Climate-Sensitive Decision-Making in the Department of Defense:

Synthesis of Ongoing Research and Current Recommendations

Prepared by:

Strategic Environmental Research and Development Program

US Department of Defense

April 2016

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Cover Photos, from left to right:

- The southbound lane of I-55 was flooded in several inches of water from the swollen Meramec River. 220th Engineers pumped water off of the interstate using a water distribution system in Arnold, Mo., Dec. 31, 2015.

- Guardsmen use their shovels to cut a line during training with California Department of Forestry and Fire Protection personnel on Camp Roberts, Calif., Aug. 7, 2014.

- Sgt. Jesus Anaya guides a D70 Bulldozer driven by Sgt. Clarence Galassini on a county road outside the small town of Dexter in southeast New Mexico. These New Mexico Guardsmen from the 920th Engineering Company based in Roswell use heavy equipment to help clear out the snow packed roads in and around the Roswell area. (Photograph by U.S. Army Sgt. John A Montoya Jr)

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Notwithstanding the above support and use of information from the three research projects, the overarching recommendations and accompanying supporting narrative are derivative and solely the result of conclusions drawn by SERDP.

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Acronyms

AFW	Air Force Weather
BRAC	Base Realignment and Closure
CARSWG	Coastal Assessment Regional Scenario Working Group
DoD	Department of Defense
DOI	Department of the Interior
ERDC	Engineer Research and Development Center
EWL	Extreme Water Level
GAO	Government Accountability Office
GCM	General Circulation Model/Global Climate Model
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
NCA	National Climate Assessment
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
OSD	Office of the Secretary of Defense
PI	Principal Investigator
RC	Resource Conservation and Climate Change
SERDP	Strategic Environmental Research and Development Program
SLR	Sea-Level Rise
TDA	Tactical Decision Aid
UFC	Unified Facilities Criteria
USACE	US Army Corps of Engineers
USDA	US Department of Agriculture
USGS	US Geological Survey

Executive Summary

The Department of Defense (DoD) expects climate change to play a significant role in the Department's ability to fulfill its mission in the future. Climate change and the potential futures it may lead to are already impacting aspects of DoD activities and decisions. In response, the DoD is pursuing a flexible and proactive approach to climate adaptation and resilience by mainstreaming climate change considerations into existing processes. It is doing this by evaluating which activities and decisions are currently affected by weather-related phenomena and how these and others may be sensitive to future climate change: that is, climate-sensitive decisions. In addition, given the breadth of its decisions and the environmental and other settings under which such decisions occur, the DoD has a need for flexible, yet comprehensive, broad scale- and installation-specific vulnerability and impact assessments to determine its current and future levels of resiliency to climate change and what adaptive actions are the most appropriate and cost efficient.

The DoD Strategic and Environmental Research Program (SERDP) has funded research efforts to improve the understanding of frameworks for integrating climate change into decision-making, as well as to identify and characterize methodologies for assessing potential vulnerabilities and impacts posed by climate change. Based on the ongoing research of these projects, SERDP, other Office of the Secretary of Defense (OSD) offices and programs, and the Military Services have learned about useful approaches and gaps in knowledge for effectively implementing climate change–related assessment protocols to support decision-making.

The primary audiences for this report are personnel in the OSD and Military Services at the installation management command level who have oversight of DoD installations and who may commission and use climate vulnerability study results to inform their oversight duties (including meeting the requirements of various Executive Orders and DoD Directives and Instructions). The report also should help mainstream climate information into climate-sensitive DoD decisions, and it should be valuable to other federal and non-federal organizations designing assessments to inform climate-related decisions and working to mainstream climate information into decision-making.

The report has two parts and three main objectives:

- Provide early insights from the ongoing SERDP-funded climate change decision framework studies
- Contribute practical methods and examples relevant to climate change decision frameworks, processes, and implementation
- Make SERDP-based recommendations to the OSD and the Military Services on climate change decision frameworks and mainstreaming use of climate information

To accomplish the first two objectives, the first part of the report is structured around four key topics to provide a logical flow for addressing the objectives: (1) identifying climate-sensitive decisions in the DoD, (2) using frameworks to inform climate-sensitive decisions, (3) incorporating climate information into DoD climate-sensitive decisions, and (4) connecting climate change vulnerability and impact assessments and adaptation responses. Findings on each of these topics are presented based on early insights from ongoing SERDP-funded research on decision

frameworks gleaned from a series of interviews with research principal investigators, review of research materials, and feedback through SERDP-led forums. The second part of the report accomplishes the third objective by providing SERDP's current recommendations to OSD and the Military Services for informing climate-sensitive decision-making in the DoD.

Synthesis of Ongoing Decision Framework Research

Identifying climate-sensitive decisions in the DoD

Climate change has the potential to affect many of the decisions that the DoD makes related to permanent installations involving built and natural infrastructure, training and testing, installation plans and operations, and acquisition and supply chains. These potentially climate-sensitive decisions can affect short-term and long-term activities, the influence can be local to global in geographic scope, and they are made at various levels of governance within the DoD, from installations to the OSD. Identifying the types of decisions that may be climate sensitive will help the DoD to consider approaches or frameworks for integrating climate change into decision-making processes and the information necessary to support those processes.

Key findings regarding climate-sensitive decisions in the DoD:

- Considering potential changes in climate is important for near-term decisions that are difficult to update and have long-term implications: for example, construction of a new building with an expected 50-year design lifetime.
- Weather-related short-term decisions may benefit from adjustments for long-term change in the frequency, intensity, variability, or average conditions associated with weather events.
- Incremental decisions, such as sequential upgrades to infrastructure, may enable updating the data underlying the decision and incorporation of new information through monitoring or other sources of learning. Phased actions provide flexibility in an uncertain environment and allow decision-makers to forego later stages of the effort if not needed. Additional research is needed to better understand which decision types can incorporate flexibility.
- Climate-sensitive decisions within the DoD may have to be considered at multiple levels of governance. In addition, they may affect functionality beyond the scope of the immediate decision. The interpretation of results of an assessment may differ across levels of governance, resulting in different actions.
- Consideration of the domain or sector-specific requirements, regulations, standards, and processes can help define the tolerance for risk and uncertainty and, as a result, the requirements for climate information and appropriate decision frameworks.

Using frameworks to inform climate-sensitive decisions

Existing processes in some parts of the DoD support decision-making in situations that include uncertain information, such as those related to DoD responsibilities for anticipating future mission

requirements. Deep uncertainties in climate information that originate from projecting future greenhouse gas emissions (e.g., mitigation of greenhouse gas emissions, changes in technology, and future socioeconomic changes), climate sensitivity, and natural climate variability, may necessitate new or augmented approaches to decision-making, especially in installation management and planning responsibilities that generally do not employ frameworks to incorporate deep uncertainties in information. The SERDP-funded research is investigating the application of a variety of frameworks for climate-sensitive decisions to help identify climate stressors, impacts, and aspects of systems that may be of concern under a changing climate and to inform decision-making.

Key findings regarding frameworks to inform climate-sensitive decisions:

- The DoD can draw on a variety of existing decision-making frameworks to integrate climate information into decision processes. Frameworks need to facilitate monitoring, evaluation, and redirection as more is learned about climate impacts and their effects on infrastructure and operations.
- Some existing DoD processes may be able to be modified to adequately incorporate considerations of changing climate conditions; others will not be easily modified (due to lack of flexibility to incorporate forward-looking information, associated uncertainties, or other reasons). Using an appropriate decision process should not be assumed to lead to effective outcomes because of the wide variance in interpretation of process implementation or results.
- The DoD can consider available information on phases of assessments to promote efficient use of resources. Additional research may be needed to better understand how to use the results of one phase in subsequent phases. In addition, a phased approach may not be needed, appropriate, or feasible for all decision types. Some decisions may require detailed information at the outset and other decisions may be capable of using only coarse information without having to resort to subsequent detailed analysis.

Incorporating climate information into DoD climate-sensitive decisions

Decisions about how to address climate change can be complex, and obtaining and applying relevant climate information in decisions may be unfamiliar to decision makers who do not have background knowledge or experience with climate change science or policy. In addition, installations located across the United States, its territories, and overseas experience a range of climate conditions; decisions that affect these locations may require information about the local context, including topography, historical local climate, and projected regional changes. This climate and non-climate information may come from a variety of sources, but in some cases information about historical extreme weather events, the associated impacts, and costs may not be available. Available information must be salient to the decision, come from a source that is scientifically credible, and be perceived as legitimate by decision makers and stakeholders.

Key findings regarding incorporating climate information into decision-making:

- Collaboration between climate information producers and providers, DoD decision-makers and practitioners, and others with specialized knowledge of the problem or systems being addressed, provides an effective means to bring the best available, authoritative, and most-relevant climate information to bear on assessments. Additional research will be needed to better understand the options for providing climate services to the DoD.
- Specific metrics used in decision-making that translate assessment information from exposure to risk management improve the communication of assessment results.
- Department of Defense repositories of weather and non-climate data provide a trusted source of information for DoD decision makers, which can positively influence the uptake within the DoD. Additional research will be needed to assess how best to ensure scientific credibility and traceability of climate information that could be included in these or other authoritative repositories.
- Tracking of key weather/climate-related variables and their cause and effect relationships to impacts (e.g., lost training days, damage to infrastructure, or cancelation of a test mission) is an important aspect of an adaptive approach to climate change assessment and response that OSD and the Military Services should consider to formally adopt as appropriate.

Connecting climate change vulnerability and impact assessments and adaptation responses

The outputs of a climate vulnerability or impact assessment can help inform the development, evaluation, and selection of adaptive responses. In some instances, it may be appropriate to plan adaptive responses simultaneously with the assessment, depending on the type or scope of decision at stake, or decision framework. When faced with the choice of responses, decision-makers can benefit from understanding whether the addition of more information can improve the adaptive responses and if the benefit to the response outweighs the effort needed to collect, process, or wait for additional information. Decisions to act should not be delayed due to uncertain information.

Key findings regarding climate decision framework connections to adaptation responses:

- The variety of decision frameworks means that different approaches are available to connect climate vulnerability and impact assessment results with adaptation actions. A phased approach to vulnerability and impact assessments supports the alignment of the assessment outputs with the information requirements of adaptation actions. Decision-makers should be prepared to move forward with action despite uncertainties that may persist in climate vulnerability and impact assessment results

Current SERDP Recommendations for Informing Climate-Sensitive Decision-Making in the Department of Defense

Specific recommendations are grouped according to the structure of the synthesis section of the report. A brief narrative is included with each recommendation, which are also described in greater detail in the main body of the report.

Identifying climate-sensitive decisions in the DoD

Recommendation 1: Understand the characteristics of the decision and how it might be affected by current weather and future climate change. The DoD is faced with a range of decisions that are affected by weather today. These and additional decisions may be affected by future climate change. Our understanding of current impacts can be a bridge to the realization that climate change in large measure will exacerbate most of these impacts in a negative manner and create new, often adverse, impacts.

Using frameworks to inform climate-sensitive decisions

Recommendation 2: Embrace decision frameworks that foster robust decisions under uncertainty. Climate change poses unique challenges to the decision-making process. Because of the inherent uncertainties associated with future climate, traditional predict-then-act or reliance on a most likely future approach are in most cases insufficient. Moreover, because climate change also has elements of non-stationarity, past climate regimes are not necessarily guides to future climate. Robust approaches should be pursued that involve the use of multiple plausible futures, or scenarios, against which to assess the potential consequences of climate change. Depending on the circumstances, scenarios can be considered at different points within the decision process.

Recommendation 3: Use existing decision processes to the extent feasible; however, recognize that some modifications may be necessary to appropriately integrate the use of climate change information. The Department has recognized that climate changes potentially affects almost everything it does and that its consideration should be integrated into extant decision processes and not stove-piped as an isolated element. Existing assessment and other decision processes, however, may require modification to incorporate the unique nature of climate information and the uncertainties involved.

Recommendation 4: Incorporate appropriate monitoring of linked climate-related variables and effects into key decision processes. Although it may be possible to make anecdotal statements about weather and its impact on mission and assets, the DoD often lacks explicit processes to document when and to what degree weather precludes a mission at its enduring installations. To fully understand the implications of climate change and how it may change over time, OSD and the Military Services should identify the key climate-related variables and their effects that should be tracked and documented over time to ensure mission sustainability. Additional information that could be tracked includes the sensitivity and adaptive capacity of the mission or asset to climate-related phenomena. Such monitoring should take advantage of existing processes: for example, taking current range (testing and training) use planning processes and adding and documenting

information on appropriate climate-related variables that cause mission degradation and when this occurs and why.

Incorporating climate information into DoD climate-sensitive decisions

Recommendation 5: Match the level of assessment to the decision being made and the availability of supporting information. A key lesson that SERDP has learned through its funded research on assessment methodologies is that the approach needs to be flexible and may involve several levels of assessment. This reflects the understanding that depending on the level of detail needed to support a decision, the assessment itself can be complicated, time-consuming, and costly. As a result, a nested approach is advised that starts with understanding current vulnerabilities (i.e., a baseline assessment) and progresses through a series of "screens" whose aim is to use ever more refined information to assess vulnerabilities and impacts, while, if possible, identifying potential adaptive responses. No specific number of assessment levels is offered. The number should be driven by the goal to minimize the "costs" involved in ruling out what is truly not vulnerable versus what may be vulnerable at each level, so that ultimately resources are focused on those decisions and associated assets for which some degree of an adaptive response is necessary and avoiding the collection and analysis of costly data sets that may be unnecessary at higher screening levels.

Recommendation 6. Use climate information only from trusted sources that is authoritative and has been appropriately documented with respect to its skill and intended and appropriate uses. Climate information is more than the raw data resulting from the output of a climate model. It includes deciding the appropriate risk-based framing to use (i.e., bounding scenarios) when applying the information for assessment and adaptive response purposes, the appropriate selection of global climate models and downscaling approaches, and the actual resultant data sets and whether they have been appropriately verified for the intended use. The National Climate Assessment has been an appropriate authoritative source for identifying which bounding scenarios to use for assessment purposes and should continue to be so in the future. The DoD-led Coastal Assessment Regional Scenario Working Group is an appropriate authoritative source for sea-level rise and extreme water level scenarios that the DoD should consider for application. Identification of authoritative downscaled data products is an emerging need. The Department should follow developments here closely and plan to engage with the rest of the federal community in seeking to identify and use authoritative data products, whose skill and appropriate usage for decision-making (versus research) have been appropriately documented. In addition, the Department should be clear about its climate information needs to ensure that the producers and providers of climate information understand that need and can respond accordingly.

Connecting climate change vulnerability and impact assessments and adaptation responses

Recommendation 7: Use an adaptive approach whenever possible that links assessments and responses in an iterative, phased process. Decisions made with respect to climate change are sensitive to the type of decision, the timeframe over which the decision needs to be effective, the expected level of performance over different future conditions, and the degree of tolerance for risk associated with the decision. For DoD, the decision also may be sensitive to governance level within

the Department, dependent on its implications at the installation level versus the command, Military Service, and OSD levels. Some decisions may be difficult to reverse once made and if the decision is risk-adverse (e.g., may have an unacceptable impact on mission if not robust against all potential future climates) may need to be robust at the outset to worst-case conditions. In many cases, however, decisions may be capable of a phased approach, in which protection against current and potential near-term climate conditions is achieved while preserving the capability to pursue options that are protective against the long-term risks. This approach may reduce the costs of adaptation should worst-case conditions fail to materialize; however, it requires a commitment by OSD and Military Service leadership to (1) continue to monitor the evolving understanding and realization of the changing climate and its implications and (2) adjust the decision over time based on the preceding. As a result, in a phased adaptive approach the decision process is iterative.

Recommendation 8: Enhance the science-policy interface that recognizes the complexities of translating climate science into useful information (i.e., actionable science) for decision-making and its iterative nature. As with the response to climate change, the interaction (dialogue) between the policy-maker, scientific community, and the practitioner (implementer) must be adaptive and iterative. The scientific community in this regard involves both the producers of scientific information and those that translate it into actionable science. Policy-makers must understand the implications of the science on their policy choices and the practitioner needs to know how to implement the science-informed policy choices. The Department should pursue organizational and policy choices that recognize and enhance the science-policy interface and its role in ensuring an appropriate, scientifically defensible, and consistent use of climate science across DoD.

2. Introduction and Background

The Department of Defense (DoD) expects climate change to play a significant role in the Department's ability to fulfill its mission in the future. Climate change already being experienced and the potential futures it may lead to are impacting aspects of DoD activities and decisions. Examples of current and future impacts on the DoD include increased need for capabilities and capacity in the Arctic region, an increased number of "black flag" days (suspended outdoor training), and increased fire hazard days (DoD 2014). In addition, many DoD military installations are located in coastal areas and also may be subject to impacts from sea-level rise (SLR), storm surge, and high winds from strong storms (DoD 2014; SERDP 2013).

The DoD is taking a proactive, flexible approach to vulnerability assessment and adaptation planning for potential impacts from climate change. A key element of the DoD approach is mainstreaming climate change considerations into existing processes (DoD 2014). It is doing this by evaluating which activities and decisions are currently affected by weather-related phenomena and how these and others may be sensitive to future climate change: that is, climate-sensitive decisions. The DoD is responsible for a diverse and complex mission and scope of operations, which are informed by a wide array of processes. These operational and planning processes provide an opportunity to the DoD to integrate climate change risks and opportunities to enhance the resilience of DoD mission (DoD 2014). In addition, the DoD regularly employs vulnerability and risk assessments as part of standard operations, which may be able to support aspects of a risk-based approach to evaluating potential climate change impacts and opportunities.

The DoD has stated that more comprehensive and region- or installation-specific vulnerability assessments than currently completed are needed to determine what adaptive responses are the most appropriate (DoD 2014). Although the DoD aims to incorporate the best available science into its approach, climate change poses a challenge to many existing decision-making processes, due in part to the deep uncertainties associated with future climate conditions and a lack of information regarding the sensitivity and adaptive capacity of systems to climate stressors.

The DoD Strategic and Environmental Research Program (SERDP) has funded research efforts to improve the understanding of frameworks for integrating climate change into decision-making, as well as methods to identify and characterize vulnerabilities to climate change. As a result of these projects, SERDP, other Office of the Secretary of Defense (OSD) offices and programs, and the Military Services have learned a number of important lessons about the gaps in our knowledge currently constraining DoD policy makers and managers from cost efficiently and effectively implementing climate change–related assessment protocols.

This report is designed to support the OSD and Military Services in planning and conducting climate change–related assessments that are intended to inform decision-making. The report also should support DoD's need to mainstream climate information into climate-sensitive decisions to reduce potential adverse impacts of climate change to installation infrastructure, readiness, and operations, while taking advantage of opportunities presented by climate change.

The report has three main objectives:

1. Provide early insights from the ongoing SERDP climate change decision framework studies
2. Contribute practical methods and examples relevant to climate change decision frameworks, processes, and implementation
3. Make SERDP-based recommendations to OSD and the Military Services on climate change decision frameworks and mainstreaming use of climate information

To accomplish the first two objectives, the first part of the report is structured around four key topic areas. Following the introduction and background (this section), Section 2 provides perspective on attributes for identifying climate-sensitive decisions in the DoD. Section 3 discusses a variety of frameworks that are available to inform climate-sensitive decisions. Section 4 addresses incorporating climate information into DoD climate-sensitive decisions. Section 5 highlights connections between climate vulnerability and impact assessments and adaptation responses. Findings on each of these topics are presented based on early insights from three ongoing or recently completed SERDP-funded research projects on decision frameworks. The report includes callout boxes on the projects to highlight recent or ongoing work that provides the reader with specific examples of decision frameworks, the information utilized within those frameworks, and the application to DoD decision-making. The second part of the report accomplishes the third objective by providing SERDP's current recommendations to OSD and the Military Services for informing climate-sensitive decision-making in the DoD.

The primary audiences for this report are personnel in the OSD and Military Services at the installation management command and headquarters levels who have oversight of DoD installations and who may commission and use climate vulnerability and impact study results to inform their oversight duties. This may include meeting requirements of Executive Orders (i.e., Executive Orders 13514 and 13653) and DoD Directives (DoD 2016). The information provided through this report should be valuable to other public or private organizations designing assessments to inform climate-related decisions and working to mainstream climate information into decision-making.

This report has been developed through a process designed to engage SERDP-funded researchers, while trying to minimize potential disruptions to the normal research process and timeline. The report draws upon a review of progress updates through written materials and oral presentations provided by the research teams to SERDP, as well as a review of other pertinent background literature. In addition, a series of individual and group discussions were held with the researchers to enrich the exchange of perspectives. Information attributable to the research teams is denoted by reference to their SERDP project number, unless the information is otherwise already published. In the latter case, an appropriate citation is included.

Along the way, the OSD and project-related Military Service Liaisons to SERDP provided feedback on the key topics to be addressed in this report and initial progress. The resultant recommendations were developed by SERDP, based upon these sources of input. As a result, the recommendations are derivative and solely the result of conclusions drawn by SERDP. This report

builds on and complements SERDP's earlier report on assessing impacts of climate change on coastal military installations (SERDP 2013).

The approach taken here by SERDP of generating early insights from research that is ongoing and mostly unpublished is atypical; however, it reflects the recognition that the demand for useful climate-related information is growing and cannot be met in a timely matter by the typical scientific publishing cycles. New approaches are needed to meet this demand, as are new frameworks for enhancing the science-policy interface related to climate change. The gulf in understanding that currently exists between the science and its application is real and either can be filled by the "cottage industries" ready to fill the gap or by recognizing that ultimately what is needed is credible, authoritative, and useful information. This report is not the final answer on climate-sensitive decision-making in the DoD, but is a necessary step in enhancing the dialogue between scientists, decision-makers, and practitioners.

3. Identifying Climate-Sensitive Decisions in the DoD

Climate change has the potential to affect many of the decisions that the DoD makes related to permanent installations involving built and natural infrastructure, training and testing, installation plans and operations, and acquisition and supply chains (DoD 2014). These potentially climate-sensitive decisions are made at various levels of governance within the DoD, from installations to the OSD. They can affect short-term and long-term activities, and the influence can be local to global in geographic scope. By identifying the types of decisions that may be climate sensitive, the DoD can better consider approaches or frameworks for integrating climate change into decision-making processes and the information necessary to support those processes. This section describes three dimensions for characterizing the types of decision made by the DoD: timeframe, level of governance, and sector. The section also provides specific examples of DoD decisions across these dimensions, and it discusses implications for decision frameworks and climate information.

Climate-sensitive decisions are choices by individuals or organizations, the results of which can be expected to affect climate change or to be affected by climate change and its interactions with ecological, economic, and social systems. Outside of decisions explicitly associated with climate change mitigation and adaptation, many climate-sensitive decisions are not currently recognized by decision-makers as such (NRC 2009). Given the complexity of interactions between timescales of decisions and climate change, this is not surprising, but it does present a challenge to changing business as usual decision-making processes. A priority is to help decision-makers realize how climate change may affect them, identify climate-sensitive decisions, and then support subsequent cost-effective, climate-aware decisions (NRC 2009).

3.1. Decision timeframes

Decisions differ with respect to time, including the time it takes to make a decision and the duration of influence of the decision (see Table 1 for examples), which can be used as a criterion to tailor climate change assessments by matching the temporal scale of the climate information (RC-2232 unpublished information). For example, decisions related to long-lived (50 years or more) infrastructure on installations, such as new barracks or power generation facilities, will require information related to the lifetime of that investment that will be different from the seasonal or annual information needed to inform certain operational decisions, such as staffing for seasonal snow removal on an installation (SERDP 2013). In addition, application of climate information that is not well matched to the decision timeframe may result in faulty conclusions and poor outcomes, such as reduction of service life of key infrastructure designed to be operational over several decades to a century, based on historical or near-term climate conditions.

Some decisions that are made rapidly (i.e., hours to days) are informed by predictions or results of weather conditions, including extreme events. In some cases, operational decisions rely on daily, seasonal, or annual weather information. For example, training schedules at some installations have been delayed in recent years due to ice buildup or wildfires (GAO 2014). In some cases, weather-related vulnerabilities are anticipated to be exacerbated under climate change and, as a result, further complicating decision-making.

Table 1. Examples of potentially climate-sensitive DoD decisions with a period of influence over different time scales.

Months to Years	Years to Decades	Decades or Longer
Short-term planning to improve readiness	Design and maintenance of short-lived infrastructure (e.g., temporary facilities meant to last less than 20 years)	Siting of new installations or design of long-lived infrastructure
Seasonal operations, such as timing of snow-free location-dependent training	Revisions or updates to installation-level water resource management plans	Design of new or upgraded stormwater management systems
Some DoD decisions may have an influence across time scales. For example, a decision to restrict water usage over short periods (i.e., days) due to regional drought conditions could lead to changes in the timing of water infrastructure upgrades or repair decisions that have an influence for years to decades. Source: Adapted from SERDP 2013.		

The amount of time to make decisions—the decision-making process—ranges from short to long time scales. In a practical sense, when considering potential future climate impacts, the amount of time that may be required to plan, review, approve, and implement a decision can be informative to analyzing the prioritization and necessary timing of taking adaptive action. Some decisions are made using processes that take weeks to months (or longer) to complete, especially those related to long-range planning or major capital investments. In addition, from a different perspective, decisions that are meant to address an issue in the near-term and may therefore not involve comprehensive evaluation of long-term effects also may make it difficult to alter future pathways (SERDP 2013); for example, coastal development or shoreline armoring may make lock-in a future development pattern of shoreline hardening, rather than one that incorporates ecosystem-based (i.e., green infrastructure) approaches. Such consequences should be considered within the original decision-making process.

The duration of the impact of the decision and the frequency with which decisions are made also differs (Moser 2012). Some decisions need to be made on a frequent basis (i.e., hourly, daily, weekly). For example, decisions related to water security made at the installation-level may occur frequently to respond to short-term needs, such as operations and maintenance of water supply infrastructure or emergency response planning to extreme weather. Such decisions may rely on weather information; if the policies that guide these actions have influence over long time periods, then climate information may be useful to inform those polices. Some related decisions may be carried out over longer timeframes, such as infrastructure construction (SERDP 2013).

Decisions or actions may have an influence over multiple timescales. For example, a decision to restrict activity in response to heat stress risk happens potentially hourly or at least daily during periods of high temperatures; however, the reduced activity level and changes in training schedules

will influence monthly or yearly actions, as such changes could require significant commitment of resources to modify training facilities and accommodate changes in support personnel scheduling (RC-2204 unpublished information). To meet desired goals, decision-making that occurs across timescales can benefit from being phased or made incrementally (Wilson and McDaniels 2007).

Using a variety of information about potential climate risks, in combination with information about non-climate stressors, can help inform broad decisions that will have significant long-term impacts. Infrequent or irreversible decisions, such as those concerning base closure and realignment (BRAC), could benefit greatly from climate information regarding the long-term conditions at installations (e.g., water supply viability). Climate models are typically used to provide projections over 20 to 100 years, which may be informative for long-term planning and capital investment decisions that will have a long period of influence, although confidence in projections differ by location and climate variable. For example, generally more confidence can be placed in temperature projections than in those for future precipitation (Stocker et al. 2013). In addition, other useful sources of information also exist, such as tree ring records, which can provide additional perspective on extreme values (RC-2204 unpublished information).

3.2. Level of governance relevant to decision

Most DoD decisions are strongly influenced by official guidance in the form of regulations and directives (RC-2204 unpublished information). This guidance often specifies the responsible level of governance in the DoD. A level of governance is the point of authority in the DoD command chain, including installation level, Military Service command level, Military Service Secretariat level, and OSD level. Consideration of the level of governance for a particular climate-related decision can inform the decision framework and assessment process needed to help support it.

Decisions affecting or addressing climate-sensitive issues appear at all levels of governance within the DoD. For example, at the installation level decisions will be needed that consider climate change in the management of natural infrastructure assets, including unique landscapes, ecosystems and habitats, particularly those supporting at-risk species. At the OSD level, decisions will be needed to anticipate demand for department capabilities, such as overseas humanitarian assistance and disaster response missions that may increase over time. See Table 2 for additional examples.

Decisions may have implications for more than one level of governance. Decisions at a lower level may require approval from higher up the command chain, decisions from a higher office may have implications down the command chain, and decisions about mission-related functions at one installation may impact the entire Service or Services that are co-located. For example, the decision processes available for installation-level adaptation to water security challenges can be illustrated in a three-tiered decision level hierarchy: decisions made and executed at the installation levels are required to maintain the day-to-day operations; decisions at the command level respond to medium-term (5–10 year) water issues that affect mission-oriented operations across multiple installations; and decisions at the Military Service headquarters level address water stress to operations across all service-related installations (RC-2204 unpublished information).

Table 2. Examples of potentially climate-sensitive decisions at different levels of DoD governance.

Installation	Command	Military Service	Office of Secretary of Defense
Review and, as needed, modify climate-sensitive management plans and programs; collaborate with state and local officials to integrate responses to extreme weather events and future climate change	Assess the effects of projected climate change on the Command's ability to carry out training and operational activities in the field environment	Assess the effects of projected climate change on the Service's ability to maintain long-term asset management and readiness capabilities across its domain	Assess how the projected effects of climate change may alter operating environments or location of mission assets worldwide
Some decisions may have an influence across levels of governance. For example, a decision by a particular installation to halt training due to extreme weather or changes in climate could affect the Military Service's ability to train personnel in particular skills to support readiness, which might affect planning for maintaining readiness across the DoD.			

Individual installations and their neighboring communities are interconnected (DoD 2014). Some installations' activities depend on built and natural assets outside the DoD's control, such as transportation infrastructure. External long-range planning of those assets, particularly without the consideration of climate change, may alter the conditions in which an installation is operating (SERDP 2013). For example, the conditions of wildland and other natural resources outside an installation contribute to the risk of wildfires. Installation-level Integrated Wildland Fire Management Plans are encouraged to develop regional partnerships to share wildland fire planning and management strategies and resources (RC-2204 unpublished information). This cross-jurisdictional coordination spans governance boundaries, and effective decisions will need to link and facilitate interactions across the boundaries and different decision networks (Moss et al. 2014).

3.3. Sector or focal domain of decision

The DoD Climate Change Adaptation Roadmap (DoD 2014) identifies four key areas that involve potentially climate-sensitive decisions: plans and operations, training and testing, built and natural infrastructure, and acquisition and supply chain. This subsection discusses ways in which the decision sector or domain can inform the type and quality of climate information the decisions may benefit from that can inform the type of decision framework or assessment necessary.

Built and natural infrastructure is at risk from a variety of potential climate change impacts.[1] For built infrastructure, this could include potential impacts to energy, fuel, transportation, water supply, and utility services on installations. Climate information, such as temperature, rainfall patterns, and storm frequency and intensity will need to be considered across this range of sectors.

[1] Decisions related to specific military operations and combat decisions are outside the scope of this report, but such activities may be impacted by climate change (see the DoD Adaptation Roadmap [DoD 2014]).

Some DoD building criteria and planning documents for the built environment, including the Unified Facilities Criteria (UFC) for Installation Master Planning (UFC 2-100-01), UFC for High Performance and Sustainable Building Requirements (UFC 1-200-02), and Floodplain Management Policy have already been revised to require the consideration of changing climate (DoD 2014).

For natural infrastructure—including habitat for at-risk species and ecosystems providing services to installations (e.g., training lands and firing ranges, recreational areas, buffer zones, and services such as water purification and flood control)—the DoD has significant responsibilities, which may be impacted by climate change. The DoD is taking action to address climate change on natural resources, including coordinating with fish and wildlife management agencies to incorporate consideration of impacts in their management (DoD 2014) and requiring consideration of climate change in Natural Resource Management Plans (DoD 2014, GAO 2014).

Planners also need to identify requirements for continuity of service or the ability to deal with disruption to service when making a decision (SERDP 2013). In some cases, minor and temporary disruptions to service are within acceptable standards, but in other cases temporary disruptions are unacceptable. Large magnitude events may cause impacts that are less tolerable, and climate change could cause extreme weather events to occur more frequently and with greater intensity, making these events less tolerable (SERDP 2013). In sectors or for decisions with low risk tolerance (e.g., specific infrastructure failure that may disrupt missions), taking into consideration information regarding low probability but high consequence events and scenarios of future climate that include "worst

IDENTIFYING THRESHOLDS TO SUPPORT DECISION MAKING

For climate-sensitive decisions, thresholds can be defined as the point beyond which an adaptive action is needed because inherent adaptive capacity is exceeded. Thresholds can be applied within decision frameworks to serve as a screen for mission criticality or risk and can potentially be used to determine what climate futures (scenarios) may need to be considered for assessment purposes.

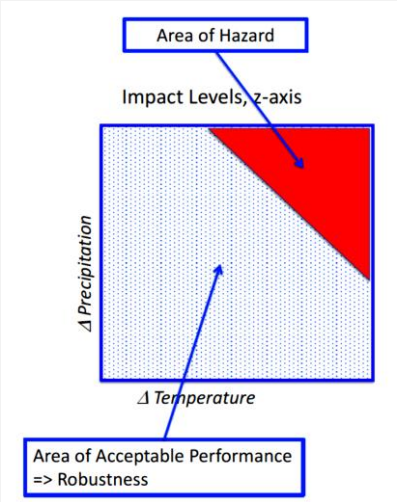


Illustration from climate stress test that utilizes a ΔPrecipitation and ΔTemperature threshold. (RC-2204 unpublished information).

No specific rules exist for setting thresholds and they will differ across sectors, locations, and policies. Information produced through a collaborative process between information providers and decision-makers can identify locally relevant thresholds. These thresholds should consider differences in local climate conditions, as well as differences in local policy context (including policies that concern stakeholders outside of installations), and budgetary, staffing, natural, and infrastructure resources.

The process for identifying appropriate thresholds can be challenging. The system response may be driven by multiple co-occurring events, making attribution to a particular threshold difficult (Moss et al. 2016).

case" conditions may be essential. In situations with greater tolerance for risk or uncertainty (e.g., many decisions that have relatively short-term performance expectations), information on a range of future climate scenarios including "best case" and "worst case" facilitates exploration of solutions that are the most cost-efficient or have the lowest regrets as risk becomes less of a factor.

These impacts, the consequences, and the tolerance for risk can differ across sectors. For example, provision of critical or emergency services (e.g., evacuation routes, electricity supply to key facilities) may be highly averse to any risks from impacts, whereas decisions regarding non-key infrastructure or services (e.g., routine road maintenance, park spaces) may be willing to accommodate a higher level of risk. Explicit evaluation of the criticality of infrastructure, services, or operations can help identify key climate-sensitive decisions. A variety of criteria can be used to evaluate criticality of assets and services, including the role in emergencies, the level of use, and the strategic function (SERDP 2013).

Key findings on identifying climate-related decisions in the DoD

- Considering potential changes in climate is important for near-term decisions that are difficult to update and have long-term implications: for example, construction of a new building with an expected 50-year design lifetime.
- Weather-related short-term decisions may benefit from adjustments for long-term change in the frequency, intensity, variability, or average conditions associated with weather events.
- Incremental decisions, such as sequential upgrades to infrastructure, may enable updating the data underlying the decision and incorporation of new information through monitoring or other sources of learning. Phased actions provide flexibility in an uncertain environment and allow decision makers to forego later stages of the effort if not needed. Additional research is needed to better understand which decision types can incorporate flexibility.
- Climate-related decisions within the DoD may have to be considered at multiple levels of governance. In addition, they may affect functionality beyond the scope of the immediate decision. The interpretation of results of an assessment may differ across levels of governance, resulting in different actions.
- Consideration of the domain or sector-specific requirements, regulations, standards, and processes can help define the tolerance for risk and uncertainty and, as a result, the requirements for climate information and appropriate decision frameworks.

Table 3 provides additional specific examples of potential climate-sensitive DoD decisions across the four key domains identified in the DoD Climate Adaptation Roadmap (DoD 2014), three levels of DoD governance, and several timeframes.

Table 3. Examples of potential climate-sensitive decisions within the DoD.

	Installation	Military Service	Office of Secretary of Defense
Plans and Operations	Short-term planning to improve preparedness	Review/modify total force capacity and capabilities for disaster relief and humanitarian assistance	Review/modify future Base Realignment and Closure (BRAC) and stationing decisions
Testing and Training	Installation-level training schedules and facility use	Review/modify training and testing plans, including the location, frequency, and duration of training and testing rotations	Share use of training and testing assets within the Department and with allies
Built and Natural Infrastructure	Assess the effects of projected climate change on the design, operation, maintenance, and repair of buildings and transportation assets	Review/modify stormwater management and other utility systems across the Service	For overseas installations, coordinate with host nation military and other appropriate organizations
Acquisition and Supply Chain	Assess the effects of projected climate change on key transportation modes and routes	Review and, as needed, modify new and existing weapons systems and their associated maintenance plans	Assess the effects of projected climate change on individual critical suppliers, as well as the cumulative effects across all Department acquisition and supply activities, to identify critical component acquisition and supply chain vulnerabilities and associated cost increases

4. Using Frameworks to Inform Climate-Sensitive Decisions

As the DoD takes action to address potential impacts from climate change across timeframes, level of governance, and sectors, it will need to draw on a variety of frameworks, either implicitly or explicitly, to support decision-making. Existing processes in some parts of the DoD support decision-making in situations that include uncertain information, such as those related to DoD responsibilities for anticipating future mission requirements. Those charged with installation management oversight and operation, however, may not be familiar with such frameworks and deep uncertainties in climate information that originate from future emissions (uncertainty dependent on policy choice and societal action), model uncertainty, and natural climate variability (Hawkins and Sutton 2009). This may necessitate new or augmented approaches to decision-making. Existing DoD decision processes or frameworks that deal with other sources of uncertainty (for example, uncertainty in weather data due to instrument uncertainty, gaps in records, or influence of local conditions) may be able to readily incorporate climate information, whereas others may not have sufficient flexibility to incorporate new types of information and, as a result, will need revision.

A variety of frameworks for climate-sensitive decisions are available to help identify climate stressors, impacts, and aspects of systems that may be of concern under a changing climate and to inform decision-making. This section explores key features of different decision frameworks and those aspects to consider when aligning the decision type and context with the decision framework.

4.1. A variety of decision framework types

A rich body of literature is related to principles for effective climate decision-making processes (see for example NRC 2009, 2010; and Melillo et al. 2014 for reviews). Several common principles emerge from this literature with regard to effective decision-making processes, including using an adaptive and iterative process, clearly defining the problem and issue at the outset, engaging stakeholders to define decision criteria and objectives, incorporation of salient, credible, and legitimate information, evaluation of options, and monitoring to enable further iteration based on effectiveness and learning over time (Melillo et al. 2014). Figure 1 presents a stylized version of such a decision process.

Although idealized frameworks exist, the details for the way an iterative decision process that is designed to manage risks is carried out can differ. In particular, a variety of ways have been developed to use different types of available information in a framework. These include deterministic, decision analytic, robust solution, and scenario planning approaches, as discussed below (see Table 4).

Deterministic approach: Many traditional decision-making processes rely on a deterministic approach that requires prediction of the most likely future conditions and then selection of the best action for that future. This type of approach can be relatively easy to implement and can provide insights for more detailed analyses. For climate-sensitive decisions, however, uncertainties in climate information make meaningful prediction with accuracy unlikely, especially at long time scales; as a result, other approaches are more appropriate.

Figure 1. This illustration highlights several stages of a general framework for resilience planning and implementation. Source: http://toolkit.climate.gov/.

Table 4. A basic characterization of common decision frameworks (adapted from Weaver et al. 2013).

Approach Type	General Method
Deterministic	Use a "best-guess" future, attempting to design the best policy for that future; sometimes referred to as "predict then act."
Decision analytic with probabilistic considerations	Maximize expected utility, often ranking alternative policy options contingent on the best-estimate probability distribution to suggest a single best option.
Robust solutions	Minimize regret under particular futures, suggesting a set of choices that perform reasonably well compared to alternatives across a wide range of future scenarios.
Scenario planning	Use descriptions of plausible futures to help planners better prepare for surprises. Scenarios can be either value-based or exploratory, or have aspects of both.

Decision analytic approach: In instances in which little predictive certainty is present, but probabilistic or likelihood information is available, decision-making can benefit from a risk management decision-making framework that considers multiple future states (e.g., CCSP 2008; Hallegatte et al. 2012; Weaver et al. 2013). In a climate change context, a probabilistic framework implies developing best estimates of the probabilities of different consequences of climate change. This type of probabilistic framework often will include sensitivity analysis to support decision choice by providing further insight into the significance of the probability estimates or underlying

model uncertainty (NRC 2009). Many engineering design decisions consider probabilistic information regarding future events, such as the probability of extreme rainfall or runoff, as part of the risk management approach. Although climate science generally does not assign probabilities to different plausible future emissions pathways, decisions may be able to draw on probabilities of climate impacts that are conditioned on the emissions pathways or scenarios (Lempert et al. 2004). Note, however, that such contingent probabilities do not eliminate the underlying uncertainties tied to future emissions.

Robust solutions approach: Probabilistic information about future climate conditions may not be available or possible, especially under conditions of deep uncertainty with regard to greenhouse gas emissions and societal response (Dessai and Hulme 2004). Frameworks that seek robust solutions aim to identify decisions that perform well over a wide range of potential futures, without necessarily including probabilistic information (Weaver et al. 2013). Formal methods have been developed, including Robust Decision-Making (see for example Lempert and Collins 2007), Eco-Engineering Decision Scaling (Poff et al. 2016), and others (Wilby and Dessai 2010), which have potential to support DoD decisions.

Scenario planning approaches: Scenario planning methods also are used to support decision-making, especially when disparate sources and types of information (including climate and non-climate information) have a bearing on the decision (CCSP 2008; National Park Service 2013; SERDP 2013). Scenario planning employs a variety of information about potential futures to inform a small set of plausible storylines that can aid decision-making. Scenarios can be prescriptive and explicitly values-based, in which they describe a future that only can be realized through particular policy actions. Scenarios also may be exploratory in nature to pose "what if" questions that aid decision-making (Weaver et al. 2013). For example, scenarios can be employed to analyze potential installation development activities that would require consideration of not only future climate, but also changes in community demographics, future policy changes, changes in budgetary or economic conditions, among others. Scenario planning approaches may be used in combination with other decision frameworks, but traditional scenario planning methods may not have specific decision application and will not be informative as to the probability of particular futures (Weaver et al. 2013).

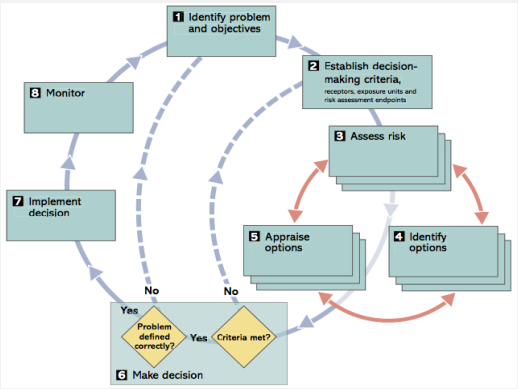
When it comes to making decisions within the DoD, many decision-making processes currently are practiced. For example, processes exist to support crisis management and emergency preparedness, energy management, and infrastructure investment priorities. Few existing DoD processes or guidance, however, such as installation emergency planning checklists or the Unified Facilities Criteria, were specifically designed to consider changing climate conditions and modifications to these existing frameworks and the governing policy direction will likely be needed. Modifications to existing processes or guidance may include updating information analyzed to include future conditions, updating terminology used within the analysis to align with new sources of climate information, and explicitly adding iteration or monitoring to the process. Some existing processes or guidance may require adjusting the implicit or explicit decision framework to be able to incorporate uncertain future climate information. In some cases, existing processes may not be flexible enough to facilitate such changes and entirely new frameworks may be necessary. Research

RC-2232: Climate Change Impacts and Adaptation on Southwestern DoD Facilities

Project locations: Naval Base Coronado, CA; Fort Huachuca, AZ; Barry Goldwater Range East and West, AZ

Project objective: The objective of this project is to engage DoD managers through interviews, workshops, and case-study pilots across a diverse range of DoD operations in the Southwest and develop robust approaches to climate change risk assessment, risk management and adaptation, all of which are supported by a set of climate adaptation tools that can be used across DoD operations. The approach combines social and biophysical sciences to first elucidate DoD management needs and then develop tools to help DoD access and use the most relevant and up-to-date climate data available. This process also emphasizes capacity building and network building (both within and outside DoD) so DoD personnel will continually be able to assess new climate threats as climate science and information evolve and make adaptive decisions in the face of a changing climate with associated uncertainties.

General description of decision framework tested as part of project: The climate change risk assessment approach provides a "tier 1" screening-level analysis of risks to an installation's function and mission caused by physical changes in climate conditions, along with consideration of non-climate factors such as interactions with neighboring landholders. It is intended to help decision makers understand the key changes in climate that are of relevance to the installation and identify informational needs across DoD operations to build adaptive capacity. It is important to stress that by risk screening, we mean a high-level analysis at the installation level, based solely on a one-day workshop and not detailed one-to-one consultation activities with operational, managerial, and financial experts. In order to increase the specificity of the risks identified for individual installations, a more detailed assessment would need to take place, employing extensive consultation, spatial analysis tools, and sensitivity and exposure analyses, among other methods. This type of detailed assessment would provide the level of granularity needed to begin identifying the priority risks related to mission success.



Decision-Making Framework for Addressing Climate Change (Source: Willows and Connell [2003])

This framework is consistent with the key principles of user-engaged science for three reasons:

1. It is an iterative process, which incorporates feedback at a number of stages. The circular nature of the framework represents the fact that climate change risk management is a continual process that will need to adapt as new evidence and policy emerges.
2. It is flexible in terms of complexity. Certain stages (3, 4, and 5) are tiered, allowing the decision maker to identify, screen, prioritize and evaluate climate and non-climate risks and options, before deciding whether more detailed risk assessments and options appraisals are required. This helps prevent unnecessary costs by avoiding the immediate use of complicated decision making and quantitative assessment methods. This tiered approach lends itself well to the "bottom-up" method of making robust decisions today in the face of an uncertain future climate. The focus is initially placed on finding those adaptation options that reduce vulnerability to past and present climate variability (as well as other "non-climatic pressures"). If the lifetime of a project, infrastructure, or resource management strategy spans several decades, climate scenarios can be used to test and appraise whether the options continue to provide the desired level of protection (Wilby and Dessai 2010). If they fail then decisions can be made to adjust the options now such that they stand up to the range of future climates, or, undertake managed / incremental adaptation over a period of time, allowing new information to inform revisions and upgrades to the adaptation options.
3. It emphasizes the importance of an open, collaborative approach to decision-making. The framework stresses the importance of taking into account the legitimate interests of stakeholder and affected parties. By encouraging active participation, the risk of overlooking potential impacts, and of failing to identify adaptation-constraining decisions will be minimized. This will also ensure that differences in the perception of risks and values are fully explored within the risk assessment and decision appraisal process. (*Continued on next page*.)

We have developed a tailored framework for user engaged climate change risk assessment on DoD facilities to guide our initial interactions with pilot DoD facilities. Although our framework maps onto the general climate change risk assessment framework above [see figure], and is informed from the bottom up by experiences we have had with user-engaged climate science in a variety of contexts (e.g., Cross et al. 2015; Garfin et al. 2016; Jacobs et al. 2005; Wall et al. 2015), its utility needs to be tested within the specific context of DoD facilities. In this regard, we have learned the importance of providing incentives, such as detailed climate change assessments and applied impacts modeling, to DoD decision makers, in order to illustrate the relevance of climate change to both their immediate and future decisions. Consequently, in our engagements with Naval Base Coronado and Fort Huachuca, we have focused our research on their requests for research that models changes to future vegetation, fire, and flood conditions. This has allowed us to more clearly and viscerally connect their immediate concerns and actions with the implications of potential future climate changes. This approach also has opened the door to further discussion of climate change in relation to other installation-level decisions.

General types of DoD decisions/actions or specific decisions/actions informed directly through the project:

- Mitigating projected climate change effects on vegetation and fire at Fort Huachuca
- Quantifying projected changes in fire-related flood risk at Fort Huachuca
- Guidance, from assessments of international defense, industrial, and business practice, on effective mainstreaming and other practices for building organizational climate change resilience
- Incorporating climate change adaptation into standard operating procedures, at multiple scales of DoD decision-making
- Alternative approaches, advantages, and pitfalls of integrating climate change risk management considerations into non-combat activities, such as facilities management, base planning, and infrastructure management

Key types of climate information used in decision framework:

- At the outset of the project, we based our future scenarios on projections from the National Climate Assessment (Walsh et al. 2014) and the Assessment of Climate Change in the Southwest United States (Garfin et al. 2013), respectively. Synthesis reports like these are inherently cautious in the information that they provide, due to their reliance on previously published, peer-reviewed literature, and on a process that favors consensus among many report authors and reviewers. We relied upon these sources, because they have been well-vetted, are perceived by many in the scientific community as credible and authoritative, and both provided timely and easy-to-access data and analyses suitable as a point of departure for discussions of adaptation to potential climate changes.
- Both sources of information use statistically downscaled climate projections,, based on the World Climate Research Programme's Coupled Model Intercomparison Project, phase 3 (CMIP3) multi-model dataset (Meehl et al. 2007), as well as dynamically downscaled projections (Mearns et al. 2013). These sources use two future global greenhouse gas (GHG) emissions scenarios, A2 (continued high rates of GHG emissions) and B1 (substantially reduced rates of GHG emissions) (Nakićenović and Swart 2000). These provide divergent possible futures, in order to contrast divergent possible futures, which is important for assessment dialogues.
- As the project has progressed, and new climate projections have become easily accessible, we have incorporated statistically downscaled CMIP5projections, with an RCP 8.5 emissions scenario, (a) to demonstrate a wider spectrum of uncertainty, and (b) as applied to modeling future vegetation, fire, and flood risks, such as we have done at Fort Huachuca.

Benefits of project: Although this project focuses on the Southwest region where climate change impacts are expected to be particularly acute, the approach builds capacity to enable climate-related decision-making more broadly across DoD operations, as well with other federal partners. The project will (1) provide vulnerability and needs assessments, (2) bring key managers up to speed on the state of the science, (3) develop university–DoD networks for climate services and communication, (4) deliver user-requested decision support products that work under a range of uncertainties to connect current and future decisions and open the door to broader discussions of climate change decision-making, and (5) provide guidance on transferable and sustainable processes that take into account DoD culture and practice, for creating resilience in the face of climatic change on DoD installations.

Anticipated project completion: 2016

Principal investigator:
Gregg Garfin
University of Arizona

that explicitly analyzes the appropriate use and potential modifications to existing processes or guidance has been limited to date.

4.2. Climate change vulnerability assessment: concepts, levels of analysis, frameworks, and methods

Although decision frameworks are used to support the general decision-making process, assessments provide information that can be used to inform the process by capturing climate-specific vulnerabilities. Climate vulnerability assessments commonly consider three components: exposure, sensitivity, and adaptive capacity. Exposure refers to the extent to which something is in contact with or subject to climate variations or changes, and sensitivity is generally described as the degree to which a system may be affected, either adversely or beneficially, by climate variability or change (Parry et al. 2007). Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, take advantage of opportunities, or cope with consequences (Parry et al. 2007). The information used in assessment of these components can differ across frameworks (see Section 3.1).

Effective climate vulnerability assessments benefit from capturing the unique place-based features that determine how climate interacts with a location's resources and the relative importance of climate change as an environmental stressor (SERDP 2013). At the same time, consistent processes and outputs of vulnerability assessments help achieve comparability across regions. Goal 1 of the DoD Adaptation Roadmap is to: "Identify and assess the effects of climate change on the department" (DoD 2014). Although the DoD (2014) has articulated the desire to use an "iterative assessment process," that is "proactive" and "flexible," to meet this goal, the DoD is at an early stage of implementation.

Although many approaches consider vulnerability to be a function of exposures, sensitivity, and adaptive capacity (e.g., Glick et al. 2011; Parry et al. 2007), recent formulations consider vulnerability to be a product of the system sensitivities and adaptive capacity, with impacts that result from the intersection of vulnerability and specific climate conditions (e.g., IPCC 2014; Moss et al. 2016; see Figure 2). Some frameworks also explicitly consider the potential of an impact to affect the ability to meet a mission or to deliver service, sometimes termed "criticality" or "mission significance" (SERDP 2013; Moss et al. 2016; see Figure2).

Although an understandable desire exists to investigate detailed potential impacts or vulnerabilities at every location in as much detail as possible, this is often neither efficient nor cost-effective. Vulnerability assessments should be conducted in a tiered or phased approach to better target resources where they are needed. Different tiers (levels of detail) of assessments can be used to address the fact that a vulnerability assessment can differ in terms of scope, approach, the nature and criticality of the decisions to be made, degree of risk tolerance, time horizon of the decision, and the cost of the assessment compared to the cost of a response decision. In general, vulnerability assessments should progressively move from less detail to more, focusing on the systems and assets that are both most important and most vulnerable, as revealed by assessments at the less detailed level (SERDP 2013; Moss et al. 2016). In some cases, a screening-level vulnerability assessment (i.e., one that uses relatively coarse information to broadly assess vulnerabilities or

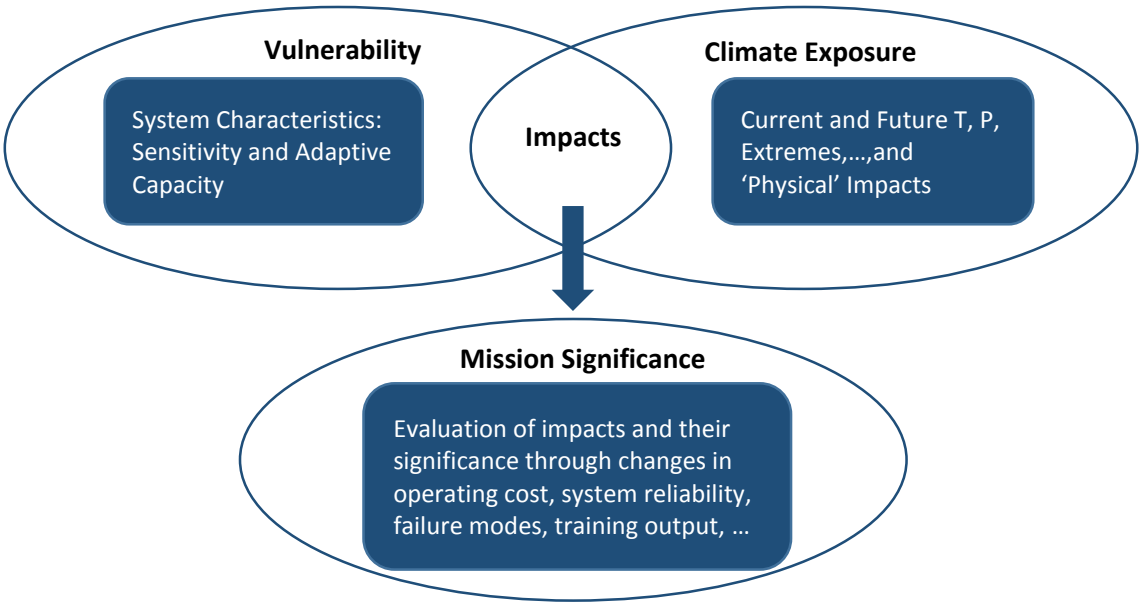


Figure 2. An example of an assessment framework that defines vulnerability as a function of pre-existing conditions based on characteristics of a facility or system, and that includes considerations of mission significance (T=temperature; P=precipitation). Source: Moss et al. 2016.

impacts) may be sufficient to inform decisions. Figure 3 provides an example of one way to characterize these tiers.

A tiered approach to vulnerability assessment, as well as the plan for any needed iteration, can help the DoD ensure efficient use of resources, a focus on installations and missions that are truly vulnerable, and a focus on the outputs of assessments that are relevant to decision-making needs and are defensible. For example, the DoD has begun implementing a phased installation-level vulnerability assessment approach (DoD 2014). This approach began with a vulnerability screening survey to assess current (baseline) installation-specific vulnerabilities to current weather-related exposure and hypothetical ("what if") future climate exposure. Screening of this type can inform the design, prioritization, and implementation of more detailed assessment phases (DoD 2014; Moss et al. 2016), including the use of more detailed future climate scenario information. In addition, for significant vulnerabilities identified by the screening process, the DoD may take immediate adaptive action (GAO 2014). The design of outputs from a particular phase of assessment should consider how they will help determine if additional phases of assessment are needed and how to design the more detailed assessment (see Section 5).

Installation-specific vulnerability assessments can employ a number of frameworks (see the boxes describing RC-2232 and RC-2206, and Moss et al. 2016, for overviews of two potential frameworks). Clear objectives and identification of decision context in the design of the initial phase of assessment are critical. Whatever detailed framework is used, conducting a vulnerability assessment typically requires expertise related to stakeholder engagement, analysis of climate and environmental exposures, and evaluation of climate change impacts and their consequences for mission attainment. In particular, for identifying and applying climate information and performing analysis of potential impacts, expertise from outside the installation, Military Service, or OSD may

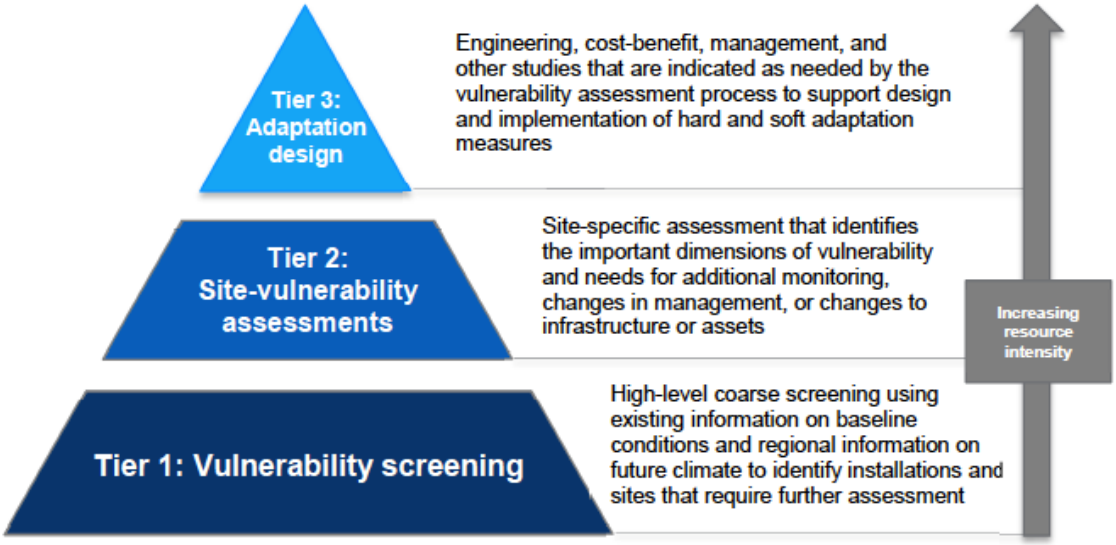


Figure 3. Example of a tiered, multi-criteria approach to vulnerability assessment. Source: Moss et al. 2016.

be required. "Stakeholders" and participants can include installation, Military Service, and OSD personnel, external service providers, representatives of other federal agencies, and, depending on the issues to be addressed, members of the surrounding community. Installation vulnerability assessments support adaptation planning. For example, these assessments can indicate the need for changes in management, maintenance, utilization, and other adaptations. A critique of vulnerability assessments is that they can be time consuming and expensive (RC-2204 unpublished information).

In the cases involving complex infrastructure, installation assessments can indicate the need for additional engineering, cost-benefit, management, and other studies. For example, a site assessment may identify vulnerabilities to water resources. Additional detailed hydrologic modeling, projections of water use, and other analyses typically will be needed to explore and plan adaptation options. In cases when installations depend on utility or other systems in the surrounding communities, vulnerabilities to these external networks also will need to be considered. This introduces complexity that can make assessment more time and resource intense.

Another approach for evaluating risks in infrastructure and natural systems is termed "decision scaling" (see box describing RC-2204 and Brown2011; Brown et al. 2012). This approach focuses on first identifying the vulnerabilities of the system being analyzed. Climate change projections are used in the latter stages of analysis to prioritize climate risks; as a result, uncertainties do not overwhelm the initial analysis. In some cases, in which the specific systems at risk have already been identified, decision scaling is effective as a stand-alone method. In others, it can be combined with frameworks such as those developed in RC-2232 and RC-2206.

Assessments also differ by the level of governance at which they are performed. A screening-level assessment may be most appropriate for informing OSD or Military Service decisions, but information to support such assessment requires information about the installations, which may only be available from installation databases or staff. This includes installation-level information on

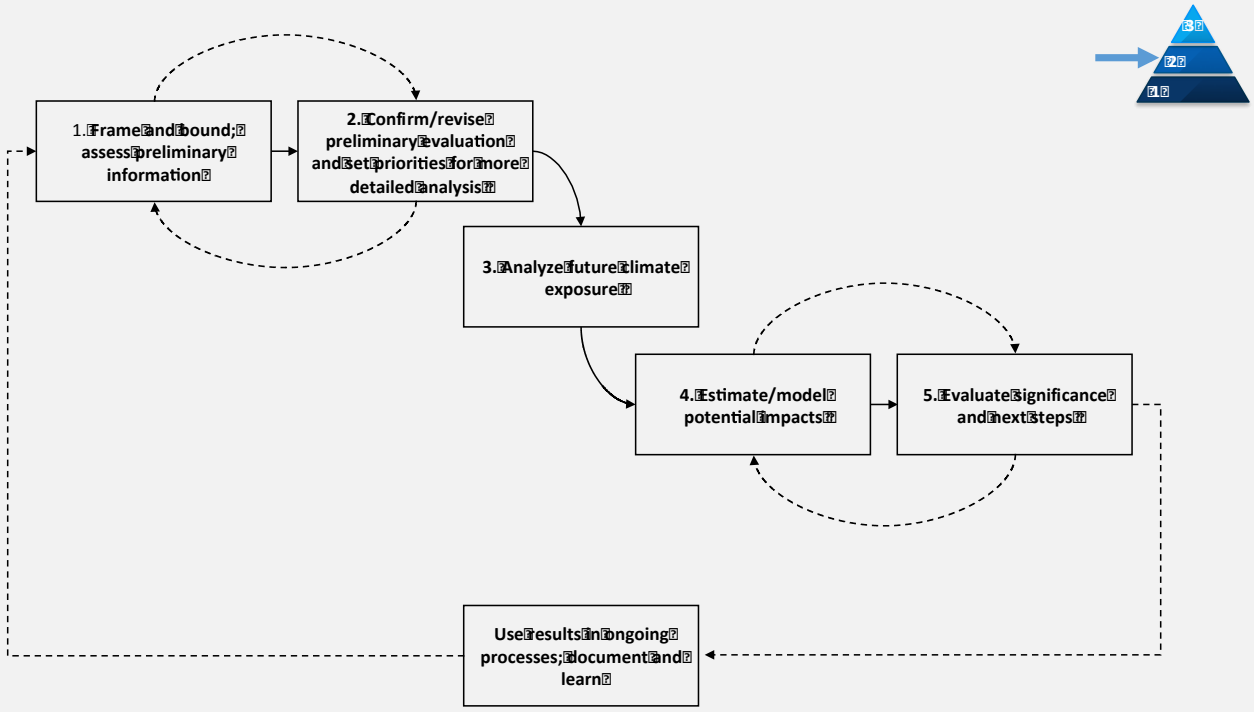
RC-2206: Understanding Data Needs for Vulnerability Assessment and Decision-Making to Manage Vulnerability of DoD Installations to Climate Change

Project locations: Fort Bragg, North Carolina (U.S. Army); Joint Base Langley-Eustis, Virginia (U.S. Air Force and U.S. Army); U.S. Naval Academy, Maryland; Dare County Bombing Range, North Carolina (U.S. Air Force and Navy)

Project objective: The objective of this project is to develop, pilot, and evaluate an approach to assess installation vulnerability tailored to DoD decision-making needs and processes. The following five research questions are addressed:

1. What is the baseline vulnerability of an installation with respect to current extreme climate events and seasonal climate variability?
2. How do decision makers use available information on climate extremes and seasonal variability to manage assets and operations? What additional information would be useful?
3. Using insights from climate models, methods to produce higher resolution climate information, observations, and climate processes research, what information can be provided about future climate for the region in which the facilities are located?
4. What are the vulnerabilities of the pilot installations to potential changes in climate and the implications of these vulnerabilities for readiness and mission attainment?
5. What assessment framework will support comparative evaluation of vulnerability across installations and help DoD personnel establish adaptation priorities?

General description of decision framework tested as part of project: In the pilot assessments, researchers are identifying and examining the current vulnerability of installations to climate changes and extreme weather events and reviewing decision processes to clarify future climate information needs. Assessing baseline vulnerability includes identifying the important assets (including ecosystems), their age and physical condition, and management systems and decision making regarding effects of climate and weather. The researchers use an innovative expert judgment-based approach to provide information on priority impact-relevant climate phenomena (see description of climate information below). Another component of the project explores a wide range of approaches for evaluating potential impacts and their significance, from complex impacts modeling such as use of a high resolution coastal inundation model to estimate location, depth, and duration of flooding from combined storm surge and sea level rise, to more heuristic methods including spatial analysis using GIS to generate statistics on asset characteristics and exposures. These methods provide a perspective on the implications of imposing future climate conditions onto the current conditions and configuration of systems at levels of detail appropriate to a given assessment. Using the experience garnered in the case studies, the project will develop a framework for comparative vulnerability assessments on DoD installations (see figure below), ideas for less-detailed vulnerability screening techniques (figure 3, above), and a typology for cataloguing and guiding development of needed methods. The implications for structuring future assessments to support prioritization of adaptation measures will be analyzed, specifically focusing on decision-support strategies and analytic methods for ongoing infrastructure decision-making processes. Active engagement with DoD and installation personnel is critical to developing decision-support strategies and analytic methods that can be used effectively by these personnel. (*Continued on next page.*)



General types of DoD decisions/actions or specific decisions/actions informed directly through the project: Operational, management, and planning decisions related to training, the built environment, and the natural environment.

Key types of climate and impacts information used in decision framework: The project will integrate climate data and knowledge derived from models, observations, and process research in development of the regional climate outlook described above. The approach guides development of climate information through enhanced understanding of the vulnerabilities and decision-making environments on the pilot installations, as well as information needed to incorporate climate vulnerability considerations into ongoing planning and management processes at higher governance levels. The method for providing climate information will offer more robust understanding of the state of knowledge on the prioritized phenomena than would result from use of any single data source or model and offers the potential to simplify the task of providing basic information commonly needed for assessments at DoD facilities within a particular region. In addition to common research quality data, data sets from the installations have been incorporated into the analysis when of sufficient quality and length. The project also stresses methods to translate climate information into estimates of impacts and significance for mission attainment that can be used in ongoing decision-making processes.

Benefits of project: This project will test methods to gather and analyze installation data needed for assessing vulnerability; identify the types of climate information used and needed by DoD personnel to assess future climate change risks; identify and test needs for methods to model potential impacts; and develop and test methods for evaluating the significance of potential impacts for training and infrastructure management and planning. A coordinated and thorough approach will be developed to assess installation vulnerability tailored to DoD decision making. A typology of methods also will be developed and extended to assess the climate change vulnerability of a range of infrastructure systems.

Project completed: September 2015

Principal investigator:
Dr. Richard Moss
Battelle, Pacific Northwest Division

important decision types and timeframes. Still, the concept of screening level is relative and may be conducted even in the context of an individual installation.

Key findings on frameworks to inform climate-sensitive decisions

- The DoD can draw on a variety of existing decision-making frameworks to integrate climate information into decision processes. Frameworks need to facilitate for monitoring, evaluation, and redirection as more is learned about climate impacts and their effects on infrastructure and operations.
- Some existing DoD processes may be able to be modified to adequately incorporate considerations of changing climate conditions; others will not be easily modified (due to lack of flexibility to incorporate forward-looking information, associated uncertainties, or other reasons). Using an appropriate decision process should not be assumed to lead to effective outcomes because of the wide variance in interpretation of process implementation or results.
- The DoD can consider available information on phases of assessments to promote efficient use of resources. Additional research may be needed to better understand how to use the results of one phase in subsequent phases. In addition, a phased approach may not be needed, appropriate, or feasible for all decision types. Some decisions may require detailed information at the outset and other decisions may be capable of using only coarse information without having to resort to subsequent detailed analysis.

5. Incorporating Climate Information into DoD Climate-Sensitive Decisions

Decisions about how to address climate change can be complex, and decision-makers may need help integrating scientific information into climate-sensitive decisions (Melillo et al. 2014). Obtaining and applying relevant climate information may be unfamiliar to decision-makers who do not have background knowledge or experience with climate. The GAO (2014) found that the modified Unified Facilities Criteria (Master Planning) identifies the National Climate Assessment and the U.S. Global Change Research Program as potential sources of information about how climate change may impact an individual installation. Its discussions, however, with installation officials revealed that some officials do not yet know how to employ the available information sources in their installation-level planning efforts, in part due to lack of experience but also because decision-relevant information for specific installations was not available (GAO 2014). A recent GAO report highlights the pervasive nature of the problem, not just for DoD but also for other federal agencies, as well as state, local, and private sector decision-makers (GAO 2015). It called for a key federal role in providing authoritative climate information and quality assurance guidelines in how to use such information.

Installations located across the United States, its territories, and overseas experience a range of climate conditions. Climate-sensitive decisions for individual installations require information about the local context, including topography, historical local climate, and projected regional changes (SERDP 2013). Information that can support decision-making, in the DoD or other contexts needs to be salient to the decision, come from sources that are scientifically credible, and provided in a way deemed legitimate by decision makers and stakeholders (Cash et al. 2003). Information that meets these criteria may come from a variety of sources, especially given the wide range of climate-sensitive decisions in the DoD (see Section 2); however, ultimately, such information also has to be considered authoritative (GAO 2015). This section focuses on the relationship between climate information providers and decision-makers, and key characteristics of climate information that will form the foundation of this collaborative relationship, as well as the integration of climate and non-climate information to support climate-sensitive decisions.

5.1. Climate information and partnerships to support DoD climate-sensitive decisions

Climate information needs will differ depending on the decision to be informed, as well as the decision framework or assessment approach. The spatial extent, governance level of the decision, and phase of assessment will be important to determining data needs. For example, detailed vulnerability and impact assessments may require the use of downscaled projections at different spatial resolutions for specific climate variables coupled with impacts models or localized process and engineering models, whereas coarser information may be sufficient for assessments by the OSD or beginning phases in an assessment process. In addition, the timescale of the decision or assessment also will be important, and different types of weather/climate information may be needed for time horizons of less than two years, two years to less than 20 years, or greater than 20 years.

CLIMATE OUTLOOKS

"Climate Outlooks" are one approach to providing climate information to decision-makers being tested through SERDP-funded research (RC-2206 used this approach for the mid-Atlantic region). The outlook describes conditions that may interact with facility vulnerabilities to produce impacts. A process of framing the assessments and conducting the initial visits to military installations was used to determine the specific aspects of climate covered. The narrative textual analysis, graphics, and other information contained in the outlook are based on observations, climate model results from several large research projects that compile and compare models results, and other knowledge for the mid-Atlantic from basic climate research on climate conditions and processes. This type of communication, including narrative descriptions of climate conditions have been shown to be effective (PROVIA 2013). The outlook includes confidence ratings that are associated with different findings based on an expert judgment approach to assist decision makers.

This research aims to demonstrate that by integrating and evaluating multiple sources of information, the outlook offers more robust understanding than when any single information source is considered independently. Evaluation of the outlook is ongoing.

Source: Moss et al. 2016.

At a national scale, the Federal Government provides many sources of climate information, including those developed through the Third National Climate Assessment (NCA) process. In addition, the White House-led Climate Data Initiative[2] provides a clearinghouse of available data aimed at supporting climate-related decisions and assessment; however, work on these initiatives is ongoing, and the scientific quality of the appropriateness of the information for specific decisions has not been evaluated (Moss 2015). For SLR, a NOAA-led working group developed a set of global SLR scenarios to support the Third NCA (Parris et al. 2012), and the DoD Coastal Assessment Regional Scenario Working Group (CARSWG) recently developed regionalized SLR and extreme water level scenarios (EWL) for use in coastal vulnerability and impact assessments of military installations worldwide (Hall et al. 2016).[3]

Too much information can lead to paralysis or poor decisions—and some information is "better" than others. It is important that information sources are both credible and useful. In addition, only the information that is most relevant to the assessment or decision should be provided. Depending upon the experience of the decision-maker, filtering out overly technical products or providing explanatory text will be critical. Partnerships with information providers or boundary organizations can assist with this process. Ultimately, the information should enable decision makers to undertake assessments that identify changing risks without having to spend hours sorting through less relevant information. Too little information, however, and one may miss full

[2] See: https://www.data.gov/climate/.
[3] The CARSWG is a multi-agency working group that involves federal and state agencies involved in relevant coastal science and its application.

characterization of key vulnerabilities. In either case, quality control for the information included is crucial.

Accurate projections of future climate conditions and impacts are difficult due to multiple sources of uncertainty, including uncertainty with regard to future levels of greenhouse gas emissions that are linked to demographic and socio-economic futures, available technologies, societal values, and policy choices (Hallegatte et al. 2012). Our scientific knowledge regarding the response of the climate system to increased levels of greenhouse gases is imperfect and an additional source of uncertainty. Natural climate variability, including the inherent randomness in the climate system, contributes to the uncertainty, especially at shorter timescales (Hawkins and Sutton 2009). This uncertainty should not preclude decision-making. Scenarios often are used to inform decisions given this uncertainty, sometimes in support of a more general decision framework (see Section 3.1).

The scientific community relies on scenarios to model the range of plausible future conditions, including greenhouse gas scenarios that drive global climate models to provide projections of possible future climate conditions. In general, the scientific community does not associate probabilities to these greenhouse gas scenarios. Many decision frameworks, however, rely on an understanding of probabilities. Approaches are available that can help to inform probabilities or likelihoods, especially when considering the probability or likelihood of impacts from changes in assumed climate conditions (that is, given a particular climate future what are the likelihoods of specific types of impacts). Expert elicitation of probabilities has been used in some circumstances (see CCSP 2008). In addition, contingent probabilities, which are dependent on a specific choice of emissions scenario and assumptions about climate sensitivity, can be developed (Lempert et al. 2004). In some frameworks, the fraction of projections that indicate "acceptable" conditions can be used to better understand the probability of future outcomes (RC-2204 unpublished information). This remains an active area of research.

Decision makers may need to consider how scenarios can be used in the decision-making process, their relationship to risk tolerance or existing standard and guidance and how to incorporate scenarios of non-climate factors (SERDP 2013). Scenarios can be used to explore a range of potential future climate conditions and levels of impact. The choice of the "upper" scenario (i.e., the one that represents the greatest amount of change or impact) sets the upper bound for conditions to be considered in the decision process and should reflect the risk tolerance of the decision. In situations where decision-makers are risk averse, including plausible scenarios of significant impact can help inform actions to avoid those impacts. A "lower" scenario may be useful to bound the range of potential futures and should be based on scientific evidence (e.g., global SLR will be positive over this century under all plausible emissions scenarios [Meehl et al. 2012]). The timescale over which the decision has influence (see Section 2.1) should be considered in the choice or design of scenarios, as the timescale increases over long periods of time (i.e., greater than 20 years) the choice of emissions scenario increases as a source of uncertainty (Hawkins and Sutton 2009).

In addition to considering multiple scenarios, decisions can be informed by a more complete understanding of the potential range of future climate conditions by using results of multiple

models and scenarios. All climate models differ in some way and use of the range of model outputs (often over several different emissions scenarios) or by running one model using different initial conditions can help to characterize the uncertainty in potential future conditions. Understanding the independence of different climate models from one another; however, and therefore the interpretation of uncertainty represented by the range of outputs, is an active area of research (RC-2204 unpublished information).

In addition, guidance for aligning climate information with decisions remains an active research area. Research funded by SERDP has supported findings that will contribute to a primer on the appropriate use of climate information, in particular downscaled information, for decision-making and impacts research (Kotamarthi et al. 2016). This primer will help those involved in climate-sensitive decision-making processes and impacts research to evaluate their climate information needs and to be better consumers of available climate information. In addition, guidance also exists regarding communicating uncertainty (see CCSP [2008] for review).

Direct engagement between information providers and users throughout the assessment or decision process also can facilitate communication of uncertainty in ways that are meaningful to end users. Figure 4 provides an example of the synergies that can arise through multiple partnerships in support of an assessment at a specific installation location. Such partnerships can draw on a variety of local, regional, or global data sources, and they can provide a foundation for addressing decisions across a range of climate-related impacts.

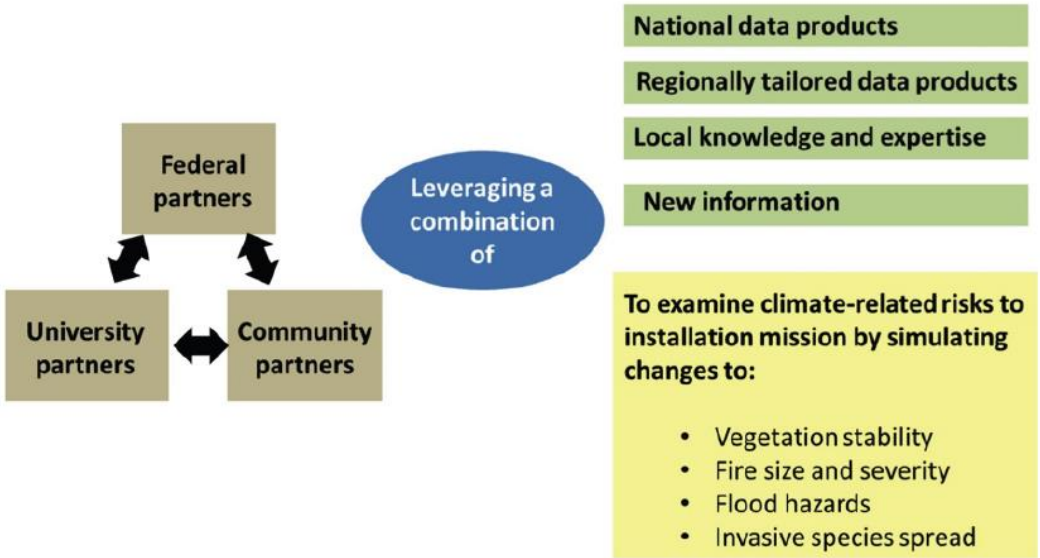


Figure 4. Synergy among multiple partners and products to produce a risk assessment tailored to a specific DoD installation. Source: RC-2232 unpublished information.

For information about projections of climatic conditions over medium to long time scales (i.e., decades to centuries), decision-makers across many parts of the DoD have established relationships with external climate information providers, such as federal agencies and academic institutions

(GAO 2014). For example, the GAO found for some installations interviewed, they lacked installation-level climate data from their military department or another DoD source. As a result, these installations relied on a variety of sources, including other federal agencies and contractors (GAO 2014). The degree to which such relationships have been formed, are regularly utilized, and contribute to actionable results differs from not yet formed to strong examples of success. One way to bring about a more structured approach to user-provider collaboration is to establish formal coordination mechanisms. More importantly, however, is the need to ensure that these relationships are based on the use of credible and authoritative sources of climate information (GAO 2015).

Application of these types of approaches to developing partnerships in the DoD environment has revealed other considerations. For example, the salience of climate change information and issues differs across installations. Installations also often have different geographic settings and missions, which can impact the best approach for engagement. The rotation of military personnel as a regular part of duty assignments poses a challenge for assessment design and implementation to maintain continuity of an engagement and leadership priorities. In some cases, the process may begin as one of one-way information collection, in which those providing climate information support work more explicitly to gather available information that can then be translated and provided in a usable form. In other situations, the engagement might involve a greater degree of two-way information exchange.

Effective collaboration and communication between climate information providers or producers (e.g., Military Service offices, U.S. Global Change Research Program, the NCA, NOAA, USGS, USDA, DOI, other federal agencies, university researchers) and decision-makers is often required to apply results-relevant information to the decision context. Climate information providers bring climate resources and expertise vital for the assessment, and DoD decision-makers provide the context to inform the appropriate information needed. Effective relationships are especially important to address concerns and confusion around the appropriate use and limitations of climate information, types of climate information needed, and uncertainty of future climate projections.

5.2. Non-climate information to support climate vulnerability assessments and DoD decision-making

In addition to climate information, non-climate information is often a critical component of climate vulnerability assessment. Relevant non-climate information may include quantitative and qualitative data, including system characteristics and design specifications that can contribute to vulnerability, information regarding costs of managing impacts, and information on co-benefits or non-market values (e.g., mission continuity, morale). Knowledge of the planning and decision processes that will influence adaptive actions as a result of vulnerability assessment also can be important inputs. Direct engagement with installation personnel who are knowledgeable about context specific factors, such as installation facilities and their operations and conditions, previous impacts from weather extremes, and installation planning, budgets, and contracting processes also are important sources of information about sensitivity and adaptive capacity (Moss et al. 2016). Additional research is needed to refine methods for collecting these types of data that are thorough, accurate, and efficient.

RC-2204: Decision Scaling: A Decision Framework for DoD Climate Risk Assessment and Adaptation Planning

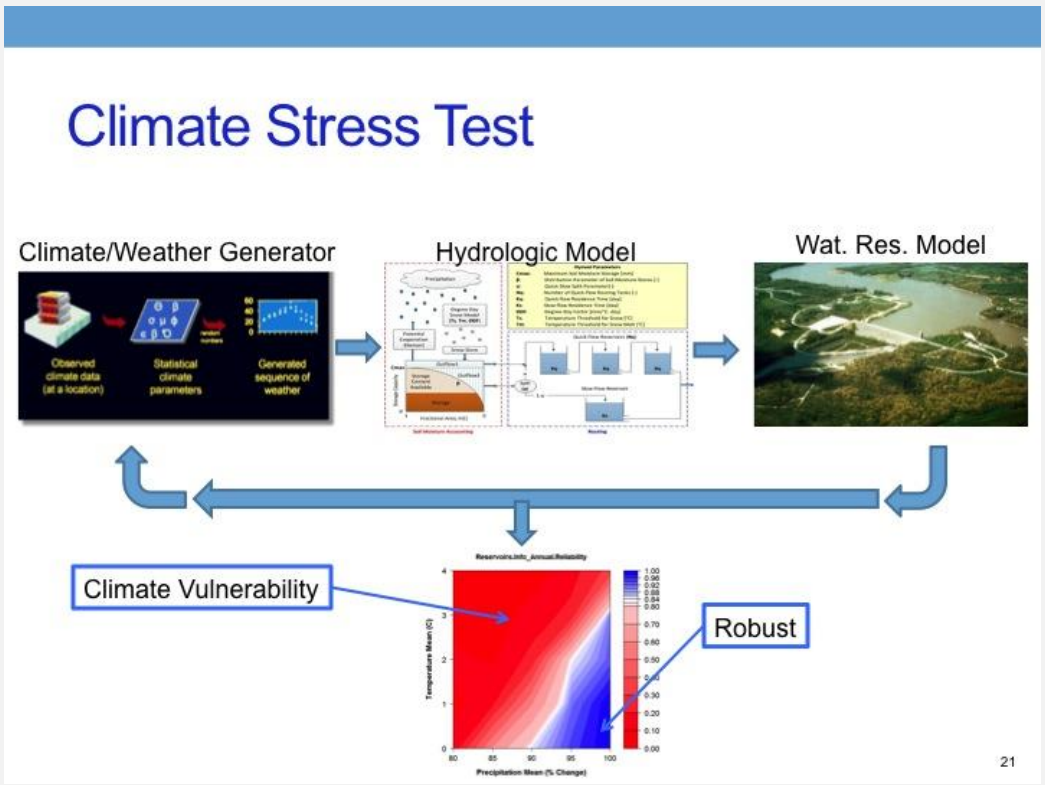
Project locations: Fort Hood, Texas (U.S. Army); Fort Benning, Georgia (U.S. Army); U.S. Air Force Academy, Colorado; Edwards Air Force Base, California

Project objective: The objective of this project is to develop and evaluate a framework for assessing Department of Defense (DoD) relevant climate change risks and for incorporating climate information into decision making. Researchers will demonstrate the framework, which links the insight revealed in bottom-up risk analysis with the climate information produced through top-down modeling. Through this approach termed "decision scaling," the sensitivity of DoD installation decision processes to climate change will be revealed through a bottom-up assessment, producing a summary of climate information needs and a prioritization of climate risks. The results will provide guidance on the use of climate information and alternative approaches for decision making such as robust decision making and adaptive management.

General description of decision framework tested as part of project: The project employs a decision-scaling framework (see figure). The vision is to focus on identifying and managing vulnerabilities to climate (and other) changes, rather than attempting to predict future climate. The advantage of this approach is that it focuses on revealing the vulnerabilities of the system being analyzed first, without reliance on climate model projections and the various uncertainties that accompany them. Climate change projections are used in the latter stages of analysis, to prioritize climate risks, and thus their associated uncertainties do not propagate through (or overwhelm) the analysis. The analysis begins with an assessment of DoD planning processes and their potential sensitivity to changes in climate. In most cases, a model of the relevant infrastructure system is used (or created if necessary) as the basis of the bottom up analysis. The key tool used in the analysis is the “climate stress test.” The climate stress test is a process in which uncertain parameters, both climate and non-climate, are varied systematically to reveal the vulnerability of the infrastructure system being analyzed. The results of the climate stress test are then analyzed using data-mining approaches to identify the combinations of factors that lead to vulnerabilities. By using this approach, the analysis identifies the vulnerabilities of the system to any changes in climate, rather than just highlighting the vulnerabilities from the climate change projections that happen to be used. This is important because it is well known that climate change projections are unlikely to span the true range of possible climate changes. Also, it avoids the problem of vulnerability analysis results being dependent on the climate change projections used, and thus requiring updating when new projections become available.

Through discussions with military planners and model-based sensitivity analysis, the climate information needs for decision making in planning decisions related to training, the built environment, and the natural environment are identified and serve as the basis for the assessment of climate simulation products. Climate simulations and downscaling approaches then are assessed in terms of their relative ability to provide credible projections of the climate information needed for specific military planning processes. Based on the results of this assessment, researchers synthesize guidance on preferred approaches to tailoring climate information for decisions and recommendations regarding alternative decision methods to deal with irreducible uncertainties, such as robust decision-making approaches. Finally, the decision framework is being piloted for four decision areas at four installations that span a range of climates and missions.

General types of DoD decisions/actions or specific decisions/actions informed directly through the project: This analysis focuses on planning decisions related to training, the built environment, and the natural environment. (*Continued on next page.*)



Key types of climate information used in decision framework: A regional scale "climate stress test" tool was created for use in conducting climate stress tests of particular locations. An assessment of climate modeling methods will be made in terms of their ability to inform the key climate information needs that emerge from the bottom-up analysis. The relative advantage of various climate information tailoring methods, including statistical downscaling and dynamical downscaling, will be evaluated in terms of their ability to provide credible, decision-relevant climate information.

Benefits of project: This project will produce a general decision framework relevant to DoD planning decisions that provides guidance on the identification of climate risks, the use of climate information and decision approaches that are appropriate for the range of uncertainties and decision types that are faced. The analysis will identify climate vulnerabilities for a set of climate-sensitive decision processes and a description of the priority of those risks based on climate change projections. An assessment of downscaling methodologies evaluated in terms of their ability to provide needed climate information for DoD planning and decisions will be produced and priority climate research needs identified. The decision framework will be evaluated through piloting at four installations with the expectation that the framework and assessment products will be appropriate for application to all DoD installations after the development and validation conducted in this effort.

Anticipated project completion: 2015

Principal investigator:
Dr. Casey Brown
University of Massachusetts

Within the DoD, historical weather and near-term weather forecasts are widely used. These data inform operations and maintenance decisions, such as assessing energy performance within buildings. Health and safety personnel utilize real-time weather data and forecasting to support emergency response planning on installations. In some cases, these historical data may provide a means for incorporating recent climate change into decision-making, especially when these data are used to create engineering design statistics, such as the "Typical Meteorological Year" used in energy planning. Incorporation of recent change into decisions, however, may not be sufficient for decisions with a long timeframe of influence, in which additional change or new rates or types of climate change may be important (RC-2204 unpublished information).

A variety of existing channels are available in which DoD decision-makers at different levels of governance turn for operational weather information and advice (as opposed to climate change information). Whereas the Army and Marine Corps each have a small, specialized weather support capability, the Naval Meteorology and Oceanography Command and Air Force Weather (AFW) are the primary sources of military weather products. Military weather missions provide decision assistance to commanders and resource managers, as well as operational units. The U.S. Army Corps of Engineers (USACE), Engineer Research and Development Center (ERDC) performs military engineering and civil works research that supports development of tactical decision aids (TDAs). These TDAs interpret the impact of weather and terrain conditions on Army systems and operations.

Military repositories of weather observations provide a useful set of information to characterize current climate trends and to contextualize potential future climate change conditions. The USACE uses a network of about 8,810 land-based gauges. About 55 percent of the sites collect meteorological data, 35 percent a combination of hydrologic and meteorological data, and 10 percent hydrologic or water quality data. The USACE funds or partially funds 61 percent (4,500) of all the gauges it uses.

At the installation level, operations and maintenance records can provide useful information on the condition of installation assets and past damages resulting from different types/severity of weather and climate, which can be helpful for understanding relevant climate-related thresholds. Documents and reports, however, require verification, as sometimes the current situation has evolved since these reports were developed (Moss et al. 2016). In addition, researchers have found that in some situations Military Service-level and installation databases were of limited utility, especially with regard to their applicability as a reference for past climate or extreme weather events or quantitative indicators of historical climate conditions (Moss et al. 2016). Service branches also collect and maintain weather data and information. Particularly at installations that do not frequently operate in extreme weather conditions, climate-sensitive decisions may benefit from information about the projected frequency and intensity of extremes (RC-2232 unpublished information). In cases in which obtaining local data from installations was problematic, researchers generally fell back on national and regional datasets. Finally, in some cases a gap will exist in the ability of available climate information to meet installation needs: for example, with regard to impacts-relevant variables such as changes in wind, for which model results only provide low confidence for future projected conditions and often are not readily available (Moss et al. 2016).

As climate vulnerability assessments should include analysis of adaptive capacity, non-climate data to support these analyses will be important. This can include information related to organizational culture, leadership, budgetary flexibility to respond to the unexpected, and opportunities to incorporate adaptation into new facilities or retrofits. Some types of data to support assessment of adaptive capacity may be limited, subjective, and difficult to verify. (Moss et al. 2016).

Data repository sites, such as Army Mapper,[4] are familiar portals for installation data. Decision-makers know that the data are approved for use by the DoD, lending to legitimacy. Although these data may have relevance, the providence or scientific credibility of these data are not always well documented within these sites. In addition, little guidance is provided on the appropriate use of the data. This makes such portals, as currently constituted, limited sources of climate data within the DoD and again speaks to the need identified by GAO (2015) for authoritative sources of climate information that are accompanied by adequate quality assurance guidelines for how to use such information.

5.3. Ensuring outputs from assessments effectively support decision-making

For vulnerability assessments, communicating the outputs to interested stakeholders and decision-makers will help to facilitate action and garner support for the assessment and subsequent adaptation actions. Early communication with stakeholders about the purpose and any intermediate results of the assessment can help to increase buy-in to the final assessment results. Assessments need to identify how physical damage or impacts could affect outcomes that are important to achieving missions within budget and acceptable tolerance for failure (Moss et al. 2016).

The outputs from a vulnerability assessment should be tailored to the specific purpose and audience for the assessment. In the DoD context, directives, policies, and other formal mechanisms often drive action. Outputs from assessments should be designed to fit within existing directives, policies, etc., or support necessary changes to these mechanisms. The findings can be presented in a variety of formats, such as a map, matrix, index, report, or other types of communication. The significance of results for decision-makers should be considered in terms of direct impacts. The understanding of assessment results also may be improved through charrettes with affected stakeholders.

An integrated vulnerability result can be useful for identifying priority installations in a comparative manner. Separate descriptions of the components of vulnerability can help determine how to focus particular adaptive actions, whether reducing exposure, reducing sensitivity, and increasing adaptive capacity to best address vulnerability. For example, a coastal installation that is experiencing degraded infrastructure due to flooding and erosion from SLR and associated extreme water levels may focus its efforts mainly on reducing exposure, such as by placing restrictions on shoreline development or moving structures further inland. In contrast, decision-makers that need to restrict training during daytime hours that exceed certain wet-bulb temperatures might address the vulnerability by increasing adaptive capacity, such as by using modified hydration and rest

[4] See: http://mapper.army.mil/.

requirements and facilities or resources for troops. Exploring the individual components of vulnerability also can help determine the type of adaptive action that might be effective, such as policies, regulations, investments in infrastructure, or ecosystem-based approaches.

Key findings on incorporating climate information into DoD climate-sensitive decisions

- Collaboration between climate information producers and providers, DoD decision-makers and practitioners, and others with specialized knowledge of the problem or systems being addressed provides an effective means to bring the best available, authoritative, and most-relevant climate information to bear on assessments. Additional research will be needed to better understand the options for providing climate services to the DoD.
- Specific metrics that will be used in decision-making that translate assessment information from exposure to risk management improve the communication of assessment results.
- Department of Defense repositories of weather and non-climate data provide a trusted source of information for DoD decision makers, which can positively influence the uptake within the DoD. Additional research will be needed to assess how best to ensure scientific credibility and traceability of climate information that could be included in these or other authoritative repositories.
- Tracking of key weather/climate-related variables and their cause and effect relationships to impacts (e.g., lost training days, damage to infrastructure, or cancelation of a test mission) is an important aspect of an adaptive approach to climate change assessment and response that OSD and the Military Services should consider to formally adopt as appropriate.

6. Connecting Climate Change Vulnerability and Impact Assessments and Adaptation Responses

The outputs of an assessment can help inform the development, evaluation, and selection of adaptive responses. In many cases, the types of actions considered will come from a variety of existing processes. For example, an action to modify a coastal pier to accommodate rising local sea levels will involve the same design process employed for general pier modification, with the difference being that climate change considerations must be incorporated into the process. Incorporating climate change considerations into existing process, policies, and procedures, or mainstreaming, is incorporated in DoD actions (DoD 2014). This approach allows for procedures to consistently account for climate change impacts across installations and also align consideration of climate impacts with analysis of other types of threats. Such an approach promotes integrated risk management actions (GAO 2014). Depending on the type or scope of decision at stake, it may be appropriate to plan adaptive response simultaneously with the assessment. Similarly, the decision context also will affect what level of detail in vulnerability information is sufficient for implementing an adaptive response and whether more detailed assessments are necessary before a response action can be taken.

6.1. Transitioning from climate vulnerability assessments to adaptation action

Using information provided through a climate vulnerability assessment, decision-makers will need to determine appropriate adaptation actions. When faced with the choice of responses, decision-makers can benefit from understanding whether the addition of more information can improve the adaptive responses and if the benefit of the response and its cost outweigh the effort needed to collect, process, or wait for additional information (Melillo et al. 2014). Such analyses can help reveal that delaying to obtain additional information does not always lead to better or different decisions (Melillo et al. 2014).

In some cases, using a phased approach in which initial assessments are followed with additional modeling can be designed to provide greater detail of information, may reduce uncertainty, and benefit the design of an adaptive response. For example, if an installation-level vulnerability assessment reveals increased vulnerabilities under a number of scenarios resulting from changes in water height associated with the 100-year flood, then this range of flood height increases could be incorporated in engineering analysis to evaluate the effectiveness of different flood protection measure designs (Moss et al. 2016). Situations will occur in which a limited ability exists to further reduce uncertainty in a manner meaningful for the decision, for instance with regard to the level of SLR at a particular location in 2100.

Decision-makers should be prepared to move forward with action despite uncertainties, but may need to adjust the process used for taking action to incorporate highly uncertain information. This has implications for mainstreaming climate considerations into existing DoD processes, as the framework or regulation guiding a particular action may need to be fundamentally modified to better incorporate information with deep uncertainties. Results from ongoing research can provide examples of how climate information and assessments fit into existing processes, but more

research is needed to better understand potential limitations of a mainstreaming approach within the DoD.

The choices of how to implement adaptation measures will be influenced by the opportunities presented by an installation's normal planning and upgrade cycle, repair and restorations needed following damaging events, and budgetary opportunities. In moving from assessment to actions, installations can look for opportunities in the long-term planning processes to incorporate adaptation measures into planned replacement or upgrades due to asset lifecycles, thus accelerating improvements in adaptation in a cost-effective manner. In addition, an understanding of priority adaptation measures will facilitate an installation's capacity to rebuild strategically following events that cause loss or damage to assets, rather than trying to identify resilience measures in the wake of a major event or recreating vulnerabilities in the system based on previous assumptions about future conditions.

In some cases, assessment results will suggest that an installation does not need to proceed to explicit adaptation actions, but that they should conduct monitoring and perhaps collect new types of information. An adaptive management approach, ongoing and iterative, in which phased decisions are made, conditions are monitored over time, and decisions are adapted to meet the changing conditions may be appropriate for some installations (SERDP 2013). Establishing effective monitoring systems are crucial to support adaptive management, and though technologies and methods exist to support monitoring of physical parameters, budget priorities might limit the implementation or upkeep of such systems. Additional research could develop data collection and analysis methods to support efficient and accurate monitoring of sensitivity and adaptive capacity in the context of ongoing reporting systems. Relevant factors include climate events interrupting mission attainment and causing damages, after-action reports, budget data, training, personnel, and other factors (Moss et al. 2016).

6.2. Joint considerations of adaptation planning with assessments

Decision frameworks often depict steps that assess vulnerabilities then design adaptation options as sequential (with iteration over these steps), but in practice adaptation actions often are identified along with the assessment of vulnerabilities. Different frameworks approach this in different ways (see SERDP-funded research boxes for examples). Advantages and disadvantages may result from explicitly designing a decision process that jointly considers adaptive actions with assessment of vulnerabilities. For instance, doing both simultaneously may cause certain adaptation options to be overlooked; on the other hand, it can streamline the process and help reach the implementation stage more quickly. It also may promote iterative learning and adaptive management.

The information requirements to transition from an assessment to action also will depend on the action under consideration and the risk tolerance associated with the type of decision or action. For low-regrets measures, or those that are inexpensive and easy to modify in the future, a high-level vulnerability assessment may be sufficient to move toward implementation. Information on the likely change in direction of a climate-related hazard may be sufficient to take action. The process of identifying climate stressors may in some cases generate enough information to directly guide the

development of relatively obvious options to reduce the negative impacts of climate stressors or to take advantage of opportunities. For example, if a drinking water aquifer at an installation location has experienced salt-water intrusion because of recent SLR, future SLR will likely worsen the situation and immediate action likely would be helpful. The installation may be able to consider options for protecting the aquifer or obtaining alternate freshwater sources within a rapid climate vulnerability assessment process.

In contrast, actions that will require large capital investments, affect key services, require detailed engineering analysis for project design, and that will have a long duration of influence that is difficult to modify will require detailed assessment. In addition, actions that will influence a large number of stakeholders also will benefit from a more extensive engagement process as part of the assessment. Additional research is needed to understand how vulnerability assessment, at any phase or level, can directly inform or provide direct inputs for the engineering design and implementation of an adaptive response.

Although we have a reasonable understanding of the characteristics that can support the choice to consider adaptation planning as part of assessment, this remains an area that would benefit from additional research. Specifically, more examples are needed to determine under what conditions joint planning is acceptable and to highlight what are the potential risks and advantages.

Key findings on connections between climate vulnerability and impact assessments and adaptation actions

- The variety of decision frameworks means that different approaches are available to connect climate vulnerability and impact assessment results with adaptation actions. A phased approach to vulnerability and impact assessments supports the alignment of the assessment outputs with the information requirements of adaptation actions. Decision-makers should be prepared to move forward with actions despite uncertainties that may persist in climate vulnerability and impact assessment results.

7. Current SERDP Recommendations for Informing Climate-Sensitive Decision-Making in the Department of Defense

Specific recommendations are grouped according to the structure of the synthesis section in the Executive Summary of the report.

Identifying climate-sensitive decisions in the DoD

Recommendation 1: Understand the characteristics of the decision and how it might be affected by current weather and future climate change. The DoD is faced with a range of decisions that are affected by weather today. These and additional decisions may be affected by future climate change. Our understanding of current impacts can be a bridge to the realization that climate change in large measure will exacerbate most of these impacts in a negative manner and create new, often adverse, impacts.

Although unambiguous attribution in regards to a cause-and-effect relationship with climate change and today's impacts remains a challenge, in a number of relevant instances, such as related to temperature and rising sea levels, the connections are clear. Climate change is not just a future concern; it is with us today. Climate change portends to affect in some way much of what the DoD does, whether that connection is clear today or will only become clearer with time. As a result, the potential impacts of climate change on DoD decisions and assets need to viewed from several different lenses: what it means today, what it means in the future, and whether the potential impact is significant relative to other considerations and so deserving of attention either through an adaptive response action or continued tracking or both. To maintain mission resilience in the face of climate change, its consequences and the effectiveness of response actions must be periodically assessed.

Using frameworks to inform climate-sensitive decisions

Recommendation 2: Embrace decision frameworks that foster robust decisions under uncertainty. Climate change poses unique challenges to the decision-making process. Because of the inherent uncertainties associated with future climate, traditional predict-then-act or reliance on a most likely future approach are in most cases insufficient. Moreover, because climate change also has elements of non-stationarity, past climate regimes are not necessarily guides to future climate. Robust approaches should be pursued that involve the use of multiple plausible futures, or scenarios, against which to assess the potential consequences of climate change. Depending on the circumstances, scenarios can be considered at different points within the decision process.

Military planners are used to making decisions under uncertainty; indeed they are leaders in this endeavor. This is less likely the case when it comes to long-term infrastructure design and asset management. Here, the DoD is at present more likely to both plan to historic conditions (an implicit assumption of stationarity) and view the future in terms of what is most likely. Climate change has elements of both non-stationarity (the past is not a guide to the future) and deep uncertainty in terms of what specific future may unfold (in large measure due to uncertainties in the climate models, but also ultimately the emissions trajectory that the world eventually follows). These

realities require a fundamental shift in the decision-making mentality and process. Many decisions must now be robust against a range of plausible futures. Single value answers to questions such as how much sea-level rise will be experienced will not be valid. Even placing probabilities on potential outcomes will be challenging and at best may be contingent on an underlying scenario (such as sea-level rise) with no assigned likelihood. The Department should strongly embrace the concept of robust decision-making to meet the challenges that lie ahead.

Recommendation 3: Use existing decision processes to the extent feasible; however, recognize that some modifications may be necessary to appropriately integrate the use of climate change information. The Department has recognized that climate changes potentially affects almost everything it does and that its consideration should be integrated into extant decision processes and not stove-piped as an isolated element. Existing assessment and other decision processes, however, may require modification to incorporate the unique nature of climate information and the uncertainties involved.

The Department has taken great strides in not stove-piping climate change and its implications; rather, it has attempted to integrate climate change as another consideration in the way it conducts its missions. It is also true that most people are comfortable working within contexts with which they are already familiar. As a result, as much as possible, climate change information should be incorporated into existing processes and trusted sources of information. Notwithstanding this general objective, however, the manner in which climate change information may need to be treated (i.e., because of the uncertainties involved) often will differ from other information. This necessitates an objective view of how best to incorporate climate information and at times a modification to the processes affected and information sources considered.

Recommendation 4: Incorporate appropriate monitoring of linked climate-related variables and effects into key decision processes. Although it may be possible to make anecdotal statements about weather and its impact on mission and assets, the DoD often lacks explicit processes to document when and to what degree weather precludes a mission at its enduring installations. To fully understand the implications of climate change and how it may change over time, OSD and the Military Services should identify the key climate-related variables and their effects that should be tracked and documented over time to ensure mission sustainability. Additional information that could be tracked includes the sensitivity and adaptive capacity of the mission or asset to climate-related phenomena. Such monitoring should take advantage of existing processes: for example, taking current range (testing and training) use planning processes and adding and documenting information on appropriate climate-related variables that cause mission degradation and when this occurs and why.

You can't manage what you don't track. To maintain mission resilience, it is important to understand what factors lead to mission degradation. Moreover, appropriate metrics and thresholds need to be developed relative to weather/climate-related variables that identify not only when a particular mission is impacted but also how often that impact occurs and how the frequency may change in the future. The Department is a master at workarounds, but at some point workarounds become infeasible. As a result, DoD should consider and develop appropriate

thresholds and track when they are exceeded not only in relation to specific climate variables but also related to their periodicity and duration and when these lead to mission degradation.

Incorporating climate information into DoD climate-sensitive decisions

Recommendation 5: Match the level of assessment to the decision being made and the availability of supporting information. A key lesson that SERDP has learned through its funded research on assessment methodologies is that the approach needs to be flexible and may involve several levels of assessment. This reflects the understanding that depending on the level of detail needed to support a decision, the assessment itself can be complicated, time-consuming, and costly. As a result, a nested approach is advised that starts with understanding current vulnerabilities (i.e., a baseline assessment) and progresses through a series of "screens" whose aim is to use ever more refined information to assess vulnerabilities and impacts, while, if possible, identifying potential adaptive responses. No specific number of assessment levels is offered. The number should be driven by the goal to minimize the "costs" involved in ruling out what is truly not vulnerable versus what may be vulnerable at each level, so that ultimately resources are focused on those decisions and associated assets for which some degree of an adaptive response is necessary and avoiding the collection and analysis of costly data sets that may be unnecessary at higher screening levels.

Recommendation 6. Use climate information only from trusted sources that is authoritative and has been appropriately documented with respect to its skill and intended and appropriate uses. Climate information is more than the raw data resulting from the output of a climate model. It includes deciding the appropriate risk-based framing to use (i.e., bounding scenarios) when applying the information for assessment and adaptive response purposes, the appropriate selection of global climate models and downscaling approaches, and the actual resultant data sets and whether they have been appropriately verified for the intended use. The National Climate Assessment has been an appropriate authoritative source for identifying which bounding scenarios to use for assessment purposes and should continue to be so in the future. The DoD-led Coastal Assessment Regional Scenario Working Group is an appropriate authoritative source for sea-level rise and extreme water level scenarios that the DoD should consider for application. Identification of authoritative downscaled data products is an emerging need. The Department should follow developments here closely and plan to engage with the rest of the federal community in seeking to identify and use authoritative data products, whose skill and appropriate usage for decision-making (versus research) have been appropriately documented. In addition, the Department should be clear about its climate information needs to ensure that the producers and providers of climate information understand that need and can respond accordingly.

The recent GAO report (GAO 2015) highlighted the importance of a federal role in providing authoritative climate information and, moreover, the need for quality assurance guidelines for how to use the information. These findings can't be overstated. With the also recent issuance of DoDD 4715.21 (DoD 2016), elements of the Department (including installations) will now feel a need to act. To whom will they turn to for authoritative climate information, when such information is currently limited? A "cottage industry" waits to fill the vacuum and could lead to inconsistency and inappropriate use of climate information. As a result, DoD should remain engaged with the rest of the federal community as this issue unfolds, seek common solutions with its federal partners, and

develop appropriate policy and guidance to ensure appropriate and consistent implementation. This may take some time. In the meantime, the Environmental Security Technology Certification Program (ESTCP) is exploring pilot efforts to better understand what authoritative climate information may look like and how it can be made available in a manner useful to DoD decision-makers and practitioners.

Connecting climate change vulnerability and impact assessments and adaptation responses

Recommendation 7: Use an adaptive approach whenever possible that links assessments and responses in an iterative, phased process. Decisions made with respect to climate change are sensitive to the type of decision, the timeframe over which the decision needs to be effective, the expected level of performance over different future conditions, and the degree of tolerance for risk associated with the decision. For DoD, the decision also may be sensitive to governance level within the Department, dependent on its implications at the installation level versus the command, Military Service, and OSD levels. Some decisions may be difficult to reverse once made and if the decision is risk-adverse (e.g., may have an unacceptable impact on mission if not robust against all potential future climates) may need to be robust at the outset to worst-case conditions. In many cases, however, decisions may be capable of a phased approach, in which protection against current and potential near-term climate conditions is achieved while preserving the capability to pursue options that are protective against the long-term risks. This approach may reduce the costs of adaptation should worst-case conditions fail to materialize; however, it requires a commitment by OSD and Military Service leadership to (1) continue to monitor the evolving understanding and realization of the changing climate and its implications and (2) adjust the decision over time based on the preceding. As a result, in a phased adaptive approach the decision process is iterative.

Much of the SERDP-funded research to date has focused on vulnerability and impact assessment-related data, models, and methods. Adaptive response frameworks are beginning to be investigated and likely deserve increased attention moving forward. The question is—whether answered qualitatively or quantitatively—what future is the adaptive response meant to address? This is the key question faced by decision-makers and practitioners, but in the absence of policy direction is often the one that is addressed only in a tangential manner. But the answer to it also cannot be addressed by a one-size-fits-all approach. And finally, it is a question, which while maintaining the long-term perspective, may be capable of being responded to in a phased, adaptive manner.

Recommendation 8: Enhance the science-policy interface that recognizes the complexities of translating climate science into useful information (i.e., actionable science) for decision-making and its iterative nature. As with the response to climate change, the interaction (dialogue) between the policy-maker, scientific community, and the practitioner (implementer) must be adaptive and iterative. The scientific community in this regard involves both the producers of scientific information and those that translate it into actionable science. Policy-makers must understand the implications of the science on their policy choices and the practitioner needs to know how to implement the science-informed policy choices. The Department should pursue organizational and

policy choices that recognize and enhance the science-policy interface and its role in ensuring an appropriate, scientifically defensible, and consistent use of climate science across DoD.

Figure 5 provides a conceptualization of the framework for coordination required as part of the science-policy interface in which the policy-maker, scientific community, and the practitioner are depicted. Lines of dialogue are multiple and involve both direct and indirect modes of communication. Given the complexities of the science involved and its dynamic nature, each of the lines of communication needs to be iterative. The state of the science/practice involves not only the scientific research community but also those individuals and institutions that function as scientific translators or boundary spanners. The relationships can be informal, but some aspects, such as when the need for authoritative information arises, need to be formal. This latter need could take the form of specific organizations designated as authoritative sources or accreditation programs that provide the policy maker and end user confidence that the information provided is credible and can be used for its intended purpose.

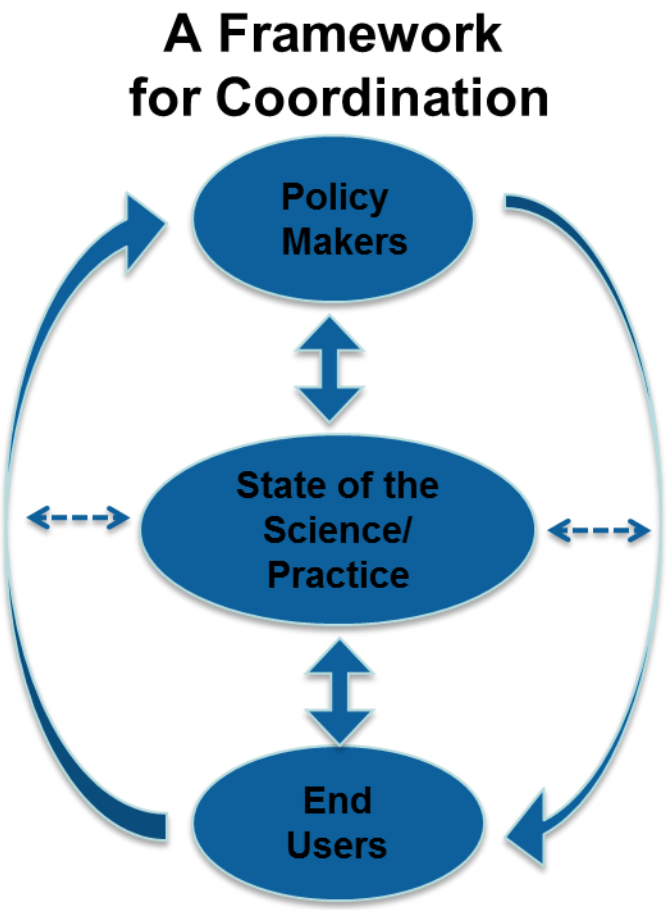


Figure 5. Conceptual framework for how coordination may occur among the state of science or practice, as represented by scientists and boundary organizations, and policy makers and end users. Solid arrows indicate direct lines of communication, whereas the dashed arrows indicates an indirect influence on the communication between the policy maker and end user. Modified from DoD (2012).

The above relationships ideally would lead to the coproduction of climate science knowledge, in which coproduction is the process of producing usable, or actionable, science through collaboration between scientists and those who use science to make policy and management decisions (Meadows et al. 2015). Different modes of communication (i.e., contractual, consultative, collaborative, and collegial) characterize scientist-stakeholder interactions, in which only the collaborative and collegial modes actually may lead to coproduction (Meadows et al. 2015). Given the structure of the SERDP-funded research, in regards to project interactions with installation staff and the Military Service liaisons that contributed to the underlying information contained in this report, these efforts likely contain elements of both the consultative and collaborative modes. Meadow et al. (2015) also defined five approaches to collaborative research that could be used to structure a coproduction process, the choice of which depends on the research or management question, decision-making context, and the resources and skill sets available to the engagement process. Each of the approaches can be mapped to the different modes of communication. Two—participatory integrated assessment and boundary organizations (both of which include scenario planning as elements of the approach)—encompass both the collaborative and collegial modes of communication. Ultimately these combinations are the space in which ESTCP, as well as OSD and Military Service policy-makers, will need to operate to achieve a functioning science-policy interface that achieves the coproduction of key climate knowledge to meet DoD needs.

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9. Appendix

Glossary of Terms

Key terms used in this report are provided below. The source citation is provided, where appropriate. Some of the definitions that are drawn from other sources may have been edited from the original to maintain a consistent editorial style. In addition, some of those terms have been further annotated to provide additional context.

Term	Definition
Actionable science	Theories, data, analyses, models, projections, scenarios, and tools that are: (1) relevant to the decision under consideration, (2) reliable in terms of its scientific or engineering basis and appropriate level of peer review, (3) supportive of decisions across wide spatial, temporal, and organizational ranges, including those of time-sensitive operational and capital investment decision-making, and (4) co-produced by scientists, practitioners, and decision-makers and result in rigorous and accessible products to meet the needs of stakeholders (DoD 2016).
Adaptation	Adjustment in natural or human systems in anticipation of or response to a changing environment in a way that effectively uses beneficial opportunities or reduces negative efforts (DoD 2016).
Adaptive capacity	Ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences (IPCC 2014: Annex II).
Built infrastructure	Basic equipment, utilities, productive enterprises, installations, and services essential for the development, operation, and growth of an organization, city, or nation (based on Parry et al. [2007] definition of infrastructure). This includes all building and permanent installations necessary for the support, deployment, redeployment, and military forces operations (e.g., barracks, headquarters, airfields, communications, facilities, stores, port installations, and maintenance stations; based on JP1-02 [2001] definition of infrastructure).
Climate	The statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system (IPCC 2014: Annex II).
Climate change	Variations in average weather conditions that persist over multiple decades or longer that encompass increases and decreases in temperature, shifts in precipitation, and changing risk of certain types of severe weather events (DoD 2016).
Climate (change) scenario	Plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships and assumptions of radiative forcing, typically constructed for explicit use as input to climate change impact models. A “climate change scenario” is the difference between a future climate scenario and the current climate (Parry et al. 2007).

Term	Definition
Downscaling	Method that derives local- to regional-scale (typically 10 to 100 km) information from larger-scale models or data analyses (Parry et al. 2007). For climate information, downscaling can be accomplished by either statistical or dynamical (regional climate model) means.
Exposure	Presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected (IPCC 2014: Annex II).
Extreme event	Event that is rare within its statistical reference distribution at a particular place. Definitions of 'rare' differ, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile. By definition, the characteristics of what is called 'extreme weather' may differ from place to place. Extreme weather events may typically include floods and droughts (IPCC 2014: Annex II).
Impact	Effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system (IPCC 2014: Annex II).
Impact assessment	Practice of identifying and evaluating, in monetary and/or non-monetary terms, the effects of climate variability or change on natural and human systems (Parry et al. 2007). It is often a quantitative assessment, in which some degree of specificity is provided for the associated climate, environmental (biophysical) process, and impact models. An evaluation of the uncertainties involved is a necessary and integral contribution to reported outcomes. It may require high-resolution data. Impact assessment may lead to identification of adaptation strategies that can reduce system vulnerabilities.
Level of governance	A level of governance is the point of authority in the DoD command chain, including installation level, service command level, Military Service Secretariat level, and OSD level. Consideration of the level of governance for a particular decision can inform the decision framework and assessment needed to help support it.
Likelihood	Likelihood of an occurrence, outcome, or result, when this can be estimated probabilistically (IPCC 2014: Annex II).
Mitigation	Intervention to reduce the sources of changes in climate, such as through reducing emissions of greenhouse gases to the atmosphere and enhancing greenhouse gas sinks (IPCC 2014: Annex II). This definition differs substantively from, and should not be confused with, the definition provided in the Terminology and Index section of the Code of Federal Regulations, Protection of Environment, Council on Environmental Quality (40 CFR 1508.20), which considers a hierarchical approach and includes the concepts of avoiding environmental impacts, minimizing impacts, rectifying the impact, reducing or eliminating the impact over time, and compensating for the impact.

Term	Definition
Natural (green) infrastructure	Features of the land and water environments, including their biota and associated ecological processes, that directly or indirectly support society. In a DoD context, this support may serve military readiness or provide protective functions for built infrastructure during extreme weather events. In the first case, natural ecological systems often provide needed training landscapes and training realism. These can range from the permafrost-controlled ecological systems of Alaska to the barrier islands off the coasts of several military installations. In the second case, coastal wetlands and barrier islands serve to protect mainland areas from the effects of storms. Natural infrastructure often implies interconnected ecosystems and other natural features that support characteristics of the water, vegetation, and soil that are essential to sustaining life.
Phase of assessment	Different phases or tiers of assessments can be used to address the fact that implementation can differ in terms of scope, approach, the nature and criticality of the decisions to be made, degree of risk tolerance, time horizon of the decision, and the cost of the assessment compared to the cost of a response decision. There is no single set of phases appropriate for all situations, but the phases generally move from the use of general or qualitative information to more detailed, location-specific information.
Prediction	Result of an attempt to produce an estimate of the actual evolution of a quantity or set of quantities in the future. Because the future evolution of the climate system may be highly sensitive to initial conditions, such predictions are usually probabilistic in nature (adapted from Solomon et al. 2007).
Projection	Potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions to emphasize that projections involve assumptions or scenarios concerning, for example, future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty (IPCC 2014: Annex II).
Resilience	Ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions (DoD 2016).
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as a probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur (IPCC 2014: Annex II).
Scenarios	Situations that detail future potential conditions in a manner that supports decision-making under conditions of uncertainty, but does not predict future change that has an associated likelihood of occurrence (DoD 2016).
Sensitivity	Degree to which a system may be affected, either adversely or beneficially, by climate variability or change (Parry et al. 2007).
Threshold	For climate-sensitive decisions, thresholds can be defined as the point beyond which an adaptive action is needed, including the point at which damage to an asset or system occurs. Thresholds can be applied within decision frameworks to serve as a screen for mission criticality or risk and can potentially be used to determine what climate futures (scenarios) may need to be considered for assessment purposes.

Term	Definition
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC 2014: Annex II).
Vulnerability assessment	Practice of identifying and evaluating the effects of climate change and climate variability on natural and human systems, so as to understand system sensitivity, exposure, and adaptive capacity. (Some definitions may exclude exposure from the definition and then link vulnerability with exposure to define impact [Moss et al. 2016]). In this report, we interpret this definition to imply a form of qualitative assessment or an assessment that is less quantitatively rigorous than an impact assessment. The degree of specificity in the climate, environmental process, and impact models is not as stringent as for an impact assessment, even when accompanied by an evaluation of the uncertainties involved. Moreover, from this perspective, data requirements, including their spatial granularity, can be more relaxed than what is required for an impact assessment. Vulnerability assessments, when defined this way, may best be tied to an initial screening process that may lead to the more detailed impact assessments for those locales and systems identified as most vulnerable or mission-critical.