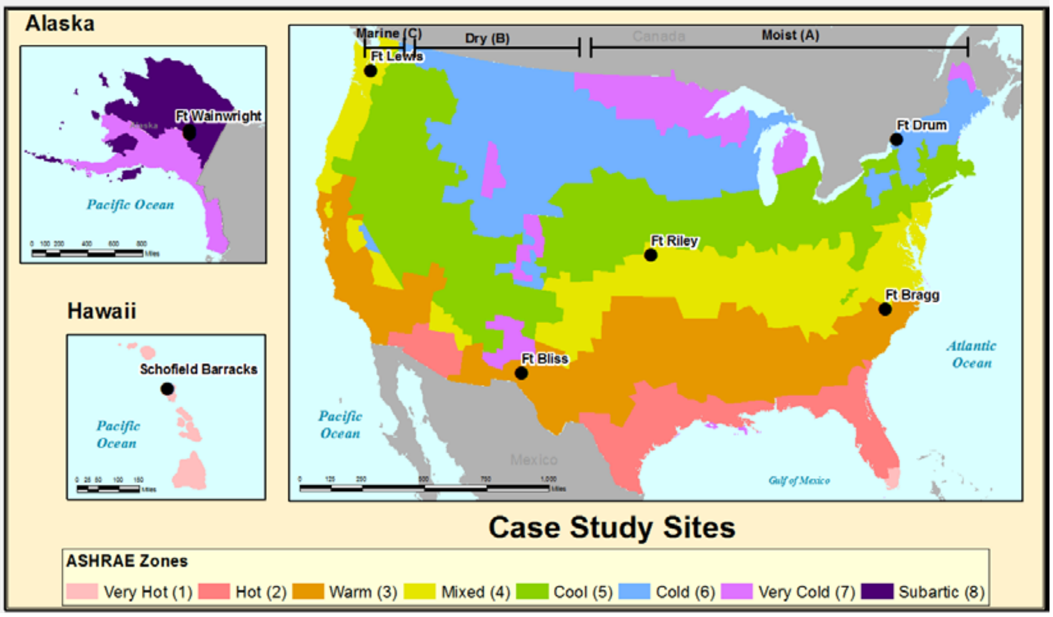
1.3 Approach

1. A literature search was done in the area of water stressor in the United States, particularly as it applies to Army stationing.
2. The System Thinking Software STELLA 10.0.6 was used to dynamically visualize and model shifts in water balance with tools that include stocks and flows, causal loops, and model equations.
3. A dynamic model was outlined that integrates water stressors resulting from Global Climate Change (GCC) and regional growth (population, water use, climate, and base expansion) to assess the availability of water in the future.
4. To test the impact of climate change on the United States Army, the model was applied to five case study installations located across the continental United States in a variety of climate zones (Table 1-1, Figure 1-2).

Table 1-1. Summary of climate zones and case study installations.

Installation	State	ASHRAE Climate Zone
Fort Lewis, WA	WA	Mixed-Marine
Fort Bliss, TX	TX	Warm-Dry
Fort Riley, KS	KS	Mixed-Moist
Fort Drum, NY	NY	Cold-Moist
Fort Bragg, NC	NC	Warm-Moist

Figure 1-2. Location and climate description of case study Army installations according to ASHRAE climate zones.



1.4 Scope

Although this work focused on five case study installations, all of the methods used in this study are scalable and can be used to assess all Army installations located within the continental United States (CONUS).

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 Water in Army Stationing

In current Army stationing practices, water is incorporated in four parts of the analysis. The current analytical process presumes water to be a static resource; i.e., it assumes that the amount of water present today will continue to be present in the future. In reality, water availability is subject to the impacts of GCC and in the coming decades, many areas will have reduced access to potable water. Current CAA water-related metrics are:

1. *Water Quantity MVA Attribute*. This attribute is used to evaluate if there is enough water in a specified area to meet the demands of the installation (CAA 2004). This indicator views water as a cost of operation and as a static (unchanging) resource. This attribute fails to consider external water pressures such as the possibility of drought, surrounding area population growth, or changes in water withdrawal trends.
2. *Environmental Elasticity MVA Attribute*. This attribute is defined as "the ability for an installation to absorb additional personnel based on the utility resource physical capacity constraints and resource costs at capacity thresholds" (CAA 2004). In the 2005 stationing analysis, the resources examined were:
   a. Training land
   b. Energy (electricity and natural gas)
   c. Water and wastewater treatment and solid waste.

   The *Environmental Elasticity* MVA attribute presumes that per capita water use will remain constant and measures the ability of an installation to support additional growth. This attribute places a threshold capacity on water supply and treatment, which may be related to treatment plant size, distribution limits, and permit restrictions. This attribute presumes that current water use in regions can be sustained in the future.

3. *Base Operating Support (BOS) Costs*. The COBRA model includes recurring and one-time environmental and waste management costs. These numbers are determined from BOS statistics. Current BOS metrics related to water are Water Services; Waste Water Services; and Snow, Ice, and Sand Removal (OACSIM 2013, p 13). The BOS costs provide an estimate of the cost of operating an installation.
4. *Criterion 8*. All scenarios developed in the previous models were assessed in relation to the Criterion 8 environmental mandates to assess the environmental impacts of a scenario. The Criterion 8 analysis focuses on the

costs of environmental remediation—either to support additional capacity or to transfer the land into other Federal hands. Water costs in the 2005 Criterion 8 analysis were descriptive rather than quantitative and focused on costs resulting from increased pollutant loads.

In BRAC 2005, Criterion 8 delineated 10 Environmental Resource Areas based on the categories required in National Environmental Policy Act (NEPA) assessments:

1. Air Quality
2. Cultural, Archeological, Tribal Resources
3. Dredging
4. Land Use Constraints, Sensitive Resource Areas
5. Marine Mammals, Marine Resources, Marine Sanctuaries
6. Noise
7. Threatened and Endangered Species, Critical Habitat
8. Waste Management
9. Water Resources
10. Wetlands.

3 Water Stress in the United States

Climate change is having far-reaching implications on water in the United States. Reduced precipitation in the southwest United States is leading to drought, increasing water costs, reducing supply water for irrigation, and degrading water quality. Although shrinking snowpacks temporarily increase floods and river flow, and improve water quality, once snowpacks are exhausted, the water reserves they represent will be gone. A warming climate increases precipitation in the atmosphere and increases the number and strength of storm events (Walsh et al. 2014). Urban sprawl around American cities is replacing farmland and forests with subdivisions, stores, and pavement. This replacement of permeable with impermeable surfaces increases water run-off and affects aquifer regeneration. The combination of shortsighted planning and Global Climate Change (GCC) has resulted in an imbalance in U.S. freshwater resources, i.e., too much water in some regions and not enough in others. Better information on how climate change will affect different regions in the United States is needed to guide the U.S. Army in making effective decisions on how to properly adapt to climate change.

3.1 Climate change and the Army

Climate change will impact how the U.S. Army accomplishes its mission. The *National Security Strategy* (White House 2015), states that climate change is an urgent and growing threat to the United States. It is anticipated that climate change will contribute to increased numbers of natural disasters, refugee flows, and conflicts over basic resources like food and water (White House 2015a). While many of the impacts outlined in the *National Security Strategy* focus on internal conflicts occurring in areas outside the continental United States (OCONUS), it is imperative that the U.S. warfighters be trained and able to respond to missions in such affected areas, and that they are able to train in areas (within or outside the Continental United States [CONUS]) that may be likewise impacted. It is essential that future stationing decisions include water supply and demand planning to ensure that the warfighter is able to respond to future mission requirements.

An analysis conducted by the RAND Corporation for the U.S. Army (Lachman et al. 2013) found that water scarcity due to climate change will be one of the key challenges for the U.S. Army in coming years. The geographic diversity of installations means that there will be disparate impacts of climate change on installations. Coastal installations like Aberdeen Proving Ground may have to deal with sea level rise. Installations in the southwestern and southeastern United States, like Fort Huachuca or Fort Bliss, may have to endure drought periods during which they may not be able to train due to heat and wildfires. The following sections focus on the impacts of climate change in the United States as a whole.

3.2 Climate change

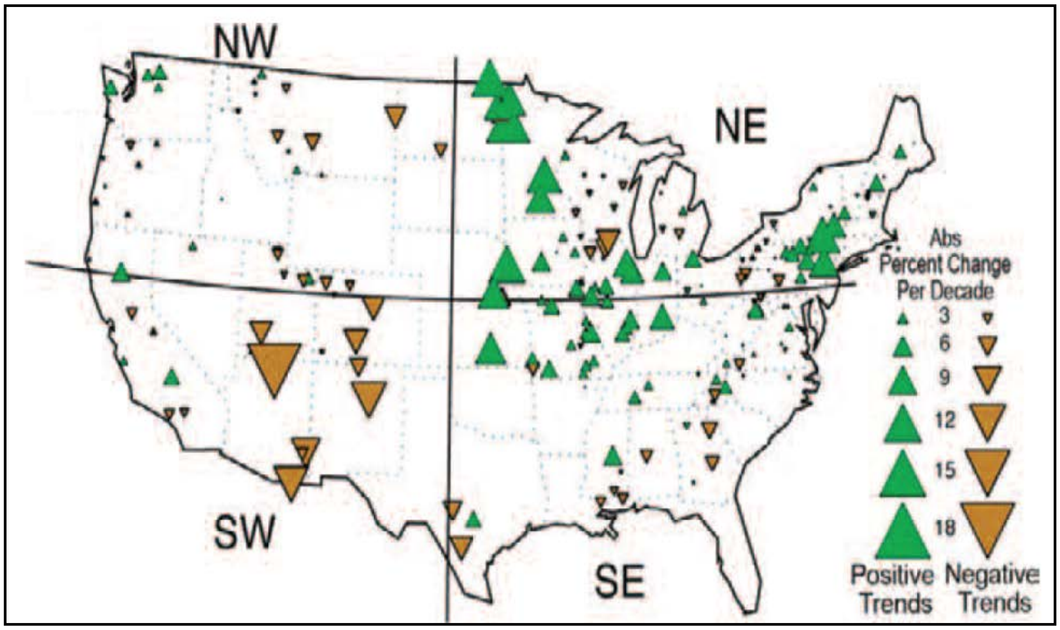
The implications of GCC on water resources in the United States will vary between regions. Some areas will experience minor divergences from the norm while others will undergo increases in extremes (Peterson et al. 2013). Areas such as the southwestern United States are expected to continue to experience reduced precipitation levels and decreased water flow in rivers and streams due to lower annual precipitation and reduced snowmelt. These areas will have to cope with increasing water scarcity despite their rising populations (where 88% of the nation’s population growth will be centered). This combination of circumstances will accelerate increases in the cost of water, place limitations on irrigation, and degrade overall water quality (Lachman et al. 2011, p 59).

Models predict that the northern United States will experience additional precipitation (particularly in the winter and spring) while the southern United States will experience reduced precipitation, particularly in the spring. While total precipitation amounts may fall or remain constant in the southern United States, the amount of rain falling in single storm events is likely to increase in most regions. Figure 3-1 shows how shifts in flood frequency have not been evenly distributed throughout the United States. The Northeast has seen increases in flooding while much of the Southwest has experienced reductions (Peterson et al. 2013).

3.3 Military impacts reduced water

Extreme weather events such as droughts, floods, snow, and ice storms have significant impacts on military training operations through increased risk to life and safety, injury, and reduction in mission performance. Although in times of conflict, commanders are forced to take larger risks in extreme weather events because of the mission, in peacetime training, Commanders should not put lives at risk because of extreme weather events.

Figure 3-1. Magnitude of annual floods from the 1920's to 2008 shown with magnitude (size) and direction (color).



Source: Peterson et al. (2013).

Consequently, the expected change in weather patterns from climate change will reduce an installation's number of training days. Overly dry conditions increase the risk of wildfires, thereby reducing training capacity. When the risk of wildfires is high, the use of live fire, high explosive rounds, and tracer rounds is suspended (or allowed with extraordinary precautionary measures). Conditions of heavy rainfall and low visibility increase risk and limit training where visual feedback is required (Hayden et al. 2013; CNA Corp. Military Advisory Board 2014).

In 2011, there were historic droughts in Texas. These drought conditions combined with live-fire training resulted in three fires at Fort Hood that summer. In total, during the 2011 season, over 19,000 acres of training land (over 8% of the installation's land) were consumed in wildfires (Vanover 2014). As a response to the fire risk, live rounds and tracer rounds were suspended for training. The ban on this training extended for so long that Commanders eventually used helicopters to drench training lands and prepositioned fire trucks so Soldiers could train with live fire (CNA Corp. Military Advisory Board 2014).

A more extreme example of water issues from urban growth and climate change is Mountain Home Air Force Base (AFB), ID, which is running out of water. The water shortage resulted from a combination of regional growth, agricultural water use, and the installation's lack of water rights. Local news media forecasts indicate that the area will experience the effects of water shortages by 2025 and that the installation may have no water by 2040 (Beeby 2013). Although resolving the issue of water for the installation will be costly, the DoD and State of Idaho are working together to secure water rights. In early 2014, Idaho Governor C.L. Otter signed a bill allocating $4 million to acquire senior priority surface water rights on the Snake River, which will be banked until the installation requires them (Idaho 2014). Mountain Home AFB's case demonstrates the need to comprehensively evaluation water in a region as climate change will exacerbate water stress.

4 Water Stress Model

The WAter Stress Projection (WASP) is a dynamic model that estimates future water stress through a water balance and population growth model at the regional level. At the most basic level, water balance describes the flow of water into and out of a system. In this case, the system is the region surrounding an Army installation. Assuming that an installation gets its water from the watershed within which it is located, or from an adjacent watershed (not piped), this model considers the water entering a region through precipitation and run-off.

A regional Water Stress Model was developed using readily available national data from the Water Supply Stress Index (WaSSI) Ecosystem Services Model developed by the U.S. Forest Service. There are many water balance models available for free use, including the WaSSI model. After evaluating these models, it was determined that none adequately addressed the needs of Army stationing—such as being easily run at a national scale, or being able to run scenarios where troops are added to a regional population.

The WASP model includes five sectors: (1) population growth, (2) Army water use, (3) land development, (4) water demand, and (5) available water. The model, which is not spatially explicit, depends on summarized data for a region. In other words, the input data are available at a resolution finer than the scale on which the model calculates. There are three scales to the input data:

1. *County*. Population characteristics and water use data were derived at the county level. These values were summed to produce an estimate for the region.
2. *HUC-8*. Estimates of surface water availability are provided on the hydrologic unit code (HUC) 8 area. HUC-8s are referred to as sub-basins and contain many rivers and streams. The average size for a HUC-8 is 700 square miles.
3. *Raster Grids*. Recharge rates and land use data were available in raster Geographic Information System (GIS) grids (1-km and 30-meter, respectively). These data were summarized to the regional area.

Aggregation is a limitation of the model as it presumes that the mean is descriptive of the region as a whole. Figure 4-1 illustrates the variation in groundwater recharge in the four counties surrounding Fort Bliss, where the northern areas having more recharge and the southern portion experiencing less. As soil structure and topography will differ throughout the region, using a non-spatially explicit model to describe land cover changes may further alter the model results as development may occur in areas with high recharge rates. Despite the challenges, the decision was made to aggregate the data to make it possible to produce a solution that is easily scalable and deployable, and that can be run for many bases at one time. Such an aggregated model adds value to stationing analysis. Figure 4-2 shows a general overview of all the various factors calculated into the WASP. The following sections discuss each of these factors.

Figure 4-1. Diagram of the annual recharge rates (mm) in the area surrounding Fort Bliss. Recharge rates are not consistent throughout the region, and calculating the mean recharge may distort these figures.

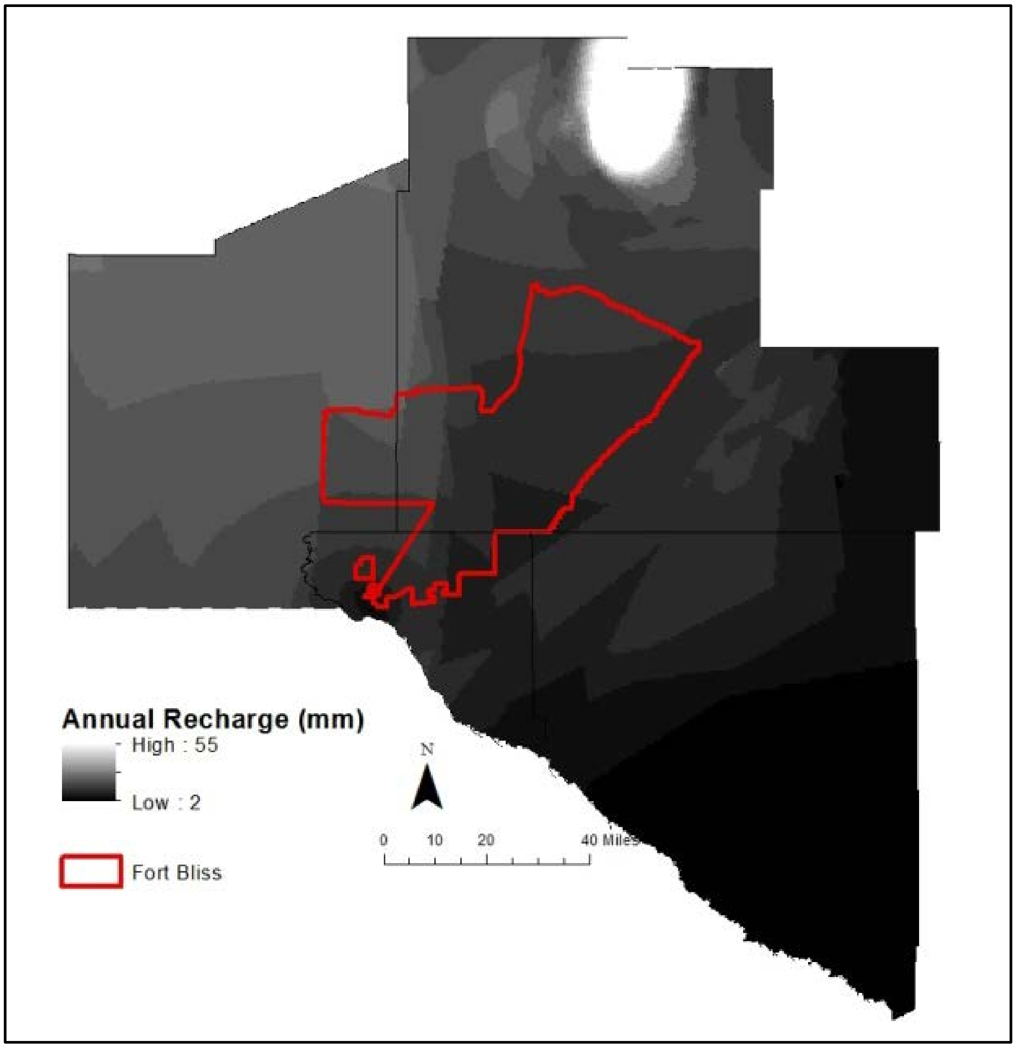
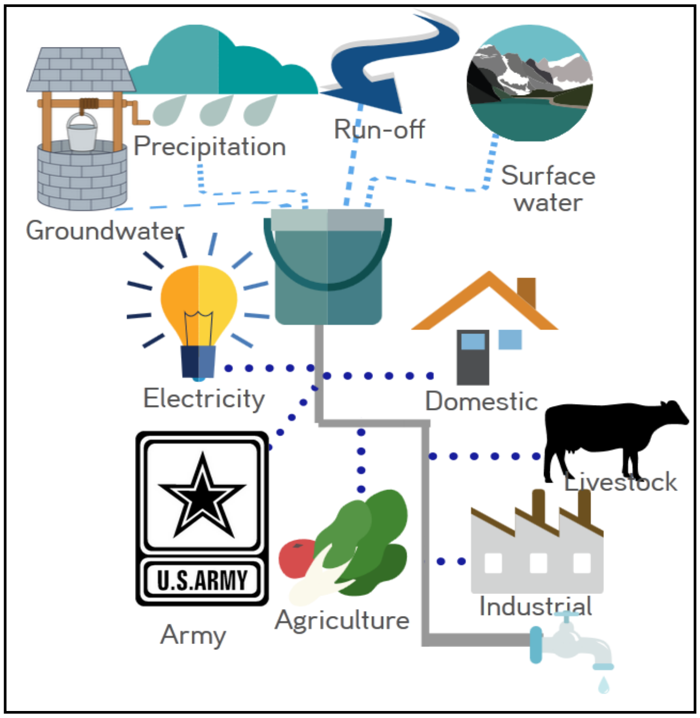


Figure 4-2. Elements of the regional water balance model.



4.1.1 Regional definition

The Water Stress Projection is a regional model that assesses future water stress by including development and pressure on water supplies both on and off the installation. Installation-specific analysis was excluded; instead, the focus was placed on the region. Regional assessments are necessary because installations water supplies do not exist in isolation; they are dependent on the political and socio-economic environment of the area where they are located.

There are many ways to define a region, and there is no comprehensive national dataset of regional councils or other regional boundaries. Many installations support a regional council comprising surrounding counties. Since there was no existing dataset, the region for each Army installation was defined as the counties adjacent to the installation. This area was selected as it represents the areas that may produce threats of encroachment, areas where service members may live, and areas that will generally depend on the same water supply. Table 4-1 lists the counties within each of the Army installation's regions. The tools outlined in this paper can be easily transferred to other regional definitions including the housing market area, the members of a local regional council, or sources of water.

Table 4-1. Counties included in the regions for the case study installations.

Fort Bliss, TX	Fort Bragg , NC
El Paso Hudspeth Otero Doña Ana	Cumberland Harnett Hoke Moore
Fort Drum, NY	**Fort Lewis, WA**
Jefferson Lewis Saint Lawrence	Pierce Thurston
Fort Riley, KS	
Clay Geary Riley	

4.2 Population projections

Population projections of the region in the future were required to estimate future water demands.* Population projections require localized knowledge of development trends, economic activity, and local social factors like household size. However, the U.S. Census Bureau no longer publishes county-level population projections. National data sources including the Integrated Climate and Land Use Scenarios (ICLUS) (Bierwagen and Morefield 2014) and Water Stress Supply Index (WaSSI) (Sun 2010) were evaluated and their population projections determined to be insufficient for this work. In many instances, these projections were found to be based on data recorded before the completion of BRAC ’05 stationing in 2011. These projections provided inaccurate current regional population estimations reducing the validity of the future projections.

Instead this analysis relied on local population projections provided by local agencies. These projections are generally produced as part of a state statistical abstract for or by the agricultural extension office of the state university. It was assumed that these forecasts did not include significant installation growth, as expansion of installations is a highly political and uncertain process that cannot be predicted. Table 4-2 lists examples of the projection sources.

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* Possible new dataset: http://proximityone.com/demographics2060.htm

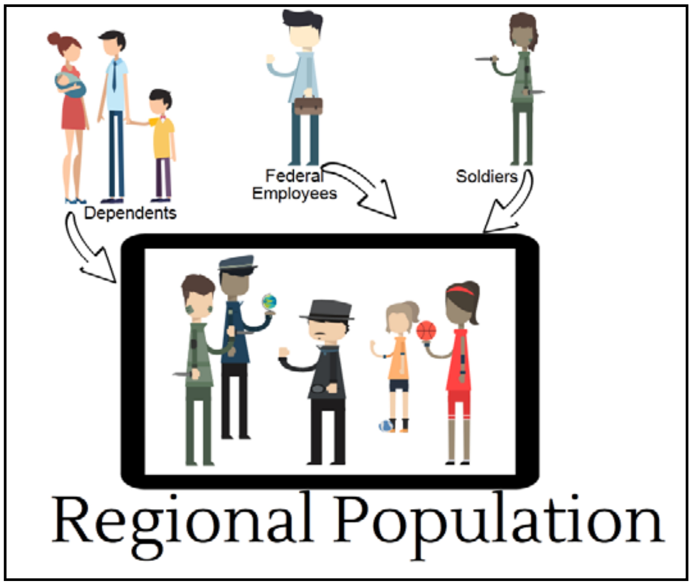
Table 4-2. Summary of population projection sources.

Installation	Projection Source	Source
Fort Bliss	University within the state (NM) and State Agency (TX)	BBER 2014, Texas CEDBR 2012
Fort Bragg	State Agency	OSBM 2015
Fort Drum	University within the state	Cornell University 2015
Joint Base Lewis-McChord (JBLM)	State Agency	BBER 2014
Riley	University within the state	CEDBR 2012

To these projections was added population from installation growth, defined in three categories: Soldiers, Federal employees, and dependents (Figure 4-3):

- *Soldiers*. The model tests the number of additional troops that a region can gain before it becomes water stressed. The Soldiers variable explores the addition of more troops in the region through stationing analysis. The variable is time enabled and tests the addition of Soldiers due to stationing between 2017 and 2021.
- *Federal Employees*. Installations also depend on civilian Federal employees. This analysis used a measure of 0.37 civilian employees per Soldier, which was drawn from the results of a West Point study of Army infrastructure (Beskow 2014). It was assumed that these employees are not being hired from the local population, but that they relocate into the region. Furthermore, it was assumed that the civilian personnel are not partnered with Soldiers.
- *Dependents*. These include the dependents of both Soldiers and Federal employees. It was assumed that Soldiers and Federal employees will move to their new installations with dependents.
    - *Family Members of Civilian Employees*. Army civilian employees were presumed to follow the U.S. median household size of 2.58 (Lofquist et al. 2010). As such, 1.58 persons were added to the region for each Federal employee added.
    - *Family Members of Soldiers*. Depending on the mission, Soldiers will often move with their families to the new installation. Using the analysis from the West Point study, it was presumed that there would be the addition of 1.5 family members for each Soldier (Beskow 2014).

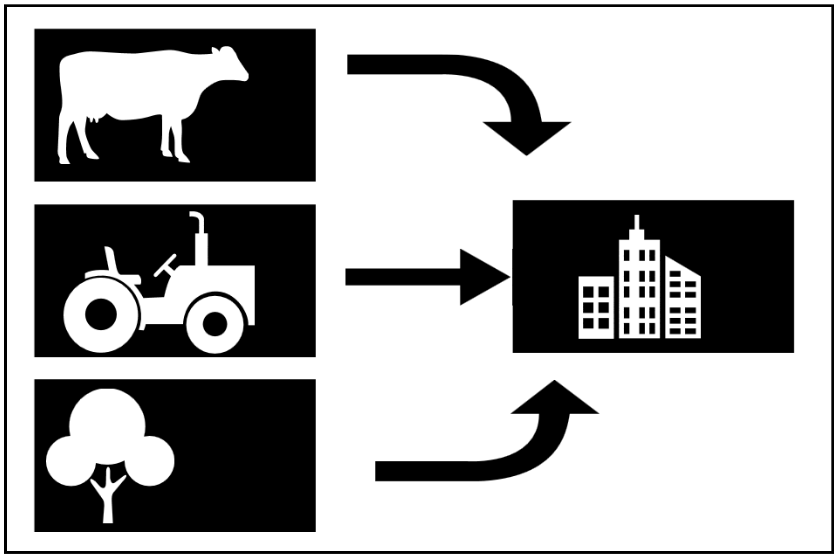
Figure 4-3. Diagram of process of adding additional population to the existing regional population.



4.3 Developing land

The amount of developed land, land that has buildings, roads, and other infrastructure affect groundwater recharge, run-off, and water use. In general, land used for agricultural purposes will demand more water than single-family homes. It is therefore important to model the land-uses that will develop in assessing regional water demand. A sector of the model was developed that projects development of land from land that was other open space, agricultural land, and cattle grazing land (Figure 4-4).

Figure 4-4. Diagram of the Regional Water Balance Model Land Cover Segment Analysis.



The National Land Cover Database (NLCD), developed by U.S. Geological Survey's (USGS's) Multi-Resolution Land Characteristics Consortium (MRLC), was used to assess the changes in land cover from open space to developed land between 2001 and 2011. The categories provided in the NLCD were used to separate the open space category into three groups that relate to water usage: agriculture, cattle ranges, and other open space. These data were used to calculate:

1. *New Development per Additional Person*. This was calculated as the amount of new land that was developed for each person added in population between 2001 and 2011.
2. *Percent of Land Developed*. To estimate the amount of land that would develop from the three open space categories in the future (due to population variability), the percent of the land being used for agriculture, cattle, and other purposes was calculated as:
    a. *Agricultural Land to Developed Land*. This was calculated as the ratio of farm land developed between 2001 and2011 and all newly developed land within that period.
    b. *Cattle Land to Developed Land*. This was calculated as the ratio of cattle land developed between 2001 and 2011 and all newly developed land within that period.
    c. *Other Open Space to Developed Land*. This was calculated as the ratio of other Open Space developed between 2001 and 2011 and all newly developed land within that period.

4.4 Water demand

Following the methodology of Roy et al. (2012), this analysis used a business-as-usual approach towards future water use that did not account for increases in water-saving technology. Responses to climate change and dwindling water supplies may mean that regions will adopt these efficiency measures, but that is not guaranteed. The recent drought in California and the delayed responses of residents and policymakers to achieve water reduction highlight the challenges in reducing water consumption.

The USGS 2010 estimate of water use in the United States highlights the first national decline in public-supply withdrawals since data collection started in 1950. Between 2005 and 2010, public-supply withdrawals declined by 5% while the national population grew by 4%. Estimating future reductions in domestic water use will be difficult as it depends on local factors. This analysis did not include estimates of increased efficiency, as there are no consistent estimates of future reductions. Domestic supply was calculated by multiplying the 2010 per capita use figure for the region by the projected population. Future work could assess the changes in per capita water use between 2005 and 2010 to determine regional increases in efficiency.

4.4.1 Land use change shifting withdrawals

The land use change model (see Section 4.3, “Developing land”) serves as an input to withdrawals for irrigation and livestock. As development increases the amount of agricultural land decreases, reducing water demands. This analysis uses the 2010 irrigation withdrawal per acre. It is likely that climate change will increase water demands for irrigation as higher temperatures increase evapotranspiration. A study of the period from 1970 to 2005 found that irrigation intensity (water use per acre) did not show a correlation with climatic drivers (Roy et al. 2012). Shifts in agricultural water withdrawals may be affected by factors such as water rights, crops being irrigated, water availability, and irrigation practices. As these factors cannot be easily determined at the national level, this analysis used 2010 county irrigation withdrawals per acre.

4.4.2 Thermoelectric withdrawals

Electricity generation accounts for over 45% of water withdrawals in the United States (Maupin et al. 2014). Barring significant technological improvements, water withdrawals will increase as energy demands increase. To project future withdrawals, first, future electricity production was calculated. The process outlined by Roy et al. (2012) was modified to scale the data differently. Thermoelectric production by county was estimated using Table 96 of the 2014 Annual Energy Report, forecasts of electricity production from 2011 to 2040 (EIA 2014, 96). EIA’s projections were provided at the Electricity Market Module (EMM) region level. Linear regression was used to forecast the annual EIA forecasts to 2050 for each EMM region. It was assumed that future electricity generation would occur in counties that currently produce electricity because they have pre-established infrastructure. The current percentage of the EMM’s total electricity generation in each county was determined and then that percentage of future electric generation was applied to that county to generate county level forecasts. For example, if a county produced 27% of the electricity in the region in 2005, it was assumed that they would also produce 27% in 2050. To calculate water withdrawals for electricity production, the baseline of this analysis assumed that 500 gallons of water were required for each gigawatt-hour of electricity generated.

4.4.3 Army water use

The Army Water Use sector estimates Army water use. Water is used in training, washing vehicles, and in supplying the needs of those living and working on the installation. The baseline analysis used the average of FY 2011-2014 consumption. The Army Water Use sector is not necessarily dependent on the number of troops stationed at the installation since an installation's mission may require some very water intensive activities (such as manufacturing) unrelated to troop numbers, in which case the addition of troops would not significantly increase water use.

Installations have been tasked with water reductions. Executive Order 13693 (signed in February 2015) tasks all Federal agencies to reduce their water consumption. Agencies are required to reduce their potable water consumption intensity measured in gallons per gross square foot by 36% by fiscal year 2025 (FY25) through reductions of 2% annually relative to a baseline of the agency's water consumption in FY07 (Executive Order [EO] 13693, *Planning for Federal Sustainability in the Next Decade* 2015 [White House 2015b]). However, installations have not been meeting their target for reductions in water use. Therefore, no scenarios were run at this time in which there was a reduction in total water use.

4.4.4 Aquaculture, industrial, and mining demands

The remaining water use sectors of industrial, mining, and aquaculture were kept at the 2010 amount. According to USGS data, the sectors of self-supplied industrial and mining had minimal fluctuations in withdrawals in the past 2 decades so this analysis presumed a continuation of 2010 levels. A close examination of the data indicates that there was a 52% increase in water use for the aquaculture sector. However, USGS explains that the increase is most likely a result of a change in the way that the estimations were derived rather than an increase in actual withdrawals (Kenny et al. 2009). As a result, the 2010 aquaculture demand for future water demand was used.

4.5 Water availability

There are two sources of water: groundwater and surface water.

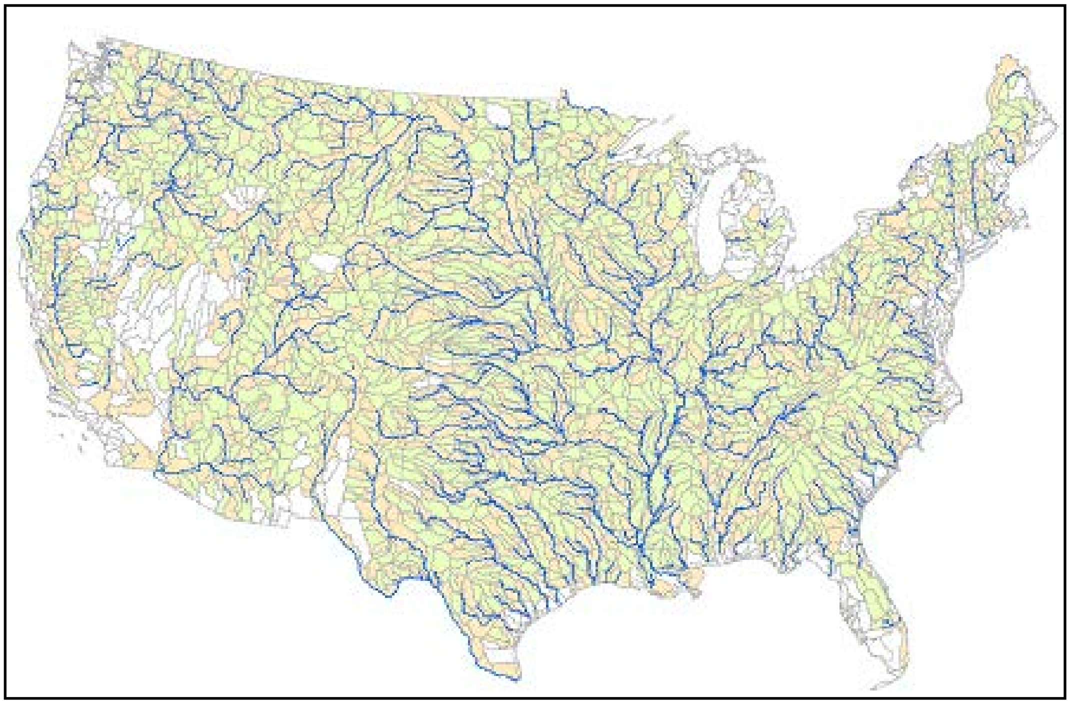
4.5.1 Surface water

Surface water refers to water that flows across the surface of the earth through lakes, rivers, and streams. The SWS_MGD variable on the table "Monthly WaSSI" from the WaSSI Model was used to estimate future surface water. Using hydrologic modeling and climate change data, the WaSSI team developed estimates of surface water at the inlet for each HUC on a monthly basis from 2010-2100 (Figure 4-5).

4.5.2 Groundwater replenishment

Climate change will undoubtedly affect groundwater recharge in the United States. However, the time scale of this impact is difficult to assess due to local conditions. Because of this uncertainty and time scale, it was assumed that historical recharge rates will continue in the future.

Figure 4-5. Map of CONUS HUC-8s.



This model used estimated mean annual natural groundwater recharge data produced by the USGS (Wolock 2003). This 1-km resolution data are an index of the mean annual natural groundwater recharge from 1951-1980. The data were derived “by multiplying a grid of base-flow index (BFI) values by a grid of mean annual runoff values derived from a 1951-80 mean annual runoff contour map.” This methodology accounts for delays between the times when raindrops hit the soil and when that rain actually reaches an aquifer. Additionally the methodology accounts for groundwater discharge into streams.

To calculate estimates of recharge from the USGS data, the zonal statistics tool in ArcGIS 10.1 was used to produce a summary of the data for the regions of interest. The outputs were various statistics for each region, including the sum of the mean annual natural groundwater recharge in millimeters per year. This figure was then divided by 12 to get an estimate of the monthly recharge.

A limitation of the WASP model is that it uses annual groundwater replenishment rather than an estimate of actual groundwater supplies. Calculating groundwater supplies is difficult as geologists often do not know aquifer depth; consequently there are no reliable national datasets of aquifer capacity.

4.6 Model output

The output of the model is a withdrawal-to-availability ratio, which is the monthly water demand divided by monthly water supply, D/S:

$$\text{Water Stress Index} = \frac{\text{Demand}}{\text{Groundwater Recharge} + \text{Surface Water Supply}} \tag{4-1}$$

An advantage of using an index formulated in this way is that it includes both the pressure from development and human use (the demand side) and the hydrological system (system side) (Shen et al. 2014, Vorosmarty 2000, Falkenmark 1989). An index value of 1 indicates that the demand equals the sustainable supply. Values over 1 indicate that the demand outstrips the sustainable supply, indicating the region is using more water than is being recharged to the aquifer.

5 Integrating WASP into Stationing

The WASP model was developed to be flexible in its application to serve CAA's needs. Depending on how it is run, the model can answer a variety of questions, including:

- What is the maximum installation size?
- What would be the impact of adding X troops be on regional water stress?
- What is the military value of an installation in regards to water stress?

This chapter focuses on the application of the WASP as an MVA attribute to highlight its applicability to Army stationing. This application is intended to serve as a proof of concept and can be modified to serve Army needs.

5.1 Methodology to create a water stress MVA attribute

This work proposed the development of a water stress attribute for Army stationing to assist CAA in restationing analysis. This section outlines a methodology to take the output from the WASP and translate it into an MVA attribute. Appendix A includes a full description of the methodology.

The analysis presented in this report is based on the A1b climate scenario. The A1b climate scenario is derived from The Intergovernmental Panel on Climate Change (IPCC) *Special Report on Emissions Scenarios* (SRES), and is often referred to as the "A1b SRES." The A1b SRES projects

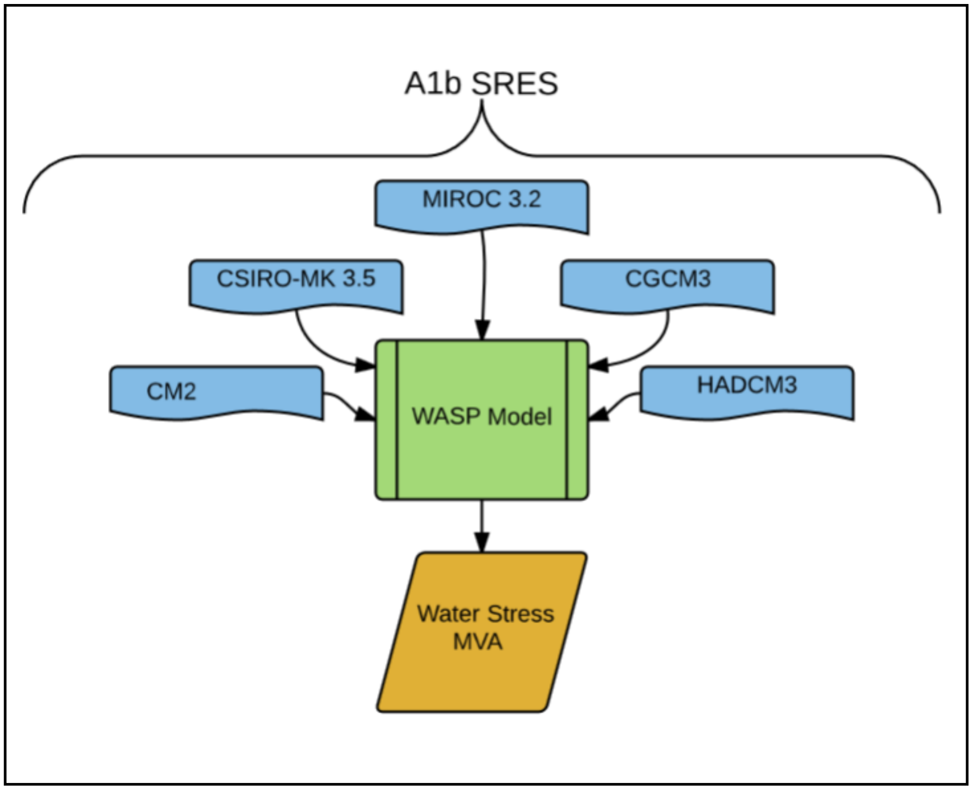
> a future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology. Major underlying themes are economic and cultural convergence and capacity building, with a substantial reduction in regional differences in per capita income. In this world, people pursue personal wealth rather than environmental quality (IPCC 2000).

This scenario describes inputs used in a variety of climate models to express a possible future. Because the future is highly uncertain and because no single model is considered to authoritatively describe climate change, climate scientists recommend using the output of a variety of climate change models running a particular scenario. The process described here used climate data from five climate change models (Figure 5-1) using the A1b scenario:

1. CSIRO-MK 3.5 SRES (Developer: CSIRO Marine and Atmospheric Research Laboratories Information Network, Australia. Components: Sea-ice, oceans, atmosphere, and land surface)
2. MIROC 3.2 SRES (Developer: National Institute for Environmental Studies, Japan)
3. CGCM3 (Developer: Canadian Centre for Climate Modeling and Analysis)
4. CM2 (Developer: National Oceanic and Atmospheric Administration (NOAA)
5. HADCM3 (Developer: Hadley Centre , United Kingdom. Components: atmosphere, ocean).

The WASP model was run using postprocessed outputs of these models from the WaSSI Ecosystem Services Model (Caldwell et al. 2013), for a total of five runs per installation. The model's output, withdrawal-to-availability-ratio (D/S), is the monthly water withdrawal for agricultural, household, and industrial sectors over the monthly renewable freshwater sources. D/S values greater than 1 indicate that the demand is outstripping the sustainable supply.

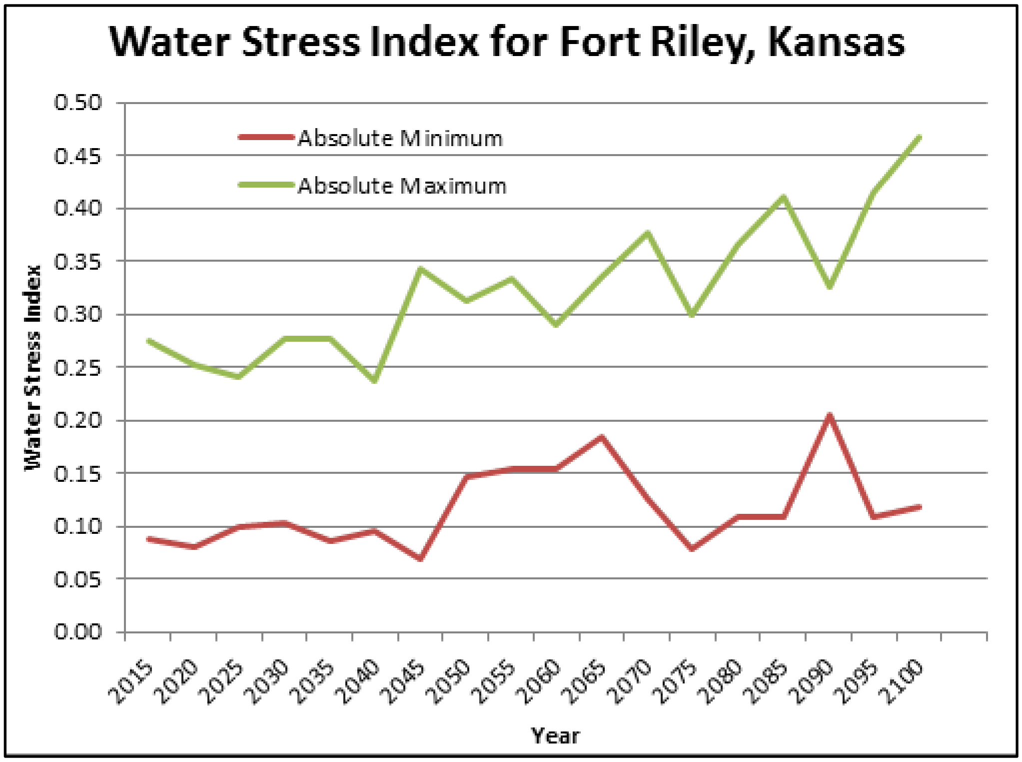
Figure 5-1. Diagram illustrating the data included in the WASP model.



The five runs for each installation were similar in their projections of future water stress, each demonstrating similar shapes. There were differences in the output ratios because surface water projections vary with the different climate models.

Despite the apparent precision 0f climate model outputs, they represent projections of the future that always include a degree of uncertainty. As a result, for this MVA attribute, the indexed results were grouped into 5-year blocks from 2015-2100 to assess the minimum stress and the maximum stress. An MS Excel®-based formula was used to obtain the range of the minimum-maximum and the absolute maximum numbers (e.g., Figure 5-2). Ranges were used to better show the worst case scenarios that the five climate models project; for this reason, the analysis focuses on the maximum values. To simplify the analysis, it was assumed that the peaks can occur at any moment within the 5 years, although the value is graphed at the end of the period.

Figure 5-2. Demonstration of the absolute maximum and absolute minimum scores for Fort Riley over 5-year periods.



To develop the MVA score, the data were weighted on two factors: stress and time levels:

1. **Stress Level**: The categorical rankings of no stress, low stress, moderate stress, and high stress were applied based on the ratio of D/S. Higher stress was given a higher value. Categorical rankings were selected rather than using the D/S ratio because these rankings account for some of the uncertainty present in model outputs, and because more complicated statistics would be required to parse out outliers in stress. Table 5-1 summarizes the given rankings and weights.
2. **Time**: Water stress values for the years 2015-2035 were given twice the weight of those from 2040-2100. This was done because CAA is primarily concerned with a 20-year Net Present Value (NPV), however, projections of the future should be included outside of that range because that will affect future installation capacity. The values for 2015-2035 range from zero (0) to 3 and are given according to the water stress category (a value of zero [0] when there is no stress to 3 when there is high stress). While the scores from 2040-2100 range from zero (0) to 1.5.

To obtain the final score for an installation, all of the values are summed and divided by the total possible score. The resulting ratio was then standardized on a scale of zero (0) to 10.

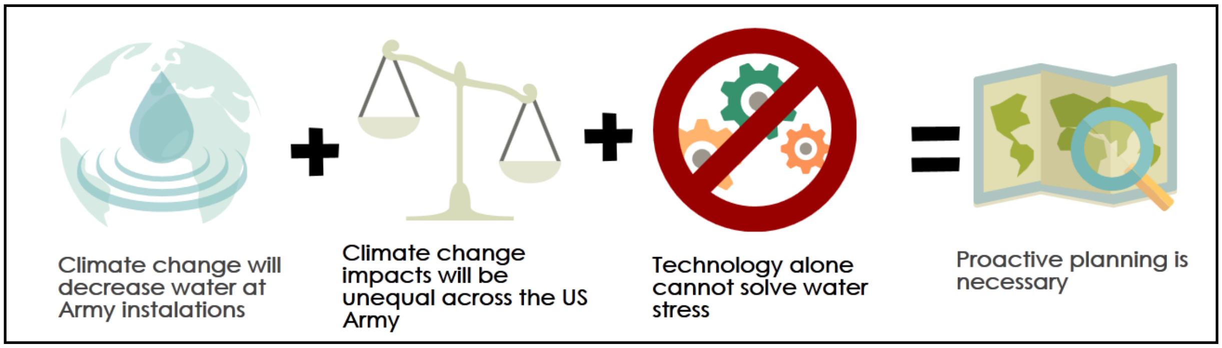
5.2 Results of water stress MVA

The results of the proposed water stress MVA attribute highlight that climate change and human pressures will affect the availability of water for U.S. Army installations in the future. It is expected that the hydrologic cycle at all installations will be impacted by climate change to some degree, but that these impacts will not be equal. Climate change may exacerbate pre-existing water stress through reduced precipitation and surface water flows. Population growth —via stationing or just normal growth— will increase competitors for a dwindling water supply in certain regions. The results of this study highlight the disparities within the Army and highlight the importance of proactive planning and action (Figure 5-3).

Table 5-1. Rankings and weights.

D/S Range	Category	Weight 2015-2035	Weight 2040-2100
Lower than 0.1	No stress	0	0
Between 0.1 and 0.2	Low Stress	1	0.5
Between 0.2 and 0.4	Moderate Stress	2	1
Higher than 0.4	High Stress	3	1.5

Figure 5-3. Graphical summary of the study's findings.



The results of the model and the MVA attribute demonstrate four themes:

1. *Climate change will decrease water at Army installations*. In the future, most installations will have access to reduced ground and surface water supplies.
2. *Climate change impacts will be unequal across the Army*. Climate change is a spatially dependent phenomena. Areas such as the southwestern United States will have significantly reduced water supplies in the future.
3. *Technological solutions alone cannot solve water stress*. While the acquisition and use of technology to increase efficiency at installations is an important step, technological solutions alone will not ensure that an installation has water in the future.
4. *Proactive planning is necessary*. As base realignments are permanent decisions for coming decades, environmental considerations need to be part of the decision-making process for base realignment. Injecting environmental analysis into realignment decisions is in the U.S. Army's interest, to better its ability to predict and respond to a changing climate.

5.2.1 Overview of results

The results of the Water Stress MVA indicate that availability and demand of water for installations will be affected significantly. Therefore the U.S. Army should consider future water stress in evaluating the Military Value of Army installations. This analysis, which is consistent with the work of others (Spencer and Altman 2010, Roy et al. 2012), finds that climate change will increase the risk that water supplies will be unable to keep pace with withdrawals. Table 5-2 lists the results of the Water Stress MVA for the five case study sites. A score of 10 indicates the lowest military value and thereby the most stress, while zero (0) represents the highest value (lowest stress).

Table 5-2. Results of water stress MVA.

Installation	Normalized Score
Fort Bliss	10.0
Fort Bragg	4.6
Joint Base Lewis-McChord	4.2
Fort Riley	3.6
Fort Drum	0.0

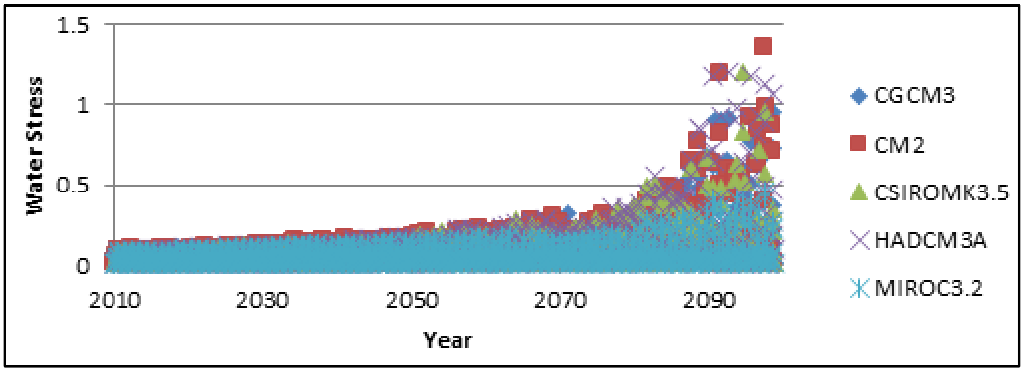
5.2.1.1 Fort Bliss, TX

Fort Bliss' high score, and low military value, is expected. Fort Bliss and the El Paso area are already responding to water stressors caused by the arid climate, a growing population, and the intensive water needs of the installation. In response to this stress, the El Paso Water Utilities (EPWU) District and Fort Bliss jointly operate the $91 million Kay Bailey Hutchison Desalination Plant, turning brackish groundwater into drinkable water. One factor pushing Fort Bliss' water consumption stress in coming decades is electricity generation in two surrounding counties, El Paso and Doña Ana, which are expected to increase their water withdrawals for electricity generation. Another large contributor to Fort Bliss' water stress is the arid climate. While the region presently receives minimal rainfall, the amount of rain is expected to decrease while temperatures are expected to rise as a result of climate change. This is expected to lead to an increase in evapotranspiration.

5.2.1.2 Joint Base Lewis-McChord, WA

The Pacific Northwest, home to Joint Base Lewis-McChord, is generally perceived as being a water rich area because of the amount of precipitation. However, by the end of the century, this region is expected to be drier than current conditions (Walsh et al. 2014). Figure 5-4 shows the raw D/S ratio from the WASP model and illustrates the fact that JBLM currently has a low water stress, but will experience increased water stress towards the end of the century. Between 2010-2070, the water stress values are clustered under 0.4 This clustering appears blue, which is the MIROC 3.2 climate model output on top of the other climate models. By the end of the century, when surface water flows will be reduced, there will be greater variability within the water stress index and higher values. Reductions in surface water flows will greatly affect supply in the region as the region primarily relies on surface water for potable water.

Figure 5-4. Raw outputs from the WASP model for Fort Riley showing D/S. Regional water stress is expected to increase at the end of the century as population growth continues while precipitation and surface water flows decrease.



5.2.1.3 *Fort Riley, KS*

Fort Riley has a high military value, with a normalized score of 3.6. This score illustrates the model's methodological assumption that water supplies in a region can actually be used. Fort Riley has very high groundwater use. Both Riley County and Geary County, which surround the installation, rely on groundwater for over 95% of their withdrawals. This is more than double the national average of 45% (Kenny et al. 2009). One reason why groundwater reliance is so high is the presence of fecal coliform bacteria in local reservoirs (Kansas Dept. of Health and the Environment 2000). This work's projections of the region's water consumption in the future far exceed groundwater recharge estimates. While the region will have water, the treatment costs to make the water consumable may be very high. Therefore there may be greater stress in the region.

5.2.1.4 *Fort Drum. NY*

Fort Drum displays no water stress. Across all runs of the WASP for the five climate models, Fort Drum's highest water stress score was 0.094, which indicates no stress. During this century, the northern New York area may have additional precipitation (2.66 in. annually) that may negate the water-stressing effects of projected regional growth. Currently, the region uses a small amount of the total available precipitation and does not rely heavily on groundwater to meet local demand. The installation itself, however, does rely on groundwater to a higher degree than the surrounding community.

5.2.2 Climate change will reduce water availability

Water availability will be reduced in the future. The 2014 National Climate Assessment indicates that the drivers of stress will include increased population, increased electricity demand for cooling, land use change, and climate change. These co-occurring factors are likely to reduce the supply of water in coming decades (Geogakakos et al. 2014).

Output from model runs show that climate change will reduce the amount of water available to Army installations. Climate models forecast that there will be variability between years, which may make water resources planning difficult. Furthermore, prolonged periods of drought dries soil, which increases the susceptibility to flooding and, for most soil types, reduces the amount of groundwater that can be absorbed. Conversely, in years with more rainfall, there is a higher risk of flooding, high amounts of run-off, and soil saturation. Therefore, this high amount of variability indicates uncertainty in supplies into the future.

5.2.3 Technological solutions alone cannot solve the water stress situation

While not discussed at length, the WASP model was created as a planning support system to allow various scenarios to be run. Various scenarios were run for Fort Bliss and Fort Bragg to assess the impact of Army mandates and technological improvements on water stress. These scenarios included decreases in water needed for power generation, reduced demands for water on the installation, increased household water efficiency, and increased agricultural efficiency.

The U.S. Army has many programs and mandates to reduce water consumption, and to thereby adapt to the uncertainties of a future climate while increasing the sustainability of bases. Technological improvements and efficiency are important to save the precious water resource and to model applications of water-saving technology to the wider community. Technological solutions are often touted as an appropriate response to climate change.

However, technological solutions alone cannot solve the water problems of the U.S. Army. Some installations are currently water stressed, and engineering and technical solutions will not resolve the stress. The analysis at Fort Bliss and Fort Bragg highlight that technology can reduce some of the risks of climate change, but that the risks are still very high.

6 Conclusions and Recommendation

6.1 Conclusions

Climate change will impact the availability of water differently throughout the United States. Reduced stream flow along with urban development will affect the volume and quality of water and therefore the overall availability of water. The RAND Corporation found that water scarcity due to climate change will be one of the key challenges for the U.S. Army in coming years (Lachman et al. 2013). The analysis outlined in this report demonstrated that, in the future, some Army bases will be located in water stressed regions. It is important to note that this water stress comes from the perspective of sustainable supplies and ground water recharge. Fort Bliss has a low military value because the installation is extracting more water than is being sustainably recharged. This analysis finds that, even in the water-resource rich environment like that surrounding Joint-base Lewis-McChord, by the end of the century with reduced precipitation, even that installation may experience water stress.

6.2 Recommendations

To ensure that installations have access to the water needed to meet mission requirements, the U.S. Army stationing analysis process should include an evaluation of water stress (a Water Stress Projection), the results of which will indicate whether Army installations under consideration will have high water stress in the future. This water stress is likely to affect the installations' ability to accomplish missions and training.

This work has outlined the WAter Water Stress Projection (WASP) model, which integrates water stressors resulting from GCC and regional growth to assess future water availability at DoD installations. The WASP is a tool that can provide CAA with a scalable solution incorporate water into the stationing process. The model can also be used to generate a maximum number of personnel at an installation, which can be used as an OSAF constraint. To test the impact of climate change on the United States Army, the model was applied to five case study installations located across the continental United States in a variety of climate zones. It is recommended that the WASP model be used as part of the Military Value Analysis process as demonstrated in this report.

Appendix A: Water Stress Index Analysis Using the Water Stress Modeling Model

1. **Date.** As of: 27 July 2015.

2. **Definition.** A regional water balance model and planning tool that takes into account population projections; available water resources (surface water and recharge); water withdrawal from agriculture, mining, military, industrial, among other sectors; land development; and climate change to estimate the water stress index of an Army installation. These indices are converted into a score that will provide a Water Stress comparison mechanism between Army installations.

3. **Purpose.** To produce a projected Water Stress Index for each Army installation to determine if more military personnel can be added. The final objective is to estimate the number of troops that could be relocated to a given Army installation without causing significant water stress in the region. A final score of the Army installation is given. The tool permits variability in climate change and in number of troops.

4. **Source.** Water Supply Stress Index Model (WaSSI) Ecosystem Services Model Version 2.1, Water Stress Modeling Model.

5. **Methodology.**

   a. Select Army installations desired for analysis. A layer with the delimitation of the installation is needed.

   b. Delineate military installation's regions. This is defined in the Water Stress Modeling (WASP) as the counties adjacent to the military installation. The rest of the methodology depends on this delimitation.

   c. Obtain percent change of land development (new developed per additional person, farm land, cattle land, and "other" sources) between years 2001 and 2011. This is achieved by processing data of a GIS layer, from the National Land Cover Database 2011 (NLCD 2011) and the use of a tool made in ArcGIS Model Builder.

   d. Retrieve population projections for the regions being analyzed using several sources, such as university studies and state agencies.

The sum of the counties' population will be the base regional population. If the first analysis seems to be favorable, then add the BRAC realignment population (Soldiers, Federal employees and the dependents) to the base regional population.

e. Obtain estimates of groundwater recharge for the aquifers within the case study regions. For this, the Annual Groundwater Recharge rates from USGS data were used.

f. Obtain monthly supply and demand and water balance output of five models using the A1b climate change scenario from the Special Report on Emissions Scenario (SRES) in the WaSSI Model. In general, the Intergovernmental Panel on Climate Change (IPCC) describes A1b SRES as "a future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology. Major underlying themes are economic and cultural convergence and capacity building, with a substantial reduction in regional differences in per capita income. In this world, people pursue personal wealth rather than environmental quality." WaSSI has five options that include the A1b scenario. The five climate change models are:

    i. CSIRO-MK 3.5 SRES (Developer: CSIRO Marine and Atmospheric Research Laboratories Information Network, Australia. Components: Sea-ice, oceans, atmosphere, and land surface)
    ii. MIROC 3.2 SRES (Developer: National Institute for Environmental Studies, Japan)
    iii. CGCM3 (Developer: Canadian Centre for Climate Modeling and Analysis)
    iv. CM2 (Developer: National Oceanic and Atmospheric Administration (NOAA)
    v. HADCM3 (Developer: Hadley Centre , United Kingdom. Components: atmosphere, ocean)

g. Incorporate data obtained from methodologies 5.a–f into the Water Stress Modeling model, done in STELLA.

h. The regional water balance model combines the data defined in the previous steps and calculates water stress, which is the water withdrawal-to-availability ratio. Water availability is focused on surface water and groundwater recharge. Also, water availability does not take into account water rights for the regions.

i. Use an Excel spreadsheet to analyze range of maximum water stress index ratios for every 5-year period.

6. Questions That Define Data.

a. Case Study Military Installation's Region. This depends on the definition of a region's area.

b. Additional Troop Capacity. Does the installation have viable water stress index projections (one that permits more troops (and other Army workforce, dependents, etc.) in the region)? The process of adding troops is done after the initial assessment of water stress indexes.

7. References.

a. WaSSI Ecosystem Services Model developed by the U.S. Department of Agriculture (USDA) Forest Service

b. Population projections: North Carolina Office of State Budget and Management, Cornell University Program on Applied Demographics, Washington Office of Financial Management, Kansas Center for Economic Development and Business Research from Wichita State University, Texas State Data Center, Bureau of Business and Economic research from the University of New Mexico.

c. Land development: GIS Software (ArcGIS 10.3) developed by Environmental Systems Research Inc. (ESRI) and GIS layer from the National Land Cover Database 2011 (NLCD 2011).

d. Military Installations and U.S. Counties GIS layers from 2014 TIGER/Line® Shapefiles developed by the U.S. Census Bureau

8. Unit of Measure. Volume of water retrieved per volume of water available (dimensionless), type of water stress ratio.

9. Equations.

a. Water Stress Index. Withdrawal-to-availability-ratio (D/S) is the monthly water withdrawal for agricultural, household, and industrial sectors over the monthly renewable freshwater sources. The WASP model also takes into account withdrawals from power plants, livestock, mining, and the Army. This index however, does not take environmental water scarcity into account.

$$Water\ Stress\ Index = \frac{Demand}{Groundwater\ Recharge + Surface\ Water\ Supply} \quad (A\text{-}1)$$

i. Water Stress Index Category (Vorosmarty et al. 2000):

W/Q Range	Category
Lower than 0.1	No stress
Between 0.1 and 0.2	Low Stress
Between 0.2 and 0.4	Moderate Stress
Higher than 0.4	High Stress

ii. Excel formulation to separate ratios according to W/Q range:

`LOOKUP(row,{0,0.1,0.2,0.4},{"None","Low","Moderate","High"})`

10. Model Requirements.

a. Model Inputs:

i. Military installation region (area) in acres

ii. Population projections

iii. Developed land (change from 2001 to 2011) analysis.

(1) New development per additional person

(2) Percentage change from farm land, cattle land, and “other” open space to developed land.

(a) Water demand analysis:

(i) Projection of water withdrawals for the generation of electricity (source: U.S. Energy Information 2014 Annual Energy Report).

(ii) Water withdrawals for domestic supply, agriculture, aquaculture, mining, livestock, industrial, thermoelectric power water withdrawals (source: USGS 2010 per capita domestic water use rate).

(iii) Army water use (Source: Army Energy and Water Reporting System [AEWRS]).

(b) Water availability analysis:

(i) Monthly surface water projections (source: model).

(ii) Annual groundwater recharge estimates (source: (Wolock 2003).

(c) Model Output:

  (i) The model provides monthly water stress ratios. The withdrawal-to-availability ratio is the model output that is analyzed using Excel.
  (ii) The user must enter the monthly water stress ratios output for the five models in the first tab (“Raw Data”) and verify if other sheets are correctly referenced with data from this tab.
  (iii) The graph of all of the monthly water stress ratios is shown next.
  (iv) Despite the apparent precision 0f climate model outputs, they represent projections of the future that always include a degree of uncertainty. As a result, for this MVA attribute, the indexed results were grouped into 5-year blocks from 2015-2100 to assess the minimum stress and the maximum stress. An MS Excel®-based formula was used to obtain the range of the minimum-maximum and the absolute maximum numbers. Ranges were used to better show the worst case scenarios that the five climate models project; for this reason, the analysis focuses on the maximum values. To simplify the analysis, it was assumed that the peaks can occur at any moment within the 5 years, although the value is graphed at the end of the period.
  (v) A scoring mechanism was implemented to further simplify the data and results. This analysis weighted the data on two factors, time and stress level. Values for the years 2015-2035 were given twice the weight of those from 2040-2100. This was done because CAA is primarily concerned with a 20-year Net-Present Value, however it is believed that projections of the future should be included outside of that range, because it will affect future installation capacity. The values range from zero (0) to 3 and are given according to the water stress category (a value of zero [0] when there is no stress, to 3 when there is high stress).

W/Q Range	Score 2015-2035	Score 2040-2100	Note
No stress	0	0	These value are given to the ranges obtained in the analysis. At the end, all of the values are summed and divided by the total possible amount (depending on the analysis period). As shown in the figure below, Fort Riley had a score of 0.91 out of one.
Low Stress	1	0.5	
Moderate Stress	2	1	
High Stress	3	1.5	

(vi) The final score can be used to compare Army installations being analyzed and to choose those that project a more viable future projection panorama (a high final score) according to the water balance regional model.

(d) Value Function:

(i) The value function converts an installation's score, which is the Water Stress Score, into a military value between zero (0) and 10.

(ii) The value function uses a single equation that measures the returns to scale of the attribute's score and returns the value of an installation's facilities.

(iii) The maximum value of 10 is given to the installation with the highest water stress score.

(i) The minimum value of zero (0) is given to the installation with the lowest water stress score (i.e., having the most water).

(ii) Normalized Scores= [(X – Xmin) (10) / (Xmax – Xmin)], where X is the water stress indexed score for an installation.

Acronyms and Abbreviations

Term	Definition
AEWRS	Army Energy and Water Reporting System
AFB	Air Force Base
ANSI	American National Standards Institute
AR	Army Regulation
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BFI	Base-Flow Index
BOS	Base Operating Support
BRAC	Base Realignment and Closure
CAA	Center for Army Analysis
CEDBR	Center for Economic Development and Business Research
CEERD	U.S. Army Corps of Engineers, Engineer Research and Development Center
CERL	Construction Engineering Research Laboratory
COA	Course of Action
COBRA	Cost of Base Realignment Actions
CONUS	Continental United States
CSIRO	Australia's Commonwealth Scientific and Industrial Research Organization
DoD	U.S. Department of Defense
EIA	Energy Information Administration
EMM	Electricity Market Module
EO	Executive Order
EPWU	El Paso Water Utilities
ERDC	U.S. Army Engineer Research and Development Center
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
ESRI	Environmental Systems Research Institute, Inc.
FY	Fiscal Year
GCC	Global Climate Change
GIS	Geographic Information System
HQDA	Headquarters, Department of the Army
HUC	Hydrologic Unit Code
ICLUS	Integrated Climate and Land Use Scenarios
IPCC	Intergovernmental Panel on Climate Change
JBLM	Joint Base Lewis-McChord
MRLC	Multi-Resolution Land Characteristics Consortium
MVA	Military Value Analysis
NEPA	National Environmental Policy Act
NLCD	National Land Cover Data
NOAA	National Oceanic and Atmospheric Administration
NPV	Net Present Value

Term	Definition
NSN	National Supply Number
OACSIM	Office of the Assistant Chief of Staff for Installation Management
OCONUS	Outside Continental United States
OMB	Office of Management and Budget
OSAF	Optimal Stationing of Army Forces
SAR	Same As Report
SF	Standard Form
SRES	The Special Report on Emissions Scenarios
TR	Technical Report
UNM	University of new Mexico, Albuquerque, NM
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WASP	WAter Stress Projection (model)
WaSSI	Water Supply Stress Index (Ecosystem Services Model)
WMO	World Meteorological Organization

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14. ABSTRACT

U.S. Army stationing is a constant multi-scale process. Large scale stationing, which is identified with strategic realignments, requires some level of modeling to determine whether the movement of tactical equipment and large numbers of personnel is both economical and continues to meet future long-term strategic requirements. This work explored how climate change implications on water resources may affect military installations in the future, and used that information to outline the WAter Stress Projection (WASP) model, which serves as a decision support system tool that integrates water stressors resulting from global climate change and regional growth to assess the availability of water to an installation in the future. WASP is a tool that provides a scalable solution to incorporate water into the U.S. Army stationing process and to generate a maximum number of personnel at an installation. To test the impact of climate change on the United States Army, the model was applied to five case study installations located across the continental United States in a variety of climate zones.

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