STO CLOSEOUT FACT SHEET

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STO NUMBER: R.INN.2015.26

TITLE: Climate Assessment for Army Enterprise Planning

SUBMITTING ORGANIZATION: ERDC

STO START YEAR / END YEAR: FY14-FY17

1. NARRATIVE:

1A. Short Description from Narrative Chart

This FY14-17 effort developed capabilities to incorporate direct and indirect impacts of climate change and related trending dynamic conditions to improve Army enterprise decisions. This effort provided Army enterprise decision metrics that are sensitive to climate and related trending changes; scientifically defensible direct causal chains that link climate to enterprise decision metrics; integrated direct and indirect causal chains that link enterprise decision metrics with climate change; and climate change causal chains and metrics incorporated into enterprise processes (stationing, land withdrawal, acquisition, closure, critical infrastructure).

1B. Detailed Description

The purpose of this research program is to develop new analytical methods for incorporating the direct and indirect impacts of climate change, and related dynamic processes such as urban encroachment, into Army enterprise long-term planning processes (e.g., stationing). This effort assures that existing Army installation-decision metrics are calculated in a way that reliably accounts for scientific understanding of climate-change impacts. The existing installation-decision metrics used in enterprise decision processes are measures for ranking an installation's value and contribution to the overall Army mission. They represent the 1) ability to support current and future mission capabilities, 2) availability and condition of lands and facilities, and 3) cost of operations. Therefore, it is critical that these metrics respond to dynamic climate-change impacts. The research improved enterprise decisions by providing analytical capabilities that account for the impacts of climate-change scenarios. These capabilities provide the Army with a consistent and multi-tiered approach for assessing climate-change impacts, from local to national scales.

The primary product is a suite of analysis tools that provide climate-sensitive metrics using underlying models that are based on the best scientific understanding of climate-change impacts and related dynamics. The models support the integration of climate-change data into the

forecasting of existing installation-decision metric values that affect Army enterprise planning decisions.

The payoff of this research improved planning processes for national and regional stationing, realignment, and associated activities to systematically account for the possible future consequences of climate change and related dynamic trends.

Army strategic planning guidance provides long-range goals for 10 – 20 years into the future, and affects all installations (Army Regulation 5-10, Stationing). Long lead times are required to modify military force structure, create the necessary facility support, program the funding, and develop political support for a change in the base structure. The effective use of planning is critical to balancing the operational, facility, and environmental requirements with political sensitivities involved in developing new stationing decisions.

The Defense Base Closure and Realignment (BRAC) Act of 1990 specifies the process for the closure and realignment of military installations to support military transformation and cost savings. BRAC is critical to reshaping DOD infrastructure to optimize military readiness and make the most effective use of limited defense dollars. Since 1988, DOD has used BRAC procedures five times, resulting in 121 major domestic base closures, 79 major realignments, and 900 lesser closures and realignments (GAO, 2013). The most recent BRAC (2005) had one-time costs of $35.1B and an estimated annual savings of $3.8B. Decisions made during the BRAC process and related restationing efforts have long-term impacts on DOD operations and costs. BRAC and stationing actions are critical enterprise decision points where climate change assessments can guide DOD and Army leaders.

1C. Additional Detail

This investment sustains training and testing mission within current land base and budget constraints by improving enterprise decision to account for future risks due to climate change and related dynamic trends. This investment provides science-based compliance with Strategic Sustainability Performance Plans through improved national and regional stationing, realignment, and associated decisions.

This effort supported product development through TRL 5 to incorporate climate change assessments into the Military Value Analysis (MVA), Cost of Base Realignment Actions (COBRA) Model, and Optimal Stationing of Army Forces (OSAF) and transition to ASA (IEE), Center for Army Analysis (CAA), and Army component organizations that are responsible for portions of the processes.

1D. Approach

The research approach identified and developed advanced decision metrics that quantified climate uncertainty impacts on mission-relevant built and natural infrastructure. It then developed causal models that quantified the underlying response of fundamental physical and ecological processes to climate change for each of the decision metrics. Where there is significant interaction among models, network analyses was conducted to account for indirect interactions and assess the relative importance of these interactions. Advanced decision metrics and cause-effect models were evaluated in a simulated environment to ensure timely, consistent analyses to support future Army enterprise stationing and realignment decisions. At the end of the program, technology transfer was facilitated through work with offices directly involved in the enterprise decision processes (e.g., stationing, BRAC) to ensure that final products address user requirements.

1E. Why should Army Leadership Care about this:

Integrating climate change into Army enterprise level decision processes (i.e., stationing, land acquisition) involves diverse Army organizations and processes that impact both built and natural assets. The wide range of Army organizations that support these decision processes and the long-term impact of these decisions on the current and future Army suggest a role for Army leadership oversight and guidance.

2. WHAT IS THE PROBLEM?

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. Federal drivers, including EO 13514, the White House Council on Environmental Quality (CEQ) and the Climate Change Adaptation Work Force, prompted DOD elements to enact policy guidance. This was reflected in the 2010 Quadrennial Defense Review (QDR), requiring that climate be seriously and directly considered in long-term Army planning. The QDR states "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". The QDR is the principal means by which the National Defense Strategy is translated into new policies and initiatives.

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 Climate Change Adaptation Roadmap (2012), the Army recognized that climate change interacts with stressors that it already considers and manages. In the 2013 Report to Congress on Sustainable Ranges, 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 a separate decision-making processes. DOD intends to fully integrate climate change considerations into its extant policies, planning, practices, and programs. This requirement was more recently described in the SECDEF Memo, "Actions Required to Support Defense Mission Readiness in a Changing Climate" (Draft 2013). That memorandum 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 (June 2013) reemphasized 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 OASA(IE&E) has the lead responsibility for integrating climate change into Army planning processes. This requirement is documented in the Army Campaign plan as objective 2-7 "Adapt / Execute Climate Strategies". In FY12, OASA(IE&E) tasked ERDC to develop an adaptation planning framework that is consistent with CEQ and goals of the DoD Climate Change Adaptation Roadmap to integrate climate change planning in existing Army installation planning processes. This effort considers 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 does 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 package is to address this Army deficiency.

The Army requirement to consider the impact of climate on long-term enterprise-scale basing and stationing decisions results from weather being inherently intertwined with the ability of the Army to successfully complete required training and testing missions, and the operation and maintenance of both built and natural infrastructure. Future weather as altered by climate change will be altered on short, mid, and long-term time-scales not only in long-term trends but also in variability and frequency of extreme events. Hence, there is a need to support the planning decision process and associated assessments of enterprise systems and installation functions with regard to their vulnerabilities to these future impacts.

Without the ability to assess and incorporate changing future conditions into Army planning scenarios, mission success as well as the long-term sustainability of the Army enterprise could be compromised. Currently, decision processes supporting enterprise and installation planning assume that current environmental conditions will be static and persist as such into the future. Therefore, installation metrics used in long-term enterprise planning (e.g. stationing, and land set-asides) are fixed values across the planning horizon. The various metrics 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.

The development of science-base, 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. WHAT ARE THE BARRIERS TO SOLVING THIS PROBLEM?

The main barriers to forecasting installation metrics used in long-term planning are the lack of dynamic models, lack of fundamental understandings, the complexity of climate impacts and related dynamics, and the lack of analytical methods appropriate for enterprise scale.

Dynamic models. Currently the Army uses data, models, and analyses to assign values to metrics that define installations, with the notion that these values are relatively fixed through the planning horizon. Models do not exist that can forecast changes in these values as direct and indirect consequences of climate change.

Fundamental understandings. There are significant gaps in our fundamental knowledge of the natural and built environment responses to climate change across enterprise scales. Therefore, we cannot reliably predict how the training and testing capacities of installations may change over longer time scales.

Complex interactions. Available models and analytical techniques typically focus on specific aspects of the natural and built environment on and around installations. It is reasonable to set fixed boundary conditions when modeling relatively transient processes. However, multi-decade analyses must recognize that these boundary conditions can change. For example, climate can affect urban development patterns, which can affect the population's tolerance of military blast noise. It can also affect wind directions and speeds, which in turn can cause changes in noise-complaint patterns in surrounding communities.

Enterprise scale. In a typical stationing and realignment analysis, dozens of installation metrics are developed for each of 10's to 100's of installations. The tools and models now available to evaluate climate, hydrology, noise, urban growth, habitat impacts, building operations and maintenance costs are costly, and can take months to apply to a single installation. In contrast, stationing analysis require more rapid and less costly responses, tapping into the best immediately available data, which allows limited time or funding to improve the data. We currently lack models that can quickly and effectively generate forecasts of installation metrics while adequately capturing climate impacts. The available models and analytical methods are suitable for very localized analyses. ERDC has excellent noise, hydrology, urban growth, climate, vegetation growth, and building operation models that can form the foundation for a solution, but these are not necessarily directly suitable for application on a nationwide scale to generate installation metrics useful in stationing analyses.

4. HOW WILL YOU OVERCOME THOSE BARRIERS?

We employed analysis, modeling, and simulation to develop advanced decision metrics that account for climate change in mission-relevant built and natural infrastructure domains. To develop a modeling and analysis capability that is rapid, works at an enterprise scale, and considers complex interactions among built and natural systems, we designed and developed an extensible component-based modeling and simulation solution. Primary inputs to the system were data representing the current state of installations and their surrounding regions, and specific forecasts that include climate change, listing of key species as threatened or endangered, and economic/population changes. The input data also encompasses currently accepted metrics used in stationing and realignment studies. We utilized causal models to investigate the underlying response of fundamental physical and ecological processes behind advanced decision metrics to climate change. Where appropriate, existing models were adapted to facilitate calculation of how metrics could be affected. For some processes, we developed meta-models that will run faster than standard models while retaining as much accuracy as possible. To capture complex dynamic interactions, we conducted network analyses of causal models to account for indirect interaction among modeled processes. The output of the analyses are ranges of values for installation-decision metrics that represent the uncertainties associated with climate change.

5. WHAT IS THE CAPABILITY YOU ARE DEVELOPING AND WHERE IS IT DESCRIBED?

Research outcomes, planning metrics, and assessment models will provide cost-appropriate and repeatable procedures for informing Army enterprise stationing, realignment, and construction decisions of potential climate change impacts.

We developed integrated component-based modeling capabilities that allow rapid forecasting of decision metrics that will be directly applicable in future base-realignment and stationing analyses. These capabilities account for direct and indirect impacts of climate change and related dynamic conditions in affected Army enterprise long-term planning processes. These capabilities deliver forecasted installation metrics that respond to future dynamic climate-change scenarios into Army enterprise decision processes, including stationing, land acquisition, closure, and critical infrastructure investments. These metrics also serve as input to networked models that capture climate change causality.

The requirements for these capabilities are described in:

- Sustainable Ranges Report to Congress (2013)

- Army Strategic Planning Guidance (2013)
- DOD Strategic Sustainability Performance Plan (2012)
- DOD Climate Change Adaptation Roadmap (2012)
- DOD Quadrennial Defense Review (2014)

6. IDENTIFY ALTERNATIVE APPROACHES/TECHNOLOGIES TO ACCOMPLISH/ ENHANCE STO OBJECTIVE(S).

Alternative technologies are not available or currently under development. The DOD Strategic Environmental Research and Development Program (SERDP) is currently making investments in climate change assessment technologies. However these technologies are primarily focused at single installation level decision making processes that are generally applicable to all Services. This proposed STO effort targets Army specific enterprise level decision processes not currently being addressed or unlikely to be addressed by other federal and/or private organizations.

Outcomes of DOD SERDP program climate change investments are being leveraged and adapted to Army enterprise process where applicable to limit Army investments.

7. WHAT WE LEARNED

The thrust of this research was to improve the process used in Army enterprise-level planning (i.e. stationing, land withdrawal, acquisition, closure, critical infrastructure) by incorporating climate change impacts into the methods for assessing installation capability to sustain mission readiness and force projection. The methods the Army uses include Military Value Analysis (MVA), Cost of Base Realignment Actions (COBRA), and Optimal Stationing of Army Forces (OSAF). The problem facing the Army has been that while they are required to consider climate risks on long-term stationing investments they lack comprehensive dynamic models to objectively quantify climate uncertainty and risk in terms of mission relevant decision metrics, and lack of fundamental understanding and prediction capabilities for natural and built environment responses to climate change across enterprise scales.

Initial research in this project described the enterprise planning process beginning with the Army proponents that support installation mission planning and operations, to the metrics they use for planning and the data that supports them, to the models used by the Center for Army Analysis (CAA) in their enterprise planning suites and their model outputs. Knowledge gained from this initial step identified the decision metrics that are likely affected by fundamental physical and ecological processes and thus also likely influenced by future changes in climate conditions. This understanding then informed work in development of decision metrics with underlying models and dynamic climate data that quantify climate uncertainty. This included metrics that support maneuver area capacity, live fire ranges, water and energy, and facility O&M costs. Summary findings in these areas of research include:

<u>Training Ranges</u>

Noise: Climate change unlikely to alter noise contours/noise impacts

Heat stress: Restricted training days would increase by 50-120 days across the South through 2099; Night-time heat index also increases in the South

Fire risk: Drought and fire risk increases across Plains and Midwest

Threatened/endangered species: Developed methodologies for estimating vulnerability to increase in TES management requirements

Urban growth: Developed software and data to inform MVA Population Impact

<u>Maneuver Ranges</u>

Propose weather-based metrics: Developed new heat, drought, extremes, and indices
Training impacts on vegetation: Use of dominant species' resistance and resilience values to classify natural vegetation communities
Implication of new TES listings: Quantified the role DOD may be expected to contribute to species conservation due to climate change
Software to forecast change:

Water

Review installation issues
Calculate regional water balance: Updated USFS methodology
Stationing impacts on water

Energy

Review installation issues: Installation energy use has been declining
Forecast installation energy need: Algorithm to estimate future need

Deployment

Future impacts: Army assets will be minimally impacted, except coastal sites

Maintenance

Forecast corrosion rate change: Rates are modest but accelerate with heat
Forecast maintenance cost: Small for since FAC but scale up a lot across installation. Costs vary considerably between FACs and between installations.

8. WHAT WE ACCOMPLISHED

This research project successfully improved the Army's enterprise planning processes by developing decision metrics that are now informed by climate change and are backed by scientifically defensible models and data. This overcame previous limitations in planning methods that assumed static environmental conditions would persist throughout decision time-scales and that lacked models to quantify climate uncertainty. Specific development accomplishments include models and related data to:

- Forecast change in in future maintenance costs
- Forecast future installation heating/cooling degree costs
- Estimate changes in the future capacity of military training ranges
- Estimate changes in the future capacity of military ranges
- Estimate changes in days safe for training and days associated with fire risk
- Estimate loss of training due to urban encroachment
- Estimate changes in regional water availability to installations

An additional accomplishment was the development of an integrated software environment for all of the models listed above and their data. This allows for a central access point to all of the models for testing, analysis, and future enhancement development. It also integrates the models so that they may provide rapid generation of potential time-series inputs for enterprise planning analysis.

9. WHAT IS/ ARE THE PRODUCT(S)/ RESULT(S) OF THIS STO?

The primary product is a suite of analysis tools that will provide climate-sensitive metrics using underlying models that are based on the best scientific understanding of climate-change impacts and related dynamics. The models support the integration of climate-change data into the forecasting of existing installation-decision metric values that affect Army enterprise planning

decisions. Specific products that address each of the technical barriers and approaches to overcome those barriers are:

- Army enterprise decision metrics that are sensitive to climate and related trending changes.
- Scientifically defensible direct causal chains that link climate to enterprise decision metrics.
- Integrated direct and indirect causal chains that link enterprise decision metrics with climate change.
- Climate change causal chains and metrics incorporated into enterprise processes (stationing, land withdrawal, acquisition, closure, critical infrastructure).

10. QUANTITATIVE METRICS RELEVANT TO THE PRODUCT(S)/ RESULT(S):

The following metrics and objectives were generated to ensure that the program products will represent a substantial improvement over existing capabilities and to ensure that program products can successfully transition to Army users. Measures and metrics are derived from information reported in the 2013 Sustainable Range Report to Congress, Army Training Strategy (2012), and Army Regulation 5-10 Stationing.

Measure	Baseline Capability	Current Effort Capability	Effort Objective	Army Goal	TRL
Incorporate global climate change (CC) adaptation measures in existing Army plans	**Enterprise processes assume static conditions**	**New effort**	**Integrate into MVA*, COBRA, and OSAF restationing processes and related processes**	**T :**	**S: 3**
				O: Incorporate CC into all relevant enterprise planning processes	**C: 5**
Installation metrics that incorporate future conditions	**Metrics assume static conditions**	**New effort**	**Account for all Army stationing metrics significantly impacted by climate change**	**T:**	**S: 3**
				O: All mission metrics impacted by climate change.	**C: 5**
Consistent evaluation of installations for future uncertainties within cost and throughput constraints	**Current evaluations are inconsistent**	**New effort**	**All SRP CAT1,2 installations (16).**	**T:**	**S: 3**
				O: All installations	**C: 5**

11. HOW WILL PROGRESS BE ASSESSED?

Initially sensitivity analyses was conducted to assess if key drivers of Army enterprise processes (MVA, COBRA, and OSAF) are covered by the STO technologies. Evaluation of technology products (models and data) was then conducted by CAA to ensure that products integrate

successfully within the MVA, COBRA, and OSAF methodologies. Evaluation was then conducted by Army component organizations responsible for specific portions of these processes to assess technologies against their requirements. Finally technologies were evaluated by higher resolution models and data for specific locations to evaluate technology performance.

12. WHAT IS THE POTENTIAL/ WARFIGHTER PAYOFF?

The payoff of this research is improved planning processes for national and regional stationing, realignment, and associated activities to systematically account for the possible future consequences of climate change and related dynamic trends.

Army strategic planning guidance provides long-range goals for 10 – 20 years into the future, and affects all installations (Army Regulation 5-10, Stationing). Long lead times are required to modify military force structure, create the necessary facility support, program the funding, and develop political support for a change in the base structure. The effective use of planning is critical to balancing the operational, facility, and environmental requirements with political sensitivities involved in developing new stationing decisions.

The Defense Base Closure and Realignment (BRAC) Act of 1990 specifies the process for the closure and realignment of military installations to support military transformation and cost savings. BRAC is critical to reshaping DOD infrastructure to optimize military readiness and make the most effective use of limited defense dollars. Since 1988, DOD has used BRAC procedures five times, resulting in 121 major domestic base closures, 79 major realignments, and 900 lesser closures and realignments (GAO, 2013). The most recent BRAC (2005) had one-time costs of $35.1B and an estimated annual savings of $3.8B. Decisions made during the BRAC process and related restationing efforts have long-term impacts on DOD operations and costs. BRAC and stationing actions are critical enterprise decision points where climate change assessments can guide DOD and Army leaders.

13. WHAT WE TRANSITIONED

Products of this research were generated that addressed planning metrics associated with training ranges, maneuver ranges, water and energy, operations and maintenance, and climate phenomena. In addition, the models and related data were captured in an integrated software environment as a common operating environment. There were four general types of products listed below and summarized in the table by installation metric:

(1) Reports that document the potential for changing future conditions associated with climate, urban growth, and listing of species as endangered or threatened to affect future stationing analyses.

(2) Reports and journal articles that present approaches for translating climate change forecasts into metrics associated with meeting Army mission goals.

(3) Software models and tools for projecting decision metric changes with respect to climate projections, and

(4) Standardized US-wide climate forecast maps.

	Product Title	Type
Training Ranges		

Firing Range Contaminants and Climate Change	Software
Regional urban growth	Software
Effects of Climate Change and Urban Development on Army Training Capabilities	Tech report
Quantifying Impacts of Urban Growth Potential on Army Training Capabilities	Tech report
An Evaluation of Methods for Assessing Vulnerability of Army Installations to Impacts of Climate Change on Listed and At-Risk Species	Tech report
Effects of Climate Change, Urban Development, and Threatened and Endangered Species Mgmt. on Army Training Cap.	Tech report
Firing Range Contaminants and Climate Change	Spec report
Climate analysis for noise assessment (Applied Acoustics)	Journal
Weather	
Heat, drought, climate and extremes installation model	Software
Summarization of CONUS weather station data climatic indices	Data
GIS layers visually summarizing climatic indices	Data
Heat stress and fire risk indices - Tables and GIS	Data
Indices of heat stress, fire risk, climate and extremes for CONUS installations	Tech report
Use of Heat and Fire-Risk Indices to Project Local Climate Impacts	Tech report
Annual Temperature and Precipitation Trends in the United States and Expected Impacts on DoD Installations (Stoklosa)	M Thesis
Future Projections of Heat and Fire-Risk Indices for the Contiguous US	Journal
Maneuver Ranges	
Estimation of maneuver land availability under any temp/precip forecast - V2	Software
Methodology for assessing vegetation community shifts on CONUS installations	Software
Estimating Resistance and Resilience of Military Lands Using Vegetation Indices	Tech report
Climate Change Vulnerability of Army Installations Attributable to Listed and At-Risk Species	Tech report
Effects of projected climate change on maneuver ranges	Tech report
Impact of Vegetation Community Shifts on Maneuver Areas (Oxley)	M Thesis
Predicting USCS soil classification from soil property variables using Random Forest (Terramechanics)	Journal
Water & Energy	
Climate impacts on installation energy consumption	Software
Climate Change Impacts on Water and Energy for Army Installations	Tech report
Deployment Infrastructure	Tech report
Climate Change Impacts on Installation Energy	Tech report
Modeling Climate Change and Water Stress (Juliana)	Tech report
Operations and Maintenance	
Climate-forecast to maintenance cost projection	Software
Approach for providing delta % installation O&M costs	Tech report
Climate-forecast to maintenance cost projection	Tech report
Integrated software	
Capturing analysis techniques	Software
Developing a user assistance application (wizard)	Software
Integrating models into the common environment	Software

A formal Technical Transfer Agreement (TTA) was established and signed with CAA (see Appendix A). Transition of technology from this effort was also agreed to by ASA(IEE) to support their policy and guidance efforts in climate change and resiliency planning.

14. TRANSITION CONCEPT/ PLAN:

FY14 – Army enterprise decision metrics affected by climate.
FY15 – Direct causal models of climate change on enterprise metrics.

FY16 – Direct and indirect causal models of climate change on enterprise metrics and processes.

To facilitate product transition, we have established a Senior Review Committee (SRC). The SRC has helped guide this proposal through participation in Red Team reviews, review of planning documents and scoping efforts. Member roles involve program oversight (O), tech transfer (T), and coordination (C). The current members of the SRC are listed in the following table. The SRC participates in ongoing In-progress Reviews, product reviews, and transition planning.

Organization	Name	Role	Domain	Email
G8 (CAA)	Sarah Harrop	T	Stationing	Sarah.e.harrop@mail.civ
G357	Tony Pellitteri	C	Ranges and Lands	angelo.a.pellitteri2.civ@mail.mil
ASA(IE&E)	Marc Kodack	O	Climate change, Water	marc.d.kodack.civ@mail.mil
ACSIM	Lorri Schwartz	C	ACUB, TES	lorri.a.schwartz@us.army.mil

15. TESTING:

Initially sensitivity analyses was conducted to assess if key drivers of Army enterprise processes (MVA, COBRA, and OSAF) are covered by the STO technologies. Evaluation of technology products (models and data) was then conducted by CAA to ensure that products integrate successfully within the MVA, COBRA, and OSAF methodologies. Evaluation was then conducted by Army component organizations responsible for specific portions of these processes to assess technologies against their requirements. Finally technologies were evaluated by higher resolution models and data for specific locations to evaluate technology performance.

16. MODELING AND SIMULATION:

Modeling and simulation results were provided to CAA to ensure that products integrate successfully within the MVA, COBRA, and OSAF methodologies. Modeling and simulation results can then be provided to Army component organizations responsible for specific portions of these processes to assess technologies against their requirements.

17. LEVERAGING OTHER PROGRAMS:

This research program targets Army climate change assessment requirements not being addressed by other programs. The proposed program builds upon relevant climate change experience, data, models, and tools for which the ERDC team has been actively involved.

The SERDP program was directed through policy guidance in the 2010 Quadrennial Defense Review to address climate change challenges. SERDP has funded a number of projects to develop climate change assessment capabilities. These projects target installation level assessment techniques rather than enterprise level assessment methods. However, we expect that some techniques developed can be adapted to address specific enterprise metrics.

The U.S. Army Institute for Water Resources (IWR) is pursuing climate change challenges under its Responses to Climate Change (RCC) Program. This program supports a broad array of initiatives focused on the management of water and ecosystems in support of the Corps' civil works initiatives. We expect that some of the national-scale data sets developed by IWR will inform the research proposed in this program.

ERDC has funded 3 prior climate change initiatives. The "Uncertain Futures" R&D program is researching approaches for identifying climatic thresholds that will be important to the survival of mission limiting species. Some installation level techniques for assessing species impacts to mission will be adapted for use within our effort. The second R&D program examining the impact of climate change on the fate and transport of military unique munitions residues found on military installations. Results of the national level assessment will be integrated into this effort. The third R&D program is developing a suite modeling and simulation capabilities that include 1) downscaled General Circulation Model projections to generate statistically valid weather scenarios, 2) high-resolution hydrological simulations, and 3) improved ecological simulation capabilities. Components of this effort including downscaling methods and weather simulation approaches will be used in our effort.

ERDC team members have been funded by ASA(IEE) to develop and demonstrate a framework for integrating climate change vulnerability assessments into installation planning processes and plans. This work only addresses installation level planning processes. Our research program will focus on national and enterprise scale processes and plans. However this experience will help ensure a consistent approach across spatial scales.

18. LOGISTICS IMPLICATIONS:

This proposed STO does not have substantial logistics implications. Technologies from this STO augment existing Army planning processes.

19. JOINT APPLICABILITY:

Portions of the Army enterprise climate change assessment metrics and models are applicable to other services that have similar resources and processes.

20. ENDORSEMENTS:

Endorsement letters have been received from the primary technology transfer partners during FY13 during development of this effort. This work package is endorsed by 1) Mr. Kidd (Deputy Assistant Secretary of the Army for Installations, Energy and Environment (ASA IE&E), 2) Dr. William Crain, Director Center for Army Analysis (CAA), 3) Mr. Tom Macia, Chief Training Support System Division (DAMO-TRS).

21. POCS (STO MANAGER, TSO, PM, AND TRADOC SPONSOR):

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22. PERFORMERS/ CONTRACTORS:
All substantial work is being executed within ERDC.

23. FUNDING ($K):

Organization	PE/Project/Task	FY14	FY15	FY16	FY17	Total
ERDC	62720/896/04	1,115				1,115
ERDC	62720/896/04V		2,000	1,763	343	4,106
Total		1,115	2,000	1,763	343	5,221

24. WHAT ARE THE SUPPORTABILITY/RELIABILITY ISSUES OF THIS TECHNOLOGY?

Not applicable. STO-R submission.

25. ANNUAL PROGRESS REPORT

Fiscal year 2017 is reduced funding year to ensure that all final integration of individual models and data are completed and all components are fully documented. There were no changes made to the planned FY17 budget or execution of the budget and timelines. Technology transition partners have been provided final products and seen demonstrations of the products. The only remaining tasks are final edits on the remaining technical report and continued coordination with transition partners.

FY17 Planned and Actual Accomplishments

Quarter	Planned	Actual
1st Qtr	Submit technical report "Climate-forecast to maintenance cost projection"	Submitted technical report "Climate-forecast to maintenance cost projection"
	2 journal articles accepted	2 journal articles accepted for publication
2nd Qtr	Complete final editing on all FY16 submitted technical reports	Completed editing on all FY16 submitted technical reports

	Complete software integration efforts	Completed software integration efforts
3rd Qtr	Demonstrate integrated software	Demonstrated integrated software
4th Qtr	Submit final software integration technical report	Software integration technical report submitted to editing. On schedule to complete milestone

26. END-OF-PROGRAM REPORT

Total funding for this STO was $5.3M. Execution began in FY14 and was completed in FY2017.

The final products resulting from this STO include methods formalized in software to forecast:

1) Installation facility maintenance costs
2) Installation facility heating/cooling energy costs
3) Ecological capacity of military maneuver areas and range
4) Soldier days safe for training
5) Installation fire risk
6) Training capacity lost due to urban encroachment
7) Regional and local installation water availability

Technology transition activities completed as part of this STO include:

1) Technology transition agreement signed with TTA signed Center for Army Analysis (CAA) to clearly define Army expectations for STO products and delivery schedules
2) Participation in CAA BRAC community of practice committees and workshops to ensure STO products capture Army requirements
3) 3 Peer-review papers to support scientific foundation of STO products
4) 17 technical reports to document all key assumptions, data, and algorithms used in STO products
5) 7 individual software products that are aligned with specific functional areas and proponents within restationing processes.
6) 1 integrated software product to facilitate use of STO component products
7) Software, reports and analyses transitioned to CAA

APPENDIX A: SIGNED TRANSITION AGREEMENTS

DEPARTMENT OF THE ARMY
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CECER-CVT

TECHNOLOGY TRANSITION AGREEMENT (TTA)
BETWEEN
U.S. ARMY CENTER FOR ARMY ANALYSIS (CAA)
AND
U.S. ARMY ENGINEER RESEARCH DEVELOPMENT CENTER (ERDC)

SUBJECT: Transition of Army US-Wide Climate Impact Analyses and Tools

1. Overview

Army stationing analyses inform the Army decisions with long-term consequences including the acquisition of property and construction of infrastructure, facilities, and ranges. The Army is currently using land, buildings, airspace, roads, and power systems established decades ago. Base Realignment and Closure exercises have allowed the Army to re-optimize the use of natural and built infrastructure to more cost-effectively support the mission of defending the nation. As the time between these exercises increase, the Army is under increasing pressure to ensure that optimization analyses look further into the future to minimize the potential for maintaining unneeded infrastructure in the future.

The U.S. Army Center for Army Analysis (CAA)uses a variety of tools and analyses to support the identification of optimal stationing recommendations. The Military Value Analysis (MVA) approach is used to determine the overall value of nominated installations to provide the capabilities, infrastructure, and social environment needed to support Army missions. The result of an MVA analysis is a rank ordering of nominated installations with respect to their overall military value in mission support. The Optimal Stationing of Army Forces (OSAF) optimization program matches military units to installations in a manner that minimizes overall long-term costs while meeting minimal mission support requirements. Additional analyses of installations can then be conducted in an ad-hoc manner to ensure that any potential challenge and opportunity associated with an installation's ability to meet mission requirements is considered. Proposed stationing and realignment solutions are then evaluated with the Cost of Base Realignment Actions (COBRA) to allow direct comparison of the costs associated with proposed stationing and alignment solutions.

Historically, stationing analyses have been conducted with the assumption that climate remains constant. Climate is, of course, associated with variable weather patterns, can usher in multi-year periods of drought or excess rain, and can be associated with severe and unusual storm events. But, overall, climate has been considered as a constant in stationing analyses. Beginning with the 2010 Quadrennial Defense Review, this view has profoundly changed. In that document, and reiterated in the 2014 QDR, it is clear that changing climate must be considered in military planning. A recent key finding by the CAN Military Advisory Board states:

> "*Projected climate change impacts inside the borders of the United States will challenge key elements of our National Power and encumber our homeland security. Of particular concern are climate impacts to our military, infrastructure, economic, and social support systems.*"

The U.S. Army Engineer Research Development Center (ERDC) has been conducting research into the impacts and management of climate change. In recent years, this research has involved the development of 1) techniques to identify temperature/precipitation change thresholds that can dramatically affect populations of species at risk; 2) modeling approaches to link climate with hydrology, ecology, and risk analyses; 3) approaches for identifying how the fate and transport of Army waste chemicals on the landscape might change with climate; 4) methods to identify potential consequences of climate change on installation missions; and 5) recommendations for how the Army might centrally and consistently consider climate in long-term installation planning.

A technology transfer agreement (TTA) is a management tool used to ensure successful transitioning of research technology solutions to the warfighter and other ERDC customers. A TTA ensures that users, technology developers, proponents, and the acquisition Program Executive Office (PEO) or Project Manager (PM) understand what is being developed and the final product(s) that will be provided from the research program. A TTA agreement formalizes and documents the acquisition program's needs for the key technologies being developed and validated against the receiving program's schedule and resources.

CAA and ERDC hereby mutually agree to enter into this TTA for the purpose of defining technology deliverables from the *Integrated Climate Assessment for Army Enterprise Planning* project. The purpose of this TTA is to document a clear understanding between both parties of the conditions required to ensure successful transition of products developed by ERDC to CAA. This technology transfer agreement is in accordance with ERDC OPORD 2012-002 (Program Development and Review Guidance).

2. Description of Products

The ERDC Integrated Climate Assessment for Army Enterprise Planning project is conducting research in how a changing climate might affect stationing and realignment recommendations. The primary purpose is to develop abilities to forecast how installation metrics used to conduct stationing analyses will change in the future, with efforts focused on metrics in these areas: maneuver capacity; firing range capacity; operations and maintenance; and water and energy. There will be four general types of products:

1. Publications documenting the potential for a metric changing in the future as a result of dynamic factors.
2. Publications documenting proposed and tested methods for estimating how metrics will change in the future. This will be pursued only if the potential for a metric changing is determined to be significant.
3. Software developed to calculate metric changes. Software will capture the developed methods for testing against a sample suite of installations, and, where possible, for all US installations.
4. Forecasted metrics. This will involve capturing results from software runs.

Products will be developed in the following areas:

1. Climate forecasts
   Published Global Circulation Model (GCM) results associated with green house gas (GHG) emission scenarios will be processed into US-wide GIS maps of forecasted temperature and precipitation by month averaged over decades, along with a supporting technical report.

2. Training ranges
   Methods developed and tested that forecast how training range throughput will change on Army installations in response to forecasted climate, urban pattern development, and listing of threatened/endangered species.
3. Maneuver ranges
   Methods developed and tested that forecast how maneuver area throughput will change in response to dynamic future conditions. Aspects investigated will include the response to changing temperature and precipitation and the listing of new threatened and endangered species.
4. Water
   Methods developed and tested that forecast installation and regional demand and availability of water.
5. Energy
   Methods developed and tested that forecast installation demand and availability of energy.
6. Maintenance costs
   Methods developed to forecast how maintenance costs are likely to change in response to climate shifts. The primary consideration here will involve forecasting the changes in corrosion rates, which affect the costs of maintaining and replacing equipment.
7. Modifications to the Optimal Stationing of Army Forces (OSAF) to allow time-series changes in metrics to be considered.

3. ERDC Responsibilities:

a. Technology products to be delivered.

(1) Reports that document the potential for changing future conditions associated with climate, urban growth, and listing of species as endangered or threatened to affect future stationing analyses.

(2) Standardized US-wide climate forecast maps.

(3) Reports and journal articles that present approaches for translating climate change forecasts into metrics associated with meeting Army mission goals.

(4) Software tools for forecasting metric changes with respect to climate forecasts.

(5) Data tables indicating how metrics might change through future decades

b. Product Metrics (Exit Criteria or Key Technical Measures of Readiness for Transition).

(1) Measureable Technology Performance Metrics (Exit Criteria):

a) Reports evaluating significant metric change (technical reports and journal articles):

(i) Reports scientifically defend go/no-go decision to develop methods for calculating cause-based metric change.

b) Methods for calculating metric change:

(i) Methods are clearly explained, demonstrated, and defended in technical reports;

(ii) Methods based on novel approaches are defended in journal articles;

(iii) Reports and articles will be approved for publication by CAA.

(iv) Methods are demonstrated for sample installations representing the different regions within the United States.

c) Software for calculating metric change
Software will take many forms and levels of newness. Sample forms include spreadsheets, geographic information system (GIS) scripts, programming languages (e.g. Fortran, C, and Python). In many cases, existing software will be used.

(i) Software will be clearly documented in the form of user manuals.

(ii) Software will ultimately generate values of how installation metrics might change over time, with associated values indicating the uncertainty in those values.

(iii) Software will, if possible, be open source, allowing third party verification.

(iv) Software will be verified to capture published methods accurately.

d) Data results

(i) Data generated from software will be in a format that can be ingested into stationing analyses such as OSAF, MV, and COBRA.

(2) Final Goal/Objective:

The ultimate goal is to 1) document the potential for system changes to alter installation metrics used in stationing analyses and 2) create and document techniques in software that allow for the rapid calculation of how forecasted changes in climate, urban development, and listing of species alter key installation metrics used in stationing analyses.

(3) Projected Transition TRL: 5

c. Technology Product(s) Delivery (month and year).

Product	Delivery Date
Technical Reports: Analyses of approaches for considering how stationing metrics will change in response to dynamic future scenarios	January 2015
OSAF update to allow consideration of changing metrics	June 2015

Software, technical reports, and data to allow forecasting of how stationing metrics will change over time.	September 2015
Final software, technical reports, data, and journal articles to allow forecasting of how stationing metrics will change over time.	September 2016

d. Integration Activities:

(1) ERDC-CERL Program Manager (PM) or designated team members will coordinate with Center for Army Analysis (CAA) stationing staff on a monthly basis to ensure that the efforts remain relevant and timely.

(2) ERDC-CERL PM and team members will participate in stationing strategy meetings.

(3) ERDC-CERL researchers will coordinate their research with subject matter experts (SMEs) that CAA relies on for providing installation metrics.

(4) ERDC-CERL researchers will assist in the generation of metrics to support stationing exercises.

4. Program Manager (CAA CAST) Responsibilities:

a. Integration Strategy:

(1) Statement Of Level Of Commitment:

Upon successful demonstration of key performance requirements (exit criteria), CAA intends to consider all documentation, tools, and data in its requirement to consider climate and changing conditions in future stationing analyses.

(2) Relevant Program Objective Supported.

To support Army senior leaders with decisions on how best to station a trained and ready force, CAA is enhancing its stationing analysis capability. CAA will provide this supporting analysis to senior leaders on Army infrastructure decisions through the CAA Analytic Stationing Team (CAST), a concerted two-year analytical effort that builds upon CAA's stationing analysis experience to create improved analytical models for immediate use. Stationing analyses will be integral to supporting the decisions that Army senior leaders will need to make in the coming years as force reductions, modernization, readiness, and mounting personnel costs make the expense of maintaining current infrastructure fiscally challenging.

CAA recognizes that to properly support Army leaders with future stationing decisions, models used in past strategic stationing efforts, such as the 2005 Defense Base Closure and Realignment Commission (BRAC 05) or the European Infrastructure Consolidation study, must be revisited. The DoD criteria and models used in BRAC 05 require updates in order to respond to new stationing considerations. For example, today's world has a greater emphasis on energy, climate change, sustainability, and infrastructure resilience than in the past; models need to be updated to address todays and future constraints.

(3) Synchronized milestones

Activity	FY14				FY15				FY16			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Training Ranges												
Changes to noise contours	■	■	■	■								
Heat stress and fire risk		■	■	■	■	■	■	■				
Threatened/endangered species									■	■	■	■
Urban growth			■	■	■	■	■	■	■	■	■	■
Maneuver Ranges												
Propose weather-based metric	■	■	■	■	■	■						
Training impacts on vegetation					■	■	■	■				
Implication of new TES listings					■	■	■	■				
Software to forecast change					■	■	■	■	■	■	■	■
Water												
Review installation issues	■	■	■	■	■							
Calculate regional water balance				■	■	■	■					
Stationing impacts on water							■	■	■	■	■	■
Energy												
Review installation issues	■	■	■	■	■							
Renewable energy tool					■	■	■					
Forecast installation energy need							■	■	■	■	■	
Electric grid vulnerability									■	■	■	■
Deployment												
Future impacts on deployment					■	■	■	■	■	■	■	■
Maintenance												
Forecast corrosion rate change	■	■	■	■	■	■	■					
Forecast maintenance cost						■	■	■	■	■	■	■

a. Risk Analysis:

(1) Benefit to a Program Manager Capability Development Document.

The Army is required to consider climate in any decisions involving long-term decision consequences. Additionally, as water resources become constrained through overuse and potentially change as a result of climate variability, the need to consider the long-term availability of water is critical in stationing and BRAC analyses. This research will help identify the potential consequences of changing water resources, changing

climate, and changes in the listing of species to the value and utility of Army built and natural infrastructure.

(2) Risk Analysis:

The technical risk is low from a science and technology standpoint. Work on the project has been scheduled in anticipation of a BRAC 2019 exercise. If an earlier BRAC is announced, the work schedule must be reevaluated.

(3) Required contractor to contractor agreements:

None.

5. Review and Change Procedures:

Review and changes will be coordinated through mechanisms defined in Memorandum of Understanding MOU-12-CERL-05. Substantial changes to research products will be documented as changes to this Technology Transfer document.

6. Points of Contact:

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7. Signatures:

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b. Approval

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APPENDIX B: DESCRIPTIONS OF DEMONSTRATIONS

All product reports, models, and software, and data have been transitioned to the Center for Army Analysis for their review and on-going testing in their assessment methodology. Coordination with CAA has been consistent throughout the project with regular meetings monthly or bi-monthly. ERDC participated and presented at 2nd Center for Army Analysis Infrastructure Analytics Workshop in November 2015 and in numerous CAA BRAC Community of Practice workshops to illustrate and demonstrate project models and data. Additional demonstrations of models and data were made to Army G3-5-7 staff, ASA(IEE), and to the Army Environmental Center (AEC). All final products including models, data, and reports were integrated into a common operating software environment for testing and demonstration.

APPENDIX C: BIBLIOGRAPHY

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