USER MANUAL

Assessing Climate Change Risks: Lessons learned from DoD installations in the Southwest

SERDP Project RC-2232

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14. ABSTRACT This user guide summarizes findings from SERDP project RC-2232: Climate Change Impacts and Adaptation on Southwestern DoD Facilities and is offered as a collection of resources that DoD managers can use to plan and implement ongoing adaptation activities. Our research focused on assessment of climate related risk and the need for iterative climate change adaptation strategies that are aligned with DoD facilities management. Our overall guidance for climate decision-making is consistent with our original hypothesis—that best practices require direct engagement of installation personnel with researchers to identify current climate-related issues of concern, and connect them through cause-and-effect impact chains to amplified or attenuated future climate-related risks. We have identified an array of promising approaches for incorporating climate time-scale thinking and climate change considerations into DoD operational practices and provide an overview of techniques used to assess risk, a series of best practices, and a compilation of resources to support DoD climate-sensitive decision-making in this guidance document.

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ACRONYMS

AFB	Air Force Base
AGWA	Automated Geospatial Watershed Assessment toolkit
ADF	Australian Defense Force
BMGR	Barry M. Goldwater Ranges (East, Gila Bend, AZ; West, Yuma, AZ)
BOT	British Overseas Territories
CIRAM	Climate Impacts Risk Assessment Methodology (UK Ministry of Defence)
CM	Camp Morena (inland training facility of Naval Base Coronado)
CMIP3	Coupled Model Intercomparison Project Phase Three
CMIP5	Coupled Model Intercomparison Project Phase Five
CMM	Camp Michael Monsoor (inland training facility of Naval Base Coronado)
DIO	Defence Infrastructure Organisation (United Kingdom)
DoD	Department of Defense
ENSO	El Niño-Southern Oscillation
FireBGCv2	Fire Biogeochemical Model Version 2
FTH	Fort Huachuca, U.S. Army
GCM	Global Climate Model
HOE	Head of Establishment
HVAC	heating, ventilation, and air conditioning
IPCC	Intergovernmental Panel on Climate Change
KINEROS	Kinematic simulation of catchment runoff and erosion processes
LANDFIRE	Landscape Fire and Resource Management Planning Tools
NAP	National Adaptation Plan (United Kingdom)
NARCCAP	North American Regional Climate Change Assessment Program
NBC	Naval Base Coronado
NCA3	Third National Climate Assessment
NDMI	Normalized Difference Moisture Index
NGO	Non-governmental Organization
NRM	Natural Resource Management
OSD	Office of the Secretary of Defense
PANYNJ	Port Authority of New York and New Jersey
PME	Professional Military Education
SERDP	Strategic Environmental Research and Development Program
SWAT	Soil Water Assessment Tool
TLB CRFP	Top Level Budget Climate Resilience Focal Point (United Kingdom)
UA	University of Arizona
UKMoD	United Kingdom Ministry of Defence
USFS	United States Forest Service (Department of Agriculture

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PURPOSE AND ORGANIZATION OF THE USER GUIDE

This user guide describes climate related risk assessment from research conducted from 2012 to 2017 for SERDP Project RC-2232. This guide offers a systematic approach for assessing risks related to climate change with a focus on planning, implementing, and fostering adaptation activities. The risk assessment framework provided in this guide is directed at assessment of climate related risk at the installation level and the need for iterative climate change adaptation strategies that are flexible and strongly aligned with current DoD facilities management needs. Information presented in this user guide is intended for use by civilian natural resource managers who frequently work at DoD facilities alongside military personnel. We also see this guide to be useful for individuals who are responsible for installation level monitoring and reporting on climate change related activities, individuals who may be asked to convey climate related risks to installation commanders, and experts working with military personnel on minimizing and adapting to climate change related risks.

This guide includes:

- An overview of techniques used to assess climate change related risk
- Examples of how the recommended framework was applied to demonstrate the utility of the iterative risk assessment process
- A set of observations and lessons learned
- A summary of broad and generalizable recommendations
- A list of climate-sensitive decision support tools and regional expertise
- A list of scholarly/technical papers produced from the RC-2232 project

The purpose of this guide is to introduce the concept of, and the need for, a multi-tier climate sensitive risk assessment process. For more information please review the full ERDP Project RC-2232 Final Technical Report: Climate Change Impacts and Adaptation on Southwestern DoD Facilities, available at https://goo.gl/GtmqYE .

We have organized this user guide in 3 distinct sections. Our aim is to highlight proven practices that have broad applications; and to emphasize how DoD may benefit from these practices. We begin with a primer on climate-sensitive risk assessment and adaptation strategies used by our team in the southwestern United States (Section 1), followed by lessons learned from defense forces of the UK and Australia, and other non-defense sectors that face climate related challenges to similar to those of the DoD (Section 2), and conclude with a list of recommendations (Section 3). To address the DoD need for credible and reliable scientific information we have provided a list of well vetted tools, databases and expertise as well as a list of scientific and technical publications from the SERDP RC-2232 project in the appendices.

BACKGROUND

The US Department of Defense (DoD) faces emerging climate risks and challenges across its portfolio of responsibilities: as a major land manager, as operator of hundreds of installations, and - in its core mission to protect global security. While the 2014 Climate Adaptation Roadmap (U.S. DoD 2014) and DoD Directive 4715.21 (U.S. DoD 2016) establish the motivation and responsibilities for development and implementation of climate change adaptation plans, the Department requires specific guidance on methods, best practices, support services needed to establish adaptation, and climate time-scale thinking as part of standard operating and facilities management procedures.

The RC-2232 project was funded by SERDP from 2012 -2017. The project team developed and tested approaches for assessing climate-related risk, in partnership with Acclimatise, UK and installation personnel (a) in pilot case studies at Naval Base Coronado (NBC), the Barry M. Goldwater Ranges (BMGR), and Fort Huachuca (FTH), (b) through research and interviews with personnel from the DoD and departments of defense in other nations, and (c) through a workshop with SERDP investigators and DoD personnel. We identified an array of promising approaches for climate change risk assessment, and incorporation of climate time-scale thinking and climate change considerations into DoD operational practices. Our overall guidance for climate decision-making is consistent with the hypothesis that best practices require a systematic approach that includes direct and continued engagement of installation personnel with researchers a) to identify current climate-related issues of concern, and b) connect these concerns through cause-and-effect impact chains to amplified or attenuated future climate-related risks.

Through the recommended iterative risk assessment process described in this guide, climate change-related risks were identified, prioritized, and related to mission success criteria through ongoing interactions between military personnel, natural resource managers and researchers. Work completed at Naval Base Coronado and Fort Huachuca is highlighted in this guide and demonstrates the scientific credibility of the process while emphasizing the need for natural resource professionals to develop tools that are directly relevant to installation decision processes. The research team also identified adaptation strategies in use by foreign defense services as well as examined how non-defense sectors were considering climate change within their planning and operations functions to understand how risk assessment is used beyond the United States Department of Defense setting. Interviews of military personnel at various command ranks were conducted and a cross-project workshop with personnel at multiple levels in the DoD hierarchy were similarly convened in order to identify gaps, needs, and opportunities for infusing climate adaptation thinking and practice into DoD operations. This guide summarizes and illustrates the processes, observations and lessons learned by our research team, and is intended to guide DoD personnel and natural resources managers in developing a DoD relative risk assessment processes.

SECTION 1. CLIMATE RISK ASSESSMENT FOR DOD FACILITIES

1.1 Why assess risk for climate-sensitive decision making?

The purpose of risk assessment is to determine, as accurately as possible, the probable impact of known climate risks - or at least a threshold level of risk to be avoided. Our work with installations in the Southwest indicates that climate-sensitive decision making and adaptation efforts are best directed at issues for which the risks are fairly well understood. To fully identify and prioritize risks, a robust risk assessment process must place.

Application of multi-tier assessments at the installation level suggests that successful risk assessment is driven by:

1. An iterative process
2. A commitment from leadership that is echoed throughout the command structure
3. Ongoing engagement that includes a wide array of expertise and
4. Credible partnerships
5. Efforts supported by a sufficient weight of scientific evidence

1.2 How is climate-sensitive risk assessment defined?

Evaluating promising approaches to climate services that mesh with military culture, leadership, and practice requires using a common language of risk. The third U.S. National Climate Assessment (Melillo et. al, 2014) and the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report, place the concept of risk firmly at the center, stating that "risk management provides a useful framework for most climate change decision making" (IPCC 2014a).

As both current climate variability and future climate change are a concern, there is an inevitable degree of uncertainty about the timing, pace, and severity of possible impacts, as well as the options for managing and avoiding them. The following risk and uncertainty definitions can help clarify language frequently used to describe the risk assessment process:

- **Risk** *The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values (IPCC 2014b). Risk is often represented as probability of occurrence (likelihood) of hazardous events or trends multiplied by the impacts (consequence) if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard are shown in Figure 1 (IPCC 2014b).*
- **Uncertainty** *A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures (e.g., a*

probability density function) or by qualitative statements (e.g., reflecting the judgment of a team of experts) (IPCC 2014b).

- **Likelihood/probability** *the likelihood / probability component of risk is a general concept relating to the chance of an event occurring. This can be expressed as a quantitative probability (e.g., >90%) or as a qualitative likelihood (e.g., "Very likely").*
- **Consequence (impact)** *The end result or effect on society, the economy or environment caused by an event or action (e.g., economic losses, loss of life). Consequences may be beneficial or detrimental. This may be expressed qualitatively (high, medium, low) or quantitatively (monetary value, number of people affected, etc.) (DEFRA 2012).*
- **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 2014b).*
- **Exposure** *The presence of people, livelihoods, species or ecosystems, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected (IPCC 2014b).*

Through our work with DoD we observed that visualizing the language of risk is also helpful for communicating and identifying risk. For example - Figure 1 (IPCC, 2016) depicts risk as a product of a complex interaction between physical hazards associated with climate change and climate variability on the one hand, and the vulnerability of a society or a social-ecological system and its exposure to climate-related hazards on the other. Vulnerability and exposure are largely the result of socio-economic development pathways and societal conditions (although changing hazard patterns also play a role). Changes in both the climate system (left side) and development processes (right side) are key drivers of the different core components (vulnerability, exposure, and hazards) that constitute risk (IPCC 2014a). Our team used the terminology and relationships shown in Figure 1 to guide conversations between researchers, natural resource managers and installation personnel and found the use of a common language of risk to be helpful in developing our preemptive phase of research which we will refer to later as the "Tier 1 preliminary risk assessment".

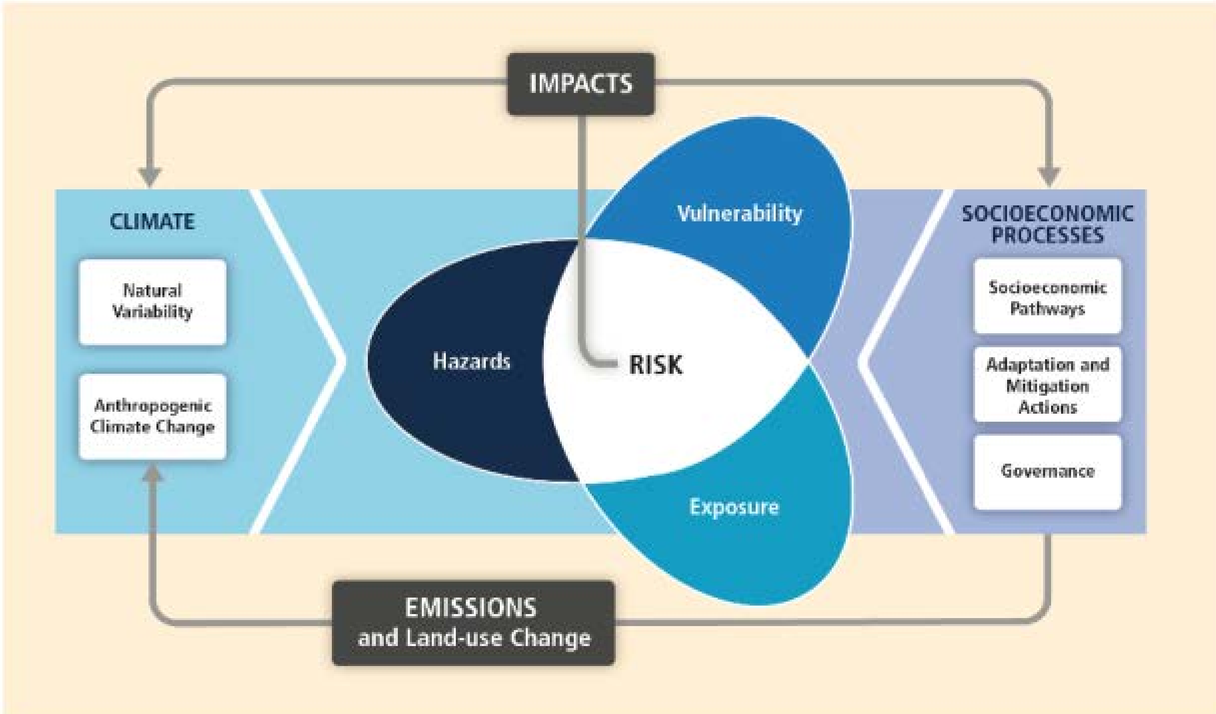

Figure 1 Schematic of intersection among the physical climate system, exposure, and vulnerability producing risk from IPCC (2014).

1.3 How might a systematic decision making framework be included in DoD climate change risk assessment?

Our approach for climate change risk assessments is based on a risk-based framework originally developed by the UK Climate Impacts Programme (UKCIP) and the UK Environment Agency: "Risk and Uncertainty Framework" (Willows and Connell 2003; Figure 2). This framework is offers a systematic approach that is widely accepted and (1) acknowledged by United Nations Development Programme as one that uniquely deals with uncertainties, and (2) has been used by the World Bank, the Intergovernmental Panel on Climate Change and other organizations in public and private sector contexts. We chose this specific framework because it is well suited for the DoD and provides flexibility to assess climate-related across a wide variety of installations, operations and environments.

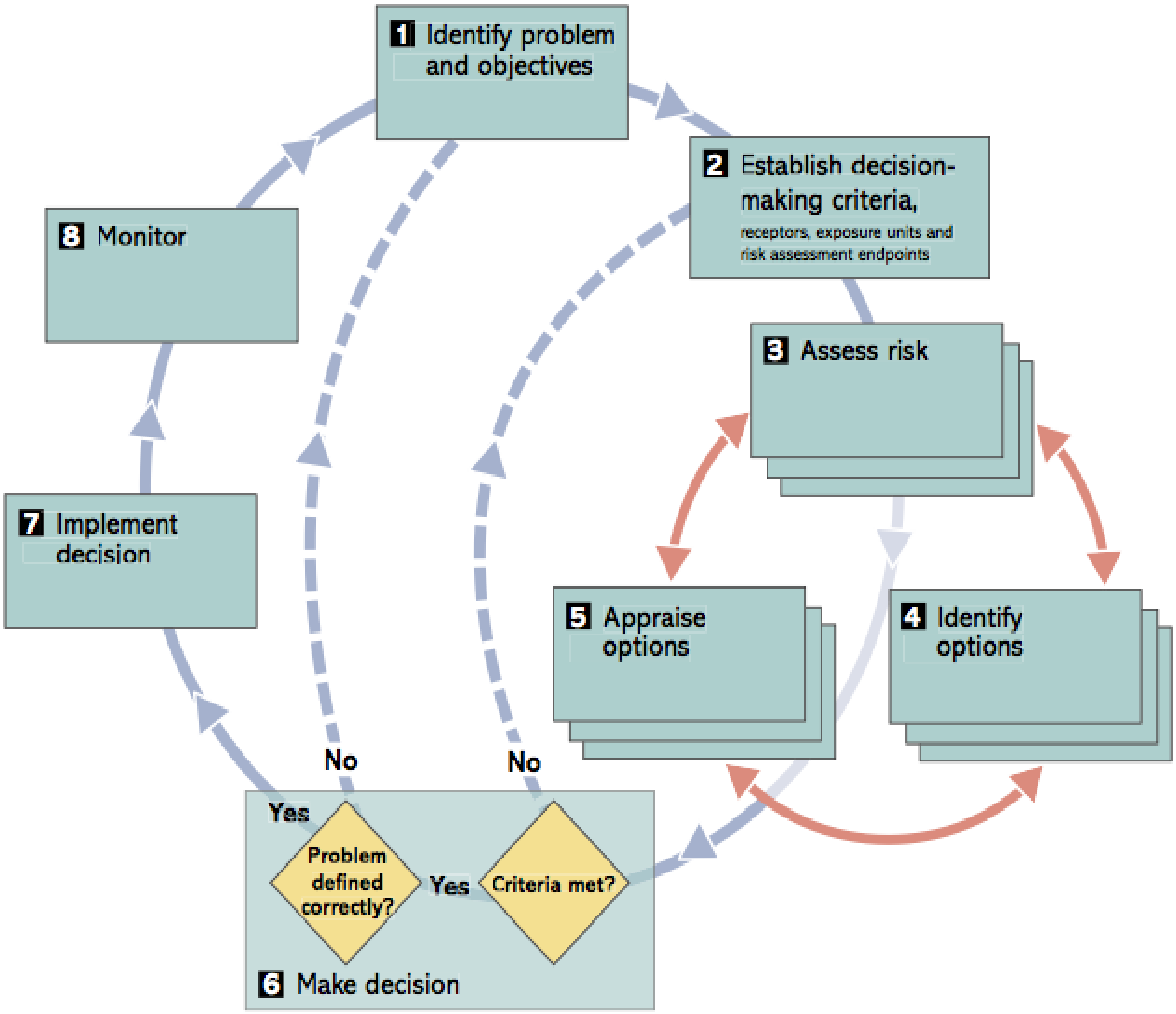

Figure 2 Schematic of the intersection among the physical climate system, exposure, and vulnerability producing risk from IPCC (2014).

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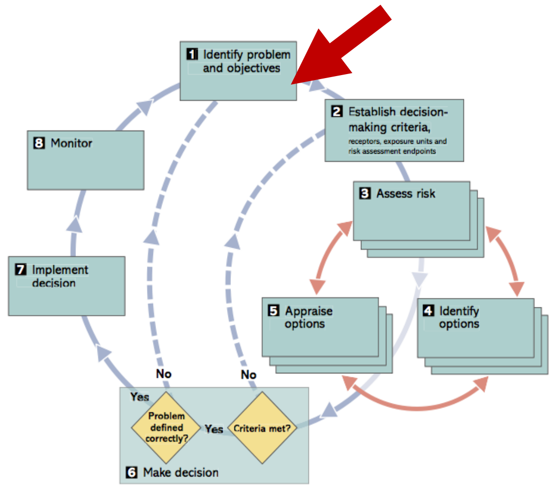
The risk-based framework shown in Figure 2 illustrates the need for **iteration** (the cyclical nature and cascading stages of ongoing communication, feedback and interaction that must occur between researchers, natural resource managers and operations personnel in order to adequately assess risk and make informed decisions). Note that each stage links back to other stages, and in most cases completion of one stage will require **repetition or revisiting of previously completed stages** (the continuous process of interaction and engagement between researchers, natural resource managers and operations personnel to collaboratively identify and prioritize risks and discuss options and resources for mitigating the co-identified risks).

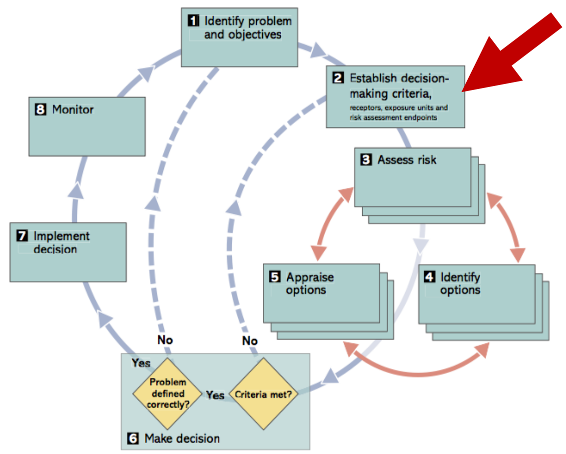
1.4 What are the most critical stages of the risk assessment process?

Each stage of the recommended risk assessment process shown previously in Figure 2 presents an opportunity to re-evaluate and re-assess, and engages personnel at multiple levels of responsibility and command to ensure the assessment is relevant. The stages provide a systematic approach may be tailored to suit the unique needs of each installation and are described in detail here:

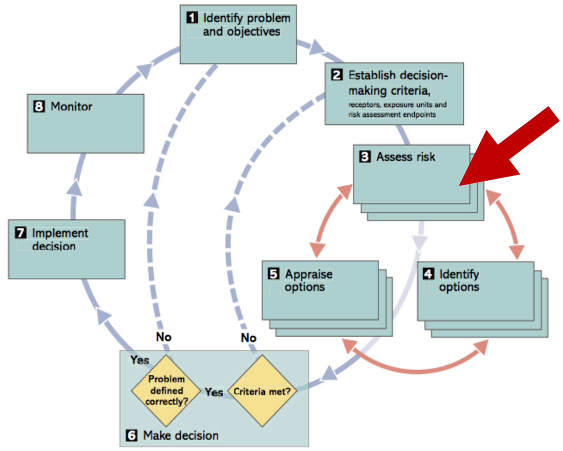
- **Stage 1** – Identify objectives: This stage involves understanding the objectives/mission of individual installations, and establishing the reasons for inclusion of climate information into decisions. This includes developing an understanding of existing vulnerabilities to climate variability and future risks from a changing climate, the relative importance of climate change as a driver of risk, and which personnel need to be involved in climate risk discussions.



- **Stage 2** – Establish decision-making criteria: This stage involves defining the risk criteria, exposure units, thresholds, receptors and performance criteria, together with determining the process by which risks will be evaluated—including how the results will be used, and identifying stakeholders (e.g., representatives of surrounding communities and land holdings just beyond the fence line) who need to be consulted about the climate change risk assessment.

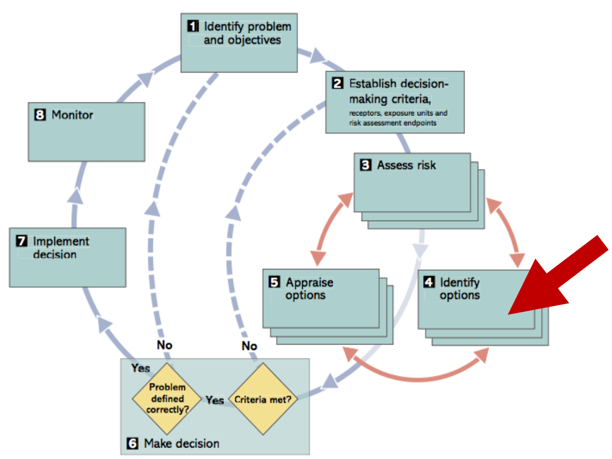


- **Stage 3** – Assess risks: Climate change risks are assessed, utilizing three central steps, which consider the three core components of risk previously depicted in Figure 1.

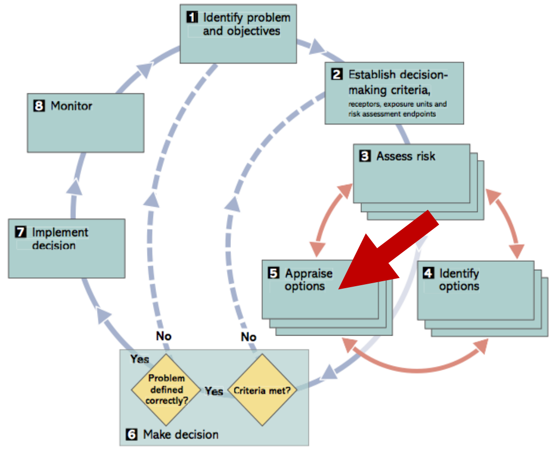


  - **Hazard identification**. This involves identification of primary climatic variables (e.g., temperature, precipitation, storm tracks), and variables directly affected by climate changes (e.g., sea level, streamflow runoff) that may represent hazards.
  - **Understanding exposure and vulnerability to enable risk identification**. This step involves identifying the pathways that link hazards to risk (i.e., cause-and-effect pathways), including decision-making criteria identified at Stage 2. Risk end-points are taken forward into the risk evaluation.
  - **Risk evaluation**. This involves analyzing the likelihood of occurrence and severity of consequence.

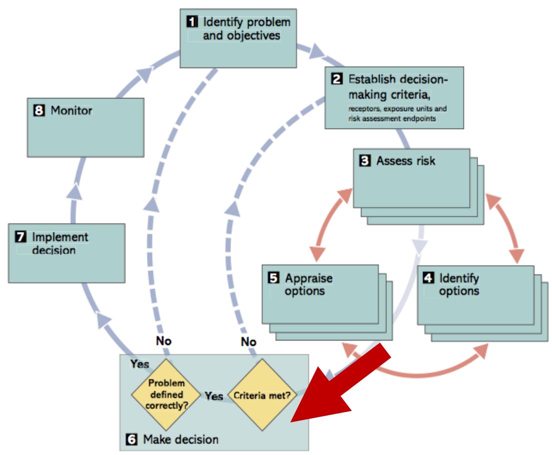
- **Stage 4** – Identify options: At this point, adaptation options are identified that are robust to climate change, and provide the greatest likelihood of meeting the objectives and criteria defined in Stage 2. In particular, focus is placed on finding 'no regret' and 'low regret' options.



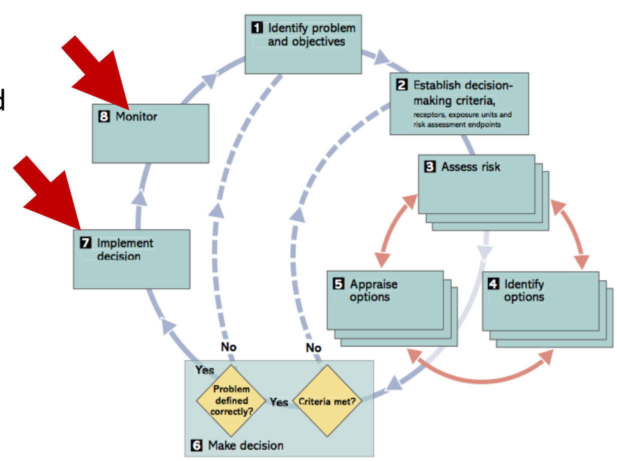
- **Stage 5** – Appraise options: Options appraisal is closely linked with risk assessment and comprises evaluation of the adaptation options against the success criteria established in Stage 2. The purpose of the options appraisal stage is to provide a robust basis upon which to identify and recommend the preferred option to meet the overall decision criteria.



- **Stage 6** – Make decision: This is the final stage before implementation and involves bringing the information together, evaluating it against the objectives and defined decision criteria. This may include a review of whether the decision objectives and criteria remain appropriate in the light of the preceding analysis.

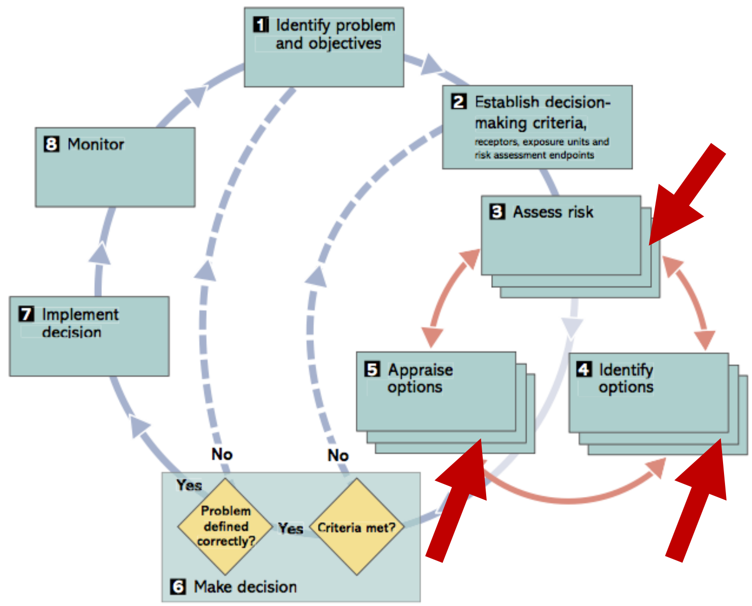


- **Stages 7 and 8** – Implement and Monitor: These represent post-decision actions and encompass a large variety of potential activities, which are context-specific.



1.5 How might the risk assessment process be aligned with the specific needs of an installation?

Note that Stages 3, 4 and 5 of the recommended risk- based framework are "tiered" to provide maximum flexibility (these tiers are represented in Figure 2 by the overlapping boxes). Each tier reflects a different level of decision making and links decisions to an appropriate pathway for assessment and analysis.



Tier 1 consists of preliminary risk assessment; **Tier 2** outlines qualitative and generic quantitative risk assessment; and **Tier 3** details specific quantitative risk assessment tasks. The tiers assist in aligning the assessment process with the specific needs of a facility.

In practice, different tiers will be used depending on:

- the level of decision (i.e., at the policy, program, or project level);
- the level of understanding they have about how climate change will affect their decision, which will be determined in part by previous assessment iterations; and
- whether a decision maker is making a **climate adaptation decision** (in which case they will have already identified climate change as a significant risk as part of a Tier 1 preliminary assessment) or a **climate-influenced decision** (in which case they will be less certain of the implications of climate change).

We have adapted a matrix of risk assessment from the work of Willows and Connell (2003) to summarize how decision making is linked to the tiered levels of risk assessment in Table 1. This matrix serves as a guidance for selecting the appropriate tier of risk assessment as users work through stages 3, 4 and 5.

Table 1. Matrix for selecting the appropriate tier of risk assessment (adapted from Willows and Connell 2003).

	Tier 1 – preliminary climate change risk assessment	**Tier 2 – qualitative, semi-quantitative and generic risk assessment**	**Tier 3 – specific quantitative risk assessment**
Decision level	Policy, Program, Project	Program, Project	Project
Climate change importance to decision-making	Start at this tier if unsure about how, or if, climate change could affect your decision.	Start at this tier if already confident that climate variables are/are not important to your decision.	Use this tier if data are available to support quantitative assessments including climate and impacts.
Decision type	Start at this tier for decisions that may be influenced by climate change.	May start at this tier for climate adaptation decisions, or following Tier 1.	For climate-influenced and climate adaptation decisions, once a range of adaptations options has been identified in "assess risk-appraise options-identify options" loop.
Purpose of risk assessment	For preliminary risk screening, in particular: • identify factors that might be a present or future climate hazard within the exposure unit (acceptable confidence level: low, medium or high); • exclude factors that are not a present or future climate hazard (acceptable confidence level: high); • exclude potential receptors not a significant risk (acceptable confidence level: high); • help to identify, in broad terms, potential climate risk management options under Stage 4.	For risk characterization, prioritization and ranking, in particular: • identify influence, dependencies, causal pathways linking climate to receptors; • assess the (relative) sensitivity of a receptor to climate (and non-climate) hazards, based on agreed assessment endpoints; • characterize the nature of the risk posed to the receptor; • priority and rank of climate and non-climate risks; • help to identify or refine Stage 4 options, including climate adaptation and climate change risk management; • help to appraise Stage 5 options, including options for climate adaptation and risk management; • form reasoned judgments on confidence level (or uncertainty) associated with risk assessment, and the performance of risk management options; • identify important assumptions	Essential where the choice between options, or the effective management of the risk, will be improved by detailed quantitative assessment of the risk or uncertainties, including exploring the sensitivity of the assessment to key assumptions.

The risk assessment tiers in Stages 3, 4, and 5 stages provide an important roadmap for analyzing and communicating various levels of risk as they pertain to decision making and serve as a fundamental step in aligning an installation's function and mission with risks caused by physical changes in climate conditions. This framework also considers non-climate risk factors, such as interactions with neighboring landholders. Tier 1 and 2 risk assessment processes are described in detail in the next several sections. As Tier 3 requires expertise and background information beyond the scope of this user guide we recommend consulting the RC2232 final technical report at https://goo.gl/GtmqYE if users are interested in learning more about Tier 3.

1.6 What are the guiding principles of the tiered levels of assessment?

The tiers in Stages 3,4, and 5 are essential and guide the recommended assessment process by:

1. **Using an iterative process**, which incorporates feedback at a number of stages. Climate change risk management is an ongoing process that will need to adapt as new evidence, policies, technologies, and other factors emerge.

2. **Enabling flexibility**, in order to accommodate complexity. Stages 3, 4, and 5 are tiered, which allows 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 time consuming and sometimes costly quantitative assessments. Like adaptive management, this tiered method is a "bottom-up" approach for 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 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 If they fail, then decisions can be made to immediately adjust options or apply incremental adaptation over a period of time—allowing new information to inform revisions to the adaptation options.

3. **Promoting an open and collaborative approach to decision-making at the onset of assessment.** The framework stresses the importance of taking into account the interests of the installation and affected parties beyond the fence line. A collaborative approach, with active participation, minimizes the possibility of overlooking potential impacts, decision constraints, and differences in the perception of risks and values.

1.7 Where does the Tier 1 Preliminary Risk Assessment process begin, and how is it implemented?

As shown previously in Table 1, the initial Tier 1 primary risk assessment process begins in a one to two-day workshop, which brings together the necessary information, experts and appropriate installation personnel to evaluate the complete array of functions carried out at the installation, as well as representatives of key stakeholders beyond the fence line (e.g., land owners, transportation and access agencies, communities immediately adjacent to the installation), and organizations (e.g., city or county emergency managers, water resource managers, planners, and others). For the installation, in an ideal situation, participants should include representatives of emergency management, facilities and infrastructure management, financial planning, long-term planning, medical services, natural resources, operations, and training. The reason for such broad representation, is to ensure that there is sufficient input from all aspects of operating and maintaining the installation that all potential mission critical risks are identified, and all potential linkages between mission critical functions are identified. Under-representation in risk assessment can result in maladaptation--where actions taken in with respect to one mission-critical function, in isolation from other mission-critical functions, can lead to a decrease in the ability to maintain mission readiness in the face of climate change. In practice, we have observed good representation from built infrastructure and transportation planners, emergency management personnel, operations and training personnel, and natural resources personnel. We discuss the initial preliminary workshop process in detail in Sections 1.8, 1.9, and 1.10.

1.8 What types of climate data are DoD relevant for a Tier 1 Preliminary Risk Assessment workshop?

In preparation for the first workshop (and as part of the Tier 1 preliminary risk assessment), it is important to have DoD relevant information available, including historical and projected climate data. To ensure that climate data products are tailored to specific regions and installation requirements using high-quality, well-vetted, authoritative climate data and climate change projections is recommended.

Many historical climate and climate change projection datasets exist, including those from the DoD, other federal agencies, and research institutes. The choice of historical data may depend on needs for spatial specificity (i.e., understanding change for a very specific location or watershed), as well as needs for a long history, in order to establish an adequate understanding of climate variations and trends. In the initial qualitative risk assessment phase, we used regional historical climate data from PRISM (Daly et al. 2008; website URL for PRISM), one of several high-quality, spatially complete, interpolated data sets for the United States. Our project used climate change projections from the Third U.S. National Climate Assessment (Melillo et al. 2014), which have undergone thorough review, and are freely available.

The following climate change web resources may be useful to newly engaged DoD mangers and those new to climate change risk assessment:

The U.S. Climate Resilience Toolkit

The U.S. Climate resilience toolkit contains over 200 digital tools for building resilience, increasing engagement and developing a climate action plan. The toolkit connects to several datasets, scalable tools and programs as well as outlines an essential framework for identifying and responding to climate-related challenges. The framework was integrated within Project RC-2232 and guides users to explore climate threats, assess vulnerability and risk, investigate options and prioritize actions. Moreover, the toolkit has a Climate Data Explorer application, which allows users to visualize climate data and projections, for multiple parameters and for multiple greenhouse gas emissions scenarios. https://toolkit.climate.gov/

The National Climate Assessment

The NCA summarizes the current and future impacts of climate change on the United States. A Federal Advisory Committee produces the NCA by coordinating efforts of 300+ researchers that contribute to the comprehensive assessment. Each assessment is extensively reviewed by the public and experts, including federal agencies and a panel of the National Academy of Sciences. The NCA collects and integrates observations and research from around the country and includes analyses of impacts on seven overlapping sectors: human health, water, energy, transportation, agriculture, forests, and ecosystems, and considers the interactions among sectors at the national level. Key impacts on the Northeast, Southeast and Caribbean, Midwest, Great Plains, Southwest, Northwest, Alaska, Hawai'i and Pacific Islands regions, as well as U.S. coastal areas, oceans, and marine resources are presented in the NCAs. The most recent assessment NCA3 was produced in 2014, and updated NCA4 is expected to be released in late 2018. http://nca2014.globalchange.gov/

UK MoD: Building a Climate Resilient Estate - A Practitioner Guide.

The UK Ministry of Defense has outlined a framework for building a climate resilient estate using a defense infrastructure and organization approach.
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/33599/20120529PG01_12BuildingaClimateResilientEstateFinalv10U.pdf

For more in-depth quantitative assessments, it may be necessary to use installation-specific projections, based on authoritative and easy-to-access downscaled climate projection data archives (e.g., Abatzoglou 2013; Maurer et al. 2007). In some cases, highly specialzed technical data may be needed and for this we suggest reaching out to regional researchers and climate experts for guidance and potential training opportunities. Existing databases may also support various phases of risk assessment - for example, for climate impacts research that used vegetation, fire, and hydrological process models, we used future gridded regional climate projections from existing databases (e.g., Abatzoglou 2013; MACA 2014) that were designed to be applied to fire impacts of climate change. These sources because they have been well-vetted, are broadly perceived as credible and authoritative, and provide timely and easy-to-access data and analyses suitable as points of departure for discussions about climate risks, and adaptation to potential climate changes. We have listed 2 credible web database resources here, and additional web based resources and regional centers of expertise may be found in the appendices.

US GCRP Global Change Information System

The GCIS is a collection of open-source web-based global change data, information, and products. GCIS assists users through coordinated links to a select group of information products produced, maintained, and disseminated by multiple government agencies and organizations. Users are able to access assessments and reports from multiple federal agencies, as well as query searchable datasets produced by the U.S. Global Change Research Program.

https://data.globalchange.gov/

PRISM

PRISM is a set of high-resolution spatial climate data that provides monthly, yearly, and single-event gridded data products of mean temperature and precipitation, max/min temperatures, 30year norms and dew-points, primarily for the United States. The PRISM Climate Group develops spatial climate datasets to reveal short- and long-term climate patterns. PRISM datasets are available at various spatial and temporal resolutions and cover the period of 1895 to present. PRISM climate data is maintained by the Northwest Alliance for Computational Science & Engineering (NACSE), based at Oregon State University. The website allows the user to download regional data at timescales as fine as months or days, and for individual grid points, if needed.

http://prism.oregonstate.edu/

1.9 What techniques and tools are used in the initial Tier 1 preliminary risk assessment workshop?

Successful workshop outcomes require bringing the "right people to the table" to provide perspective, expertise, and appropriate background information. Producing measurable outputs during workshops also require completion of well aligned objectives. In this section we describe steps in the process of convening a workshop in order to assess climate change risks at DoD installations. We applied this process at Naval Base Coronado, and the Barry M. Goldwater Ranges. The process has similarly been applied numerous times in the United Kingdom, by the climate adaptation consultants, Acclimatise (http://www.acclimatise.uk.com/). A direct benefit of the workshop process is the development of a common understanding of climate-related decisions across a variety of mission-related functions, which decreases the likelihood of generating a maladaptive approach to dealing with climate change.

1.10 What benchmarks should be met during the initial Tier 1 preliminary risk assessment workshop, and how can they be measured?

As previously mentioned, gathering together the appropriate individuals over the course of a few days and providing installation relevant climate information are essential workshop elements. Communicating clear and measurable workshop objectives is equally important as it provides a common understanding of expectations for the initial workshop, and offers a benchmark for measuring success. Post workshop debriefs and feedback also provides organizers and participants with opportunities to improve the workshop process for follow up activities.

The objectives of the initial workshop are to:

1. Identify and discuss key climate risks to and how these are affected by, and affect the decision-making process for key land, highway, and resource managers—including managers of adjacent lands.
2. Discuss how existing risks are managed AND how this may change in the future.
3. Identify the information gaps for adequately managing future risks.
4. Start to identify information, models and tools needed to manage priority climate risks.

To complete Objective #1:

1. In small groups, with expertise intermingled, discuss recent weather-related impacts and consequences for the installation. Identify shocks to the system, and weak points. Understand how the installation prepared for and responded to these episodes.
    a. This exercise aids in understanding exposure to severe weather events, vulnerabilities, and the associated direct and indirect consequences.
2. In small groups divided by function or expertise (e.g., built infrastructure, natural resources, operations, training, transportation) define the objectives and mission success criteria of the installation, and of neighboring agencies. Questions may include: What is our group's primary role at the installation or as a neighboring entity to the installation? What are the success or decision-making criteria for __________, and how do we judge success? What key issues, policies or decisions are we considering now?
    a. This exercise aids in ensuring a common understanding of broad objectives and success criteria, so that when you move on to identify risks, the causal chains linking success or failure to climatic factors can be identified.

To complete Objective #2:

1. Present a brief history of climate and weather conditions for the installation. Include best understanding of average and extreme conditions, and long-term trends. We recommend tailoring the information to focus on key seasons, and phenomena that have demonstrated effects (e.g., hurricane season, El Niño, monsoon season).
2. Present, briefly, key projections of future climate, focusing on (a) key seasons, (b) important climate and weather phenomena, (c) related variables (e.g., sea level), (d) levels of certainty and confidence in the projections. We recommend using multiple future climate scenarios, based on key concerns (e.g., a much hotter or drier future), or different emissions scenarios.
3. In functional groups, using the success criteria identified in Objective #2, generate an inventory of risks and opportunities associated with the future climate scenarios. Where possible, identify key sensitivities and critical thresholds. Then, prioritize these risks and opportunities, based on the following criteria:
    - *Critical thresholds may be breached*
    - *Systems highly sensitive to changes*
    - *Decisions with long-term consequences*
    - *Where "failure is not an option"*
4. Recognizing that risks are trans-boundary and likely to cut across areas of performance, different organizations and community divisions, explore risk interconnections. Participants from each functional group circulate and review other group's inventory of climate change risks and opportunities, and highlight the consequential risks to their own group.

5. Summarize a master list of key issues, and present it to the whole group. Participants vote on the priority risks identified across functional groups.
   a. The purpose of this exercise is to reach consensus on the issues participants felt were most critical to installation.
6. These exercises generate a preliminary assessment of risks, cross-cutting risks, and priorities to address in quantitative risk assessments, and in adaptation strategy and planning exercises.

To complete Objectives #3 and #4:

1. Take as subset of most critical risks identified in Objective #2. Functional groups discuss how they are currently managed and how future experiences with these risks may be managed. To focus the discussion, for each risk, answer the following questions:
   - *Roles and responsibilities – Who manages this risk?*
   - *Existing guidance – What current plans are currently in place for this risk?*
   - *Existing controls – What is the process for dealing with this risk?*
   - *Needs – What informational/human resources/financial resources/monitoring is needed?*
   - *Barriers – What is getting in the way, or may get in the way of responding?*
   - *Opportunities - What factors promote response, and are there benefits to acting now?*

1.11 How might critical thresholds, risk registers, and causal risk narratives support the co-identification of risk during the initial workshop?

Co-Identifying and communicating risk often feels like an overwhelming task. Here we define critical thresholds and introduce the concepts of linking critical thresholds, risk registers, and risk casual narratives as part of the expert assessment approach. During our work with installations we found these concepts to be useful tools for tackling risk assessment. By using these concepts to frame risk, we were able to steps through the risk assessment process in an efficient and less daunting manner.

Critical thresholds represent the boundaries between 'tolerable' and 'intolerable' levels of risk. Figure 3 demonstrates what can happen to a critical threshold in the future, when this threshold is based on a stationary (historic) climate. The critical threshold may for example be a maximum safe working temperature for training exercises, or the height of a flood defense. In a stationary climate, the threshold may be designed to tolerate infrequent breaches and its consequences. In a future climate, the threshold may be crossed more often and with greater intensity, now representing an intolerable level of risk. For continued successful operation, this would require adaptation (blue area) in order to raise the acceptable threshold. Referring to this image during the preliminary workshop may help frame the discussions.

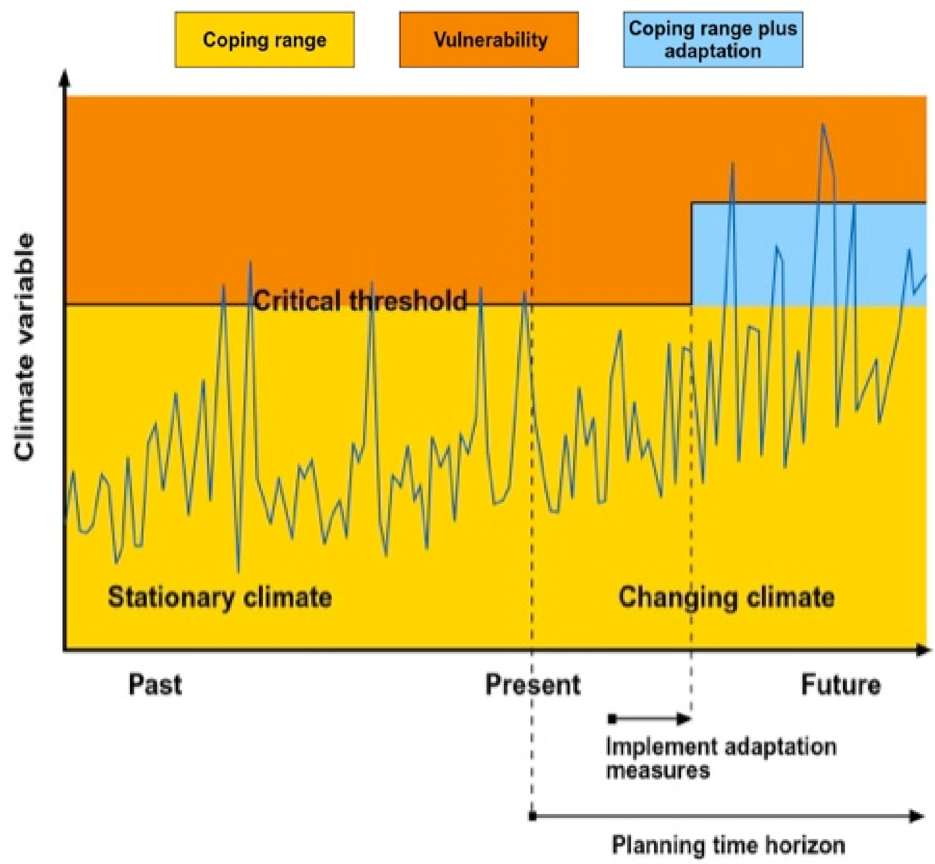


Figure 3 The relationship between coping range, critical threshold, vulnerability, and a climate-related performance criterion.

The **expert assessment approach** uses a semi-quantitative technique applied to risks identified by workshop participants. The aims of this approach are (a) to document and organize the causal linkages between climate (e.g., increased temperature), intermediate process (e.g., vegetation and endangered species habitat change), and consequence (e.g., restrictions in land available for training), (b) to link them to the workshop success criteria and risk priorities, and (c) evaluate risk, based on likelihood (which can be qualitative or quantitative) and consequence (e.g., qualitative or quantitative assessment of impact). The result is a **risk register** (or list) of qualitative and quantitative assessment information regarding individual risks. A direct benefit of the risk register expert assessment process is the development of cause-and-effect chains, that link climate drivers of change with consequences for functional areas (e.g., operations, training, land management), and the ability to quantify aspects of risk, such as asset vulnerability, potential for injury or loss of life, and so on.

The expert assessment approach can be used in a generic manner, but to adequately quantify risk, it is best applied to existing risk management methodologies used by the appropriate military branch. Cause and effect linkages allow for quantitative modeling, such as in further iterative steps for follow-up assessments. We give a generic hypothetical example in Table 2 showing the structure of a risk register, and a specific example from Naval Base Coronado. To provide consistency of description, one can also develop **risk causal narratives**, based on input garnered from the risk assessment workshop. These narratives clearly link climate to impact, through the “cause”, “process” and “consequence” categories and are also reflected in Table 2.

Table 2 . Generic example of a register, for assessing and quantifying climate-related risks. The risk scoring criteria, in the Likelihood and Impact columns, are defined in collaboration with individual installations. Here, we show qualitative assessment of likelihood and impact; these can be quantified, if sufficient data are available, or if a semi-quantitative rating system is used in risk assessment

Reference (e.g., Environment = E, Facilities = F, Operations = O, Training = T)	**Climate driver** (cause)	**Process**	**Consequence**	**Risk category** (linked to success criteria, from workshop)	**Number of votes at workshop**	**Likelihood** (A = Very high; B = High; C = Significant; D = Low; E = Very low; F = Almost impossible)	**Impact** (I = Show stopper; II = Critical; III = Marginal; IV = Negligible)
F1	Increased likelihood and severity of exceptional drought	causes increased competition for resources	with consequences that supplies may be reduced in favor of supply to other local users	Third party infrastructure	15	A	I
O1	Sea level rise and higher wave surge	causes coastal flooding and erosion	with the consequence that it is difficult to maintain a perimeter around installations	Safety	10	B	II
T1	Incremental climate change	causes change in use of space	with the consequence that land available for training is restricted, with affects for operational readiness	Encroachment	10	B	II
O2	Incremental climate change and extreme events	cause changes in the natural environment	with the consequence that costs associated with emergency preparedness increase (equipment, drills)	Emergency Preparedness	5	C	IV

1.12 CASE STUDY 1: How was the *Expert Risk Assessment Approach* used at Naval Base Coronado (NBC)?

The mechanics of the risk assessment process used at NBC draws on existing U.S. Navy risk management methodologies, in order to ensure that the process is familiar to installation personnel and that the outputs can be easily integrated into existing threats, hazards and consequences procedures. We procured existing risk management methodologies from the U.S. Navy Installation Emergency Management Program Manual (CNI 3440.17), Standard 4 notes that *"Emergency Management planning must be predicated on critical asset, threat/hazard, vulnerability, consequence, and response capability assessments. These assessments are used to evaluate an installation's ability to respond to a threat/hazard, protect the population on the installation and implement future strategies to mitigate risks"* (U.S. Navy 2006). Risk is defined in The Manual as being: *"a function of threats/hazards, vulnerability to threats/hazards, and resulting consequences if these threats/hazards were to strike a critical infrastructure on an installation".* The following equation is used to provide a quantitative assessment of the relative risks posed:

$$Risk = \frac{Critical\ Infrastructure\ (CI) \times [Threat\ (T)\ or\ Hazard\ (H)] \times Vulnerability\ (V) \times Consequence\ (C)}{Response\ Capability\ (RC)}$$

Each of the components of this equation, and assumptions made in our application of the equation to climate change risk assessment are discussed in more detail below. Importantly, we assume that that no additional adaptation measures are in place to address climate change (i.e. the green line in Figure 4) – rather than rating risks post-adaptation (red line in Figure 4). This will allows personnel to consider how significant the risks of climate change could be, if no adaptation action is taken.

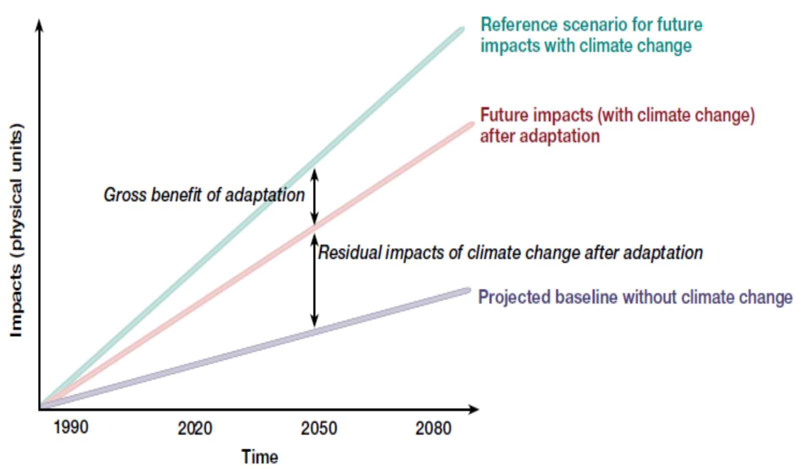


Figure 4 Illustration of climate change risks in absence of adaptation (difference between green line and blue line) and residual risks post-adaptation (difference between red line and blue line) adapted from Metronomica (2004).

Table 3. Example risk causal narrative from NBC. Risk reference codes relate to the workshop breakout groups, where risk was originally identified: O = Operations, F = facilities, T = Training and EN = Environment.

Risk ref no.	Causal narrative		
	Cause (climate driver)	Process	Consequence
F12	More frequent heavy downpours of rain	causes flooding of underground infrastructure	with the consequence that critical IT, power and water supply may be affected

In cases where climate drivers were unspecified and simply termed *"climate change"* or *"global warming"*, we used the standardized term *"incremental climate change"* to describe the slow, 'creeping' manifestations of longer-term climate change (e.g. increase in temperatures over several decades). This term has also been used in cases where specifying the exact climate drivers is particularly challenging (e.g. factors that determine outbreaks of infectious diseases). We used the term *"extreme events"* to describe acute climate variability, both over short and longer timescales.

- An *extreme weather event* is typically associated with changing weather patterns, that is, within time frames of less than a day to a few weeks.

- An *extreme climate event* happens on longer time scales. It can be the accumulation of several (extreme or non-extreme) weather events (e.g., the accumulation of below average rainy days over a season leading to substantially below average cumulated rainfall and drought conditions).

Some climate extremes (e.g., droughts, floods) may be the result of an accumulation of moderate weather or climate events (this accumulation being itself extreme). Compound events, that is, two or more events occurring simultaneously, can lead to high impacts, even if the two single events are not extreme per se (only their combination). Finally, not all extreme weather and climate events have extreme impacts.

There is an increasing body of empirical evidence suggesting that extreme weather events have become more common in recent years, and the majority of scientists relate the increased frequency and intensity of such events to climate change. Looking forward, the recent IPCC report (2012) on extreme weather events judged it *"very likely that the length, frequency, and/or intensity of warm spells or heat waves will increase over most land areas"* and *"likely that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe"*. The generally well-documented nature of extreme events has generated greater interest in planning for more severe and frequent climatic events. In contrast the "creeping" average changes are much harder to recognize and are more likely to be overlooked. To identify the risks associated with both incremental changes and extreme events, the terminology used in the risk causal narratives highlights this distinction.

Critical infrastructure (CI) value: *Using the guidance provided in The Manual, NBC is an operational base and therefore we assigned all risks a critical infrastructure value of 2. The NBC risk assessment was undertaken at a strategic / installation-wide scale (rather than individual asset-scale), the critical infrastructure value has been standardized across all risks.*

Threat (T) or hazard (H) probabilities: As shown in Table 4 the hazard assessment criteria is composed of two elements: Hazard Relative Probability (Values) and Onset Values. Each of the climate drivers were assigned a Hazard Relative Probability score, as shown in Table 3. For the Onset Values, each individual risk causal narrative was reviewed and the definitions outlined in The Manual were applied unchanged.

Table 4. Hazard Relative Probability score for each of the climate drivers assessed.

Relative ranking	Climate driver	Hazard Relative Probability	Reasoning
1	Incremental climate change	10	Based on observed climate data over the past few decades, warming of the climate system is unequivocal (IPCC 2013). The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased. There is high confidence and high certainty that these trends will continue over the next few decades, irrespective of efforts to reduce greenhouse gas emissions, due to inertia in the climate system.
2	Sea Level Rise	10	There is high confidence and high certainty.
3	Extreme high temperatures	10	There is high confidence and high certainty.
4	Warmer and drier	2	Warmer is very certain, but drier (less precipitation) is less certain. Some of the uncertainty regarding precipitation is due to natural year-to-year and decade-to-decade variations.
5	More frequent heavy downpours	1	Currently, there is no trend in this statistic.
6	Sea level rise and higher wave surge	0.5	Sea level rise is very likely, but future higher wave surge is unknown because future changes in storm intensity are highly uncertain and the science of modelling wave surge from coarse-scale (i.e., modelled storm system) data is not refined enough for looking at the spatial scale of the NBC beachfront.

Vulnerability (V) value: *As defined in The Manual, critical asset vulnerability values for natural hazards are assessed based on the following criteria:*

- *Compliance with building construction codes and HAZMAT Storage/Handing codes;*
- *Sheltering-in-Place, Evacuation Plans, Mass Notification System; and*
- *EM Awareness Training.*

Each individual risk causal narrative was reviewed and the definitions outlined in The Manual were applied unchanged, based on our team's professional judgment, as informed by feedback from installation personnel, to validate our assessment. We assumed that compliance with health and safety, and environmental regulation, will be particularly stringent and as such, risks containing these elements were typically given a low vulnerability value.

Consequence (C) value: The consequence value is based on a sum of the following criteria (each of which has a 5-point scoring scale):

- Installation Death or Injury;
- Installation/Asset Infrastructure (includes environmental remediation by EPA); and
- Asset Mission Capability.

For our assessment, we reviewed each individual risk causal narrative and we applied the definitions outlined in The Manual unchanged, based on our team's professional judgment. Using the guidance provided in The Manual, NBC's existing response capabilities are Group 1; therefore, all risks were assigned a **Response Capability value (RC)** of 8 (the factor under consideration is a Natural Hazard). Table 5 shows an excerpt of semi-quantitative climate risk assessment for NBC, using the combination of the risk register approach and the U.S. Navy Installation Emergency Management Program Manual (CNI 3440.17).

Table 5. Example of semi-quantitative climate risk assessment, applied to U.S. Navy Installation Emergency Management Program Manual scoring protocols.

REF#	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	**Risk**
F03	Warmer and drier conditions	causes increased risk of wild fires	with the consequence that training grounds and buildings are damaged / destroyed; environmental damage occurs	I		2	2	2	0.5	5	1	2	2	8	12.5
OP19	More frequent heavy downpours of rain	causes flooding of sewer systems and lift stations	with the consequence that mission essential services are compromised	XC	3	2	1	2	0.5	5	0	1	1	8	3.75
T10	More frequent extreme high temperatures	causes heat stress	with the consequence of loss of training days	XC		2	10	0	0.1	5	1	0	1	8	2.5

1.13 Where does the Tier 2 Follow-Up Iterative Risk Assessment begin, and how is it implemented?

Tier 2 interactions begin with a less structured, but more iterative, approach of one-on-one dialogue with personnel, ongoing interactions through field work and semi-structured group updates, and debriefing workshops, in order to address the particular risks at DoD installations. This level of interaction more clearly and viscerally connects immediate concerns and actions with the implications of potential future climate changes; this approach can open the door to further discussion of climate change in relation to other installation-level decisions. Whereas the aforementioned interactions may follow any number of styles of interaction, the cornerstone of the assessment is detailed quantitative risk assessment, based on the aforementioned dialogues.

To examine connections between current threats and future risks at the installation level, the Tier 2 process follows up on the findings from initial risk assessment workshops. The first step is to refine the understanding of risk, by working together with personnel to formulate a series of research questions addressing perceived links between current or recently experienced climate-related threats to installation operations, personnel, or training. The result of these discussions is a set of prioritized climate challenges, aimed at exploring a range of available information and methods to address one or more of the challenges at the installation. Next is a set of preliminary analyses to precisely summarize and quantify relevant trends from historical data, and from new field data collections, if necessary to augment existing data. Generating new data or assessments of the current baseline status of ecosystems or infrastructure engenders trust and adds value to the process. When using regional and national geospatial information, it is important to ground-truth the information, by local personnel or researchers from our project, to garner trust in the data and the process.

Following the initial steps, preliminary custom modeling, using appropriate process-based models, can be used to project climate effects to, for example, ecosystem processes and hydrology. It is important to present preliminary results and engage in iterative discussions with personnel, to discuss climate-associated risks, to modify the approach—to better align research outputs with installation relevant climate concerns. In addition, clear and transparent presentation of assumptions and uncertainties is essential to quantifying risk, and satisfying participants of the legitimacy of the process. Final modeling results, then presented to a larger audience of personnel, resource managers, and commanding officers, can be used as a basis to discuss how locally applicable, and well quantified, climate risk information can be integrated into current planning, funding, and operational frameworks.

The combination of iterative discussion, modeling, debriefing, model refinement, and so on mutually reinforces the identification of risk and the diffusion of science results to inform decisions. The development of specific modeling results, in the mode of a consultation (i.e., the installation has a particular issue, and the science consultant provides an estimate or *answer* to the issue), can be beneficial in the short run; the equivalent of, as the adage goes, providing a hungry man with a fish. The addition of a structured process to *co-identify* risk, and evaluate perceptions of current and future risk in light of projections of current and future risk, enables the development of capacity to use scientific results in light of uncertainty—or teaching the hungry man how to fish. This so-called "discussion support," in which models are used to provide an array of plausible potential futures, explore "what if" questions, interpret model results in light of uncertainties, develop strategies, and evaluate the need to implement strategies and whether to implement strategies in the near future, or at a decision point down the road. The iterative process provides more information than a typical answer-oriented consultation, and confirms whether perceived risks are validated by scientific information.

1.14 What steps must be taken in the Tier 2 Iterative Follow-Up process?

The follow-up iterative risk assessment process requires foundational work during which experts facilitate meetings and coordinate actions to co-identify initial climate-related risks with installation personnel, using tier 1 risk assessment workshop process described in earlier sections. Researchers must meet with installation personnel, from the entire array of installation operations and management processes, to qualitatively understand the spectrum of climate-related decisions, the ways in which decisions may be affected by future climate, and the relationships between risk and decisions across the many operations and management processes. The goal of the initial engagement is to identify, and prioritize, climate-related risks—for more in-depth assessment through the initial workshop process. We have stepped out steps that should follow the initial Tier 1 workshop process in earlier sections. The Follow-up iterative risk assessment we describe here compliments the initial workshop process and zooms in on steps 3, 4 and 5 previously presented in Figure 2. We have also provided a case study in Section 1.16 to demonstrate a specific example of the Tier 2 level of assessment.

Step 1. Co-Inventory Installation Needs with Installation Personnel

After completing the workshop process described in Sections 1.8, 1.9, and 1.10 researchers meet with installation personnel to understand the command structure, service components, and the training and operational functions performed at each installation. In this step assessment begins with the researchers listening to the concerns of installation personnel and inventorying the challenges or concerns that the installation may be facing.

Step 2. Co-Identify Risks with Installation Personnel

In this step researchers work with personnel in a fieldwork setting to understand landscape and infrastructure vulnerabilities (e.g. visiting training facilities to understand potential fire-flood-vegetation dynamics) and an iterative workshop setting (e.g. conduct briefings with natural resource managers, operations and training personnel) to co-identify detailed site-specific risks, vulnerabilities, and current coping strategies (e.g. vulnerable assets, capacity to address risk)

Step 3. Integrate Climate and Non-Climate Information/Inputs/Models

Informed by previous discussion with various personnel from a variety of service components and command, researchers can now integrate an array of tools such as climate projections (e.g.

temperature, precipitation, emissions models), and remote sensing applications (e.g. fire, vegetation, flood mapping tools) to develop exposure-specific scenarios that illustrate current and future risks, and begin researching various levels of adaptive actions that may be taken (e.g., risks and actions specific to wildfire).

Step 4. Illustrate Vulnerabilities/Risk and Address Uncertainty using Installation Specific Scenarios

Based on input from installation personnel and use of climate and non-climate data, researchers may adopt various imagery/graphics/maps/visual scenarios to convey immediate and future vulnerabilities, and illustrate existing resiliencies, and future opportunities to build capacity. This crucial step creates dialogue which elucidates a shared understanding of risk.

Step 5. Co-Prioritize and Refine Informative Scenarios to Meet the Specific Needs of Installation

Researchers work with installation personnel in an iterative workshop setting (e.g. conduct briefings with natural resource managers, operations and training personnel, and commanders) to a) review functionality and utility of scenarios, b) refine scenarios based on what was deemed useful by installation personnel and c) co-prioritize installation specific risks. Best practices from other sectors may also be integrated here, now that there is a shared understanding of risks.

Step 6. Submit Iterative Risk Assessment and Adaptation Strategies to Installation Personnel/Command

Technical reports submitted should include the results of the risk assessment, co-identified flexible adaptation strategies that may be phased and tailored to installations so that commanders can make informed decisions that are tailored to the needs of the installation, and present a series of go/no go scenarios and adaptive options. The details of implementing these options are eventually determined by installation commanders and personnel and may require further action to continue the iterative process as new policies and budget reforms are handed down from the Pentagon. As each commander transitions, this process ensures the use of credible source materials, maintains rapport with expertise and most importantly, provides continuity between the researchers and the installation.

1.15 Why is the Tier 2 iterative follow-up process necessary for assessing risk?

The combination of iterative discussion, modeling, debriefing, model refinement, and so on mutually reinforces the identification of risk and the diffusion of science results to inform decisions. The development of specific modeling results, in the mode of a consultation (i.e., the installation has a particular issue, and the science consultant provides an estimate or *answer* to the issue), can be beneficial in the short run; the equivalent of, as the adage goes, providing a hungry man with a fish. The addition of a structured process to *co-identify* risk, and evaluate perceptions of current and future risk in light of projections of current and future risk, enables the development of capacity to use scientific results in light of uncertainty—or teaching the hungry man how to fish. This so-called "discussion support," in which models are used to provide an array of plausible potential futures, explore "what if" questions, interpret model results in light of uncertainties, develop strategies, and evaluate the need to implement strategies and whether to implement strategies in the near future, or at a decision point down the road. The iterative process in all of the tiers provides more information than a typical answer-oriented consultation, and confirms whether perceived risks are validated by scientific information.

By using iterative risk assessment, at the Tier 2 level—which produces more detailed, thorough, and quantitative assessment, installation personnel will be better able to connect imminent climate and weather-related risks with projected future climate change-related risks. Without placing future risk into the context of current concerns, climate change messages appear to be too abstract for DOD personnel to devote their limited time, attention, and resources. Base managers (and others) must first understand "how will this affect me?" This is in fact a fundamental lesson in climate communication studies more generally: engaging people in participatory and deliberative decision making that addresses their own experience directly, and addresses their beliefs about their self-efficacy (e.g., that the actions that they take today in their operational job duties will have an impact on a desired outcome), and that motivates constructive engagement—rather than engendering fear or indifference—is an effective way to get their attention about issues that are perceived to be in the distant future (Bostrom et al. 2013; Frumkin and McMichael 2008; NRC 2010). Addressing immediate concerns facilitates engagement, promotes a sense of efficacy, and garners interest in continued engagement and action.

The Tier 2 assessment methods previously described use *multiple future scenarios*, specified by discussion with installation personnel, and which allow installation personnel to explore questions of concern about possible treatments, interventions, or solutions to address climate-related risk. The outputs, model data, visualizations, and reports provide a portfolio of information with which personnel can assess the progress of strategies that have been implemented. Moreover, iteration, through successive phases of field work, modeling, and consultation provides opportunities to better align adaptation strategies and options with existing guidance, emerging issues, and changes in decision-making contexts (e.g., budgets; occurrence of extreme events, such as drought; new operational partnerships). Finally, Tier 2 risk assessment successfully fosters examination of uncertainties, which aids in prioritizing near-term and long-term preparedness and actions. A brief case study using Tier 2 iterative follow-up risk assessment at Fort Huachuca is provided in the next section as an example of how these factors culminate.

1.16 CASE STUDY 2: How was the Tier 2 Iterative Follow Up process used to assess assess fire and post-fire flood risk under current and future climate at Fort Huachuca (FH)?

The landscape of Ft. Huachuca (U.S. Army) in southeastern Arizona has been managed actively for military uses for more than 135 years. As shown in Figure 5, the Fort is flanked by a metropolitan area (pop. 44,000) along its eastern boundary, a National Forest to the west, and a nature preserve to the south. Controlled burning and other active fuel reduction measures are conducted regularly in lower elevation grasslands, but in the ~1/3 of the Fort that is located within the Huachuca Mountains, decades of fire suppression have resulted in high fuel loading in much of the Madrean juniper, oak, pine, and dry mixed-conifer forest along the 1,350 m ascent from the lower basin to the central ridge of the mountain range.

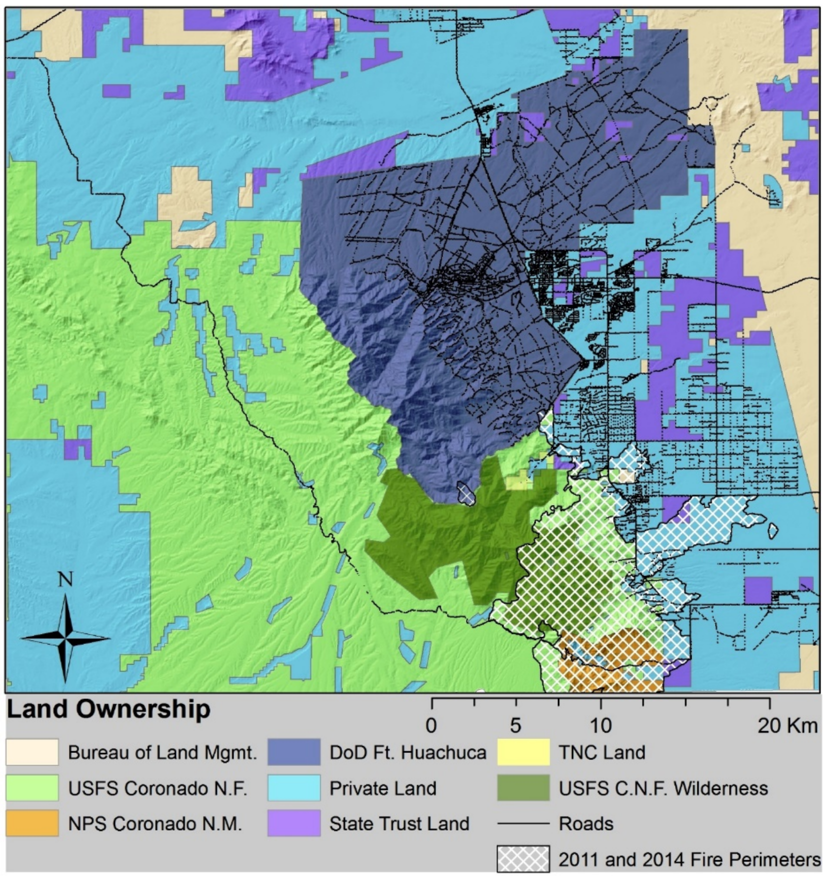


Figure 5 Mosaic of land ownerships near the Army installation at Fort Huachuca, Arizona.

As mentioned by installation personnel, in a preliminary vulnerability assessment workshop, and in subsequent Tier 2 risk assessment conversations, fires and post-fire flooding are significant concerns for resource managers at Fort Huachuca and surrounding land ownerships. Fort Huachuca shares boundaries with the USFS Coronado National Forest (Coronado N.F.), Private land owners in and around the city of Sierra Vista, the State of Arizona, and the Bureau of Land Management. Wildland fires and floods starting in any of the adjacent ownerships is likely to affect neighboring land owners.

A June 2011 fire that started on nearby Coronado National Monument burned 12,230 ha of federal, private, and city lands, including a section of The Fort (Figure 6); almost 50% of the fire burned at moderate to high severity, resulting in substantial post-fire flooding and debris flows during summer thunderstorm soon after the fire (Youberg and Pearthree 2011).
Climate projections for the region suggest that increased temperatures, and decreased late winter and spring precipitation will result in a longer fire season during upcoming decades. This growing window for fire ignition and spread coincides with abnormally high fuel loadings, fuel continuity, and a 30-year trend of larger, more severe wildfires across the region (O'Connor et 17al. 2014). Sensitive U.S. Army infrastructure, located at the mouth of Huachuca Canyon, is exposed to substantial risk associated with the combination of increasingly severe fire conditions and post-fire monsoon flooding. Other climate-related risks at the Fort include invasive species, climate impacts on fuels and plant communities, safety, and interruption to the installation's training mission. Land management decisions in this extremely diverse landscape are also influenced by threats to habitat of sensitive wildlife species.

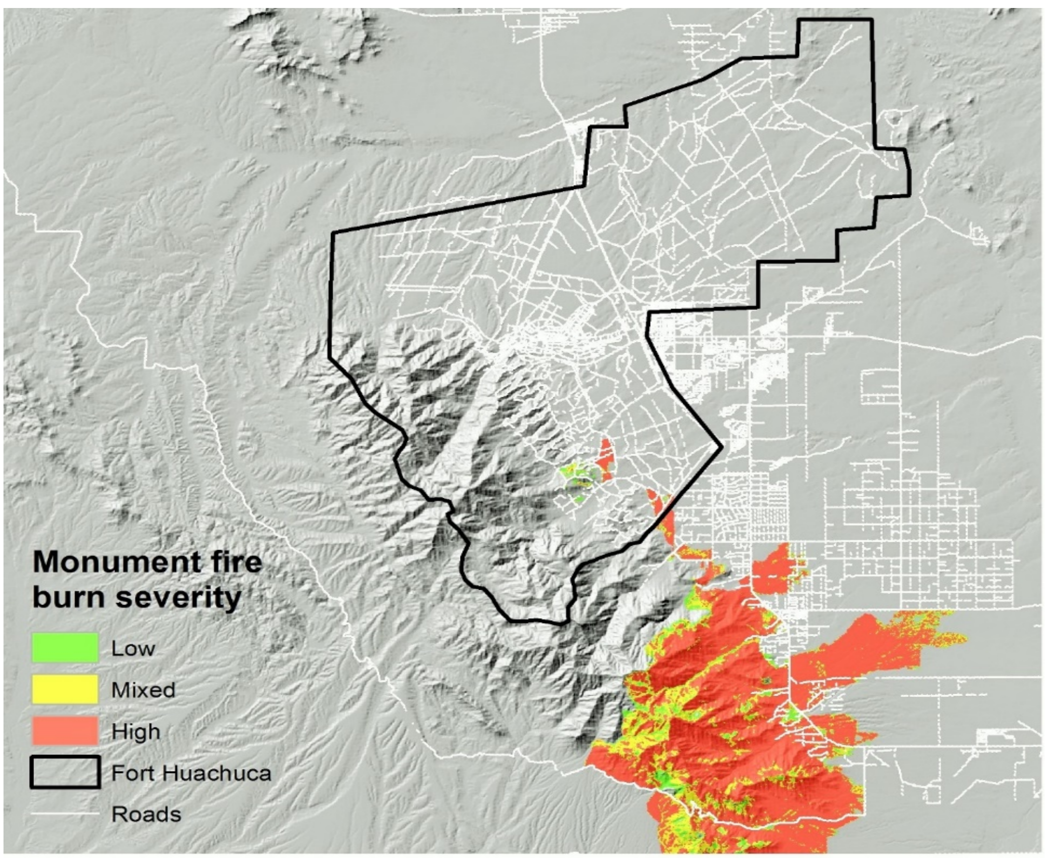


Figure 6 The 2011 Monument fire narrowly missed Fort Huachuca, and threatened the town of Sierra Vista, Arizona to the south. Vegetation burn severity classes are relativized difference Normalized Burn Ratio (rdNBR) classified using values from Miller and Thode (2007).

Fort Huachuca staff requested an assessment of projected changes to vegetation, fire, and flood risk over the next several decades. Scenarios, developed along with Fort natural resources personnel, specified continued fire suppression activities, with and without fuel reduction treatments designed to reduce fire severity. The scenarios also assumed the need for coordination with adjacent, beyond the fence line, landholders, in order to address significant overlaps in shared fire risk. Using an iterative process of discussion, modeling, and scenario refinement, our group developed multiple scenario projections of climate change and fire effects on the Huachuca Mountains landscape; these scenarios incorporated existing information from previous studies quantifying fuel loading, fire history and fire risk to wildlife. The team adapted a modeling system that was originally developed for forests of the Northern Rocky Mountains (O'Connor 2013), and input regionally-downscaled projections (Abatzoglou 2011), based on an ensemble of three CMIP5 global climate models known to provide an adequate representation of the highly seasonal regional precipitation regime (Sheffield et al. 2013). Model results suggested that, by mid-century, there would be a plausible and significant reduction in total plant biomass and an increase in peak flow flood potential, associated with increasing risk of high-severity fire in the projected altered vegetation (Figure 7). Results also suggested decreased potential fire severity, if increasing levels of fuel treatment activity were applied by the installation's natural resources managers and managers of neighboring landholdings.

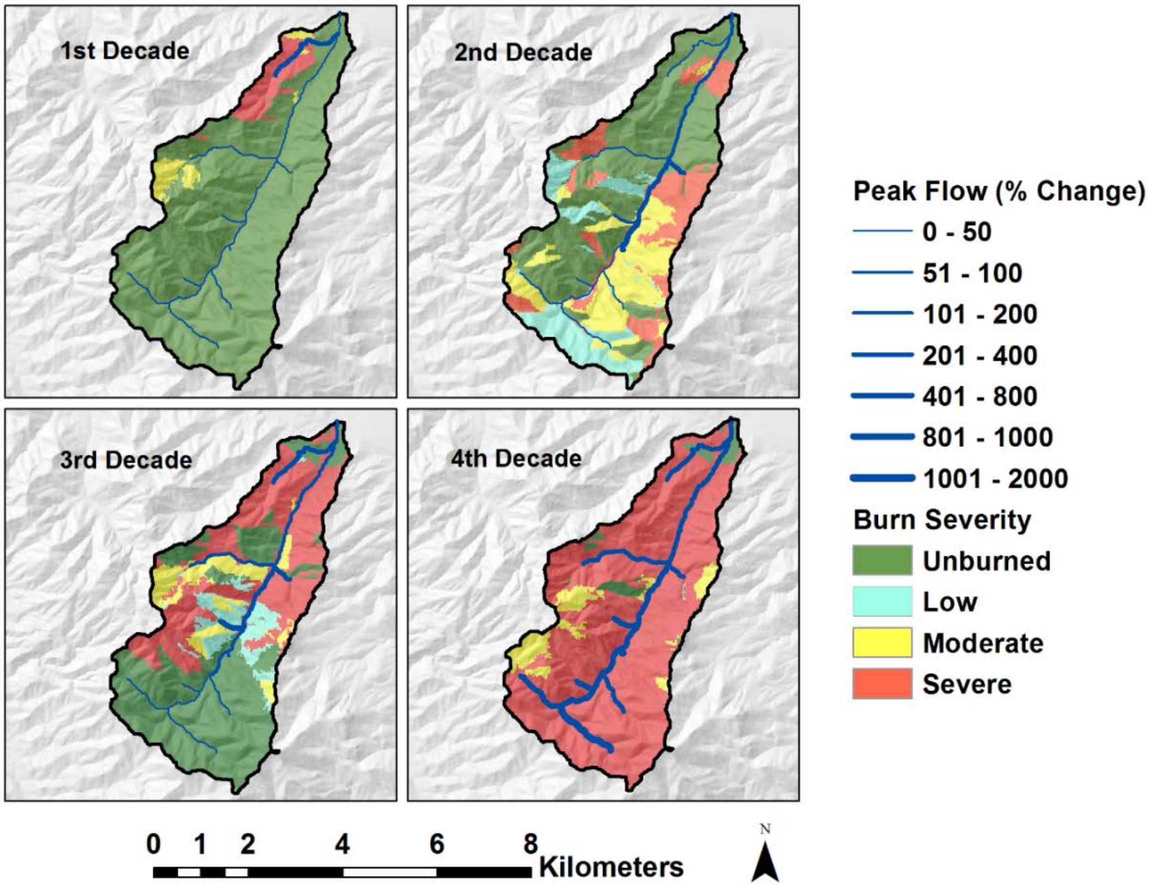


Figure 7 Simulated flood intensity (peak flow, percent change from 2010 baseline) projected one to four decades following climate driven increases in fire severity and changes in vegetation/fuel type In Huachuca Canyon, Fort Huachuca, Arizona. Figure adopted from O'Conner et al. (2015) courtesy of Brian S. Sheppard.

Debriefings with personnel representing natural resource management, emergency management, and built infrastructure, along with the garrison commander fostered diffusion of key ideas about future fire risks, as well as current and near-term strategies to mitigate risks. A pilot program to implement fuel reduction treatments and restore fire resilience to woodlands catalyzed cooperation among managers from surrounding ownerships. Subsequently, multiple land managing agencies agreed to carry out fuel treatments jointly on their adjacent lands. This model of synergy among local, regional, and national resources to develop a cooperative climate change risk response could be applied to other DoD installations, with the co-benefit of improving relations with local communities.

SECTION 2. LESSONS LEARNED FROM OTHER SECTORS

During our project cycle we were able to identify a range of adaptation strategies that integrate climate change services with planning and management efforts. In addition to interactions with the initial 4 study sites mentioned in the introduction of the user guide, examples from foreign defense forces and non-defense sectors were identified to further inform SERDP of approaches worthy of significant consideration. In this section we draw upon lessons learned from British and Australian militaries, the State of California, the Ports of Los Angeles, Humboldt Bay and San Francisco Harbor, the Port Authority of New York & New Jersey, and the extractives sector. Each of these cases has qualities similar to DoD in that these organizations are challenged with integrating climate change and uncertainty within their planning and operational practices. These sectors are also similarly confronted with lowering costs, increasing resilience and minimizing risk. Lessons gleaned from other defense forces and sectors may be applied broadly in assessment and adaptation activities.

2.1. How are other defense forces adapting to climate change?

A principal finding across domestic and foreign defense forces is that if mission readiness is key, then climate risk management should be reframed in terms of capabilities not installations. Rather than focusing climate risk assessments on an asset by asset basis, our research demonstrates that there are many opportunities to refocus on risks to mission readiness and capabilities.

Australian Defense Force

In vulnerable regions such as the Asia-Pacific, in which over half of the world's natural disasters occur, it is likely the Australian Defense Force (ADF) will be called upon more frequently to deliver humanitarian assistance. A changing climate is also likely to affect critical military infrastructure. Sea level rise and changes in magnitude and frequency of extreme weather pose a risk to defense property such as naval and military bases (Barrie et al. 2015). The importance of these risks is emphasized in the adaptive approach being adopted by the ADF. The ADF is now faced with increased frequency and intensity of heatwaves, when coupled with overall rising temperatures, this will have health implications for ADF personnel working, training, and exercising under those conditions. To examine how sea level rise will affect the ADF's bases, the military spent AUS$2 million on research (UNISDR ARISE n.d.).

The research, carried out by international engineering and consulting firm AECOM (2016) in partnership with the United Nations Office of Disaster Risk Reduction, involved a two-stage process with high-level risk assessments and prioritizations of sites at higher risk, followed by detailed site assessments and the identification of adaptation options and was acknowledged it ADF's *2016 Defence White Paper* (Australian Government Department of Defence 2016a). The 2016 White Paper, which represents the ADF's overall vision and development goals for the next two decades, is fully costed and centered on mission capability. Beyond 2025, the Defence estate footprint will need to be further developed to accommodate new high technology capabilities and ensure that Defence is appropriately postured for future strategic requirements and the implications of climate change. This will involve developing new bases, wharves, airfields and training and weapons testing ranges. It will also include considering the long-term future of some Defence bases, such as Garden Island in Sydney Harbour, as issues such as urban development, encroachment and capacity constraints within existing infrastructure affect the ADF's ability to safely and effectively execute its mission. The investment plans also have external private sector assurance, and the government has agreed to fund the goals set out in the paper "by increasing the Defence budget to two per cent of Australia's Gross Domestic Product by 2020-21". This will result in an investment of AUS$195 billion over ten years (Australian Government Department of Defence 2016a). To illustrate even more concrete measures, the Royal Australian Navy Base HMAS Sterling on Garden Island, Western Australia (not to be confused with Garden Island in Sydney Harbour), has been diversifying its power and water resources since extreme heat, wind and wave events threatened the supply of both.

United Kingdom Ministry of Defence

In the United Kingdom, climate resilience is also one of the top priorities of the government and defense as identified in the *UK National Security Strategy (NSS) 2010 A Strong Britain in an Age of Uncertainty* (HM Government 2010). The UK is equally vulnerable to a range of climate impacts and weather extremes. Severe winters, heatwaves, and flooding from rivers, the sea, storms, and gales are becoming more common with annual insured losses from such extreme events amounting to £1.5 billion (DEFRA 2012). In December 2015, Storm Desmond alone caused estimated flood losses of £662 million (Insurance Journal 2016). Additionally, as noted by the Foreign and Commonwealth Office (2012) the British Overseas Territories (BOT) are amongst the most vulnerable places on earth and are almost certain to experience severe climate change impacts, including sea level rise and changes in weather patterns. The UK Ministry of Defence (UK MoD) is the second largest landowner in the UK with an estate of 240,000 hectares. Out of this, 80,000 hectares are built estate, which includes offices, living accommodation, aircraft hangers and naval bases. 160,000 hectares are rural estate, which comprises mainly training areas and is often environmentally important (National Audit Office 2007). The UK MoD's worldwide estate, which extends over the BOT and other countries, including Germany and Kenya (British Army 2016), is valued by the National Audit Office (NAO) at £18 billion.

The need for more comprehensive planning has grown over the last decade. In 2006, a report by the NAO contained a *Defence Estate Strategy* in which delivering "*the adaptations and efficiencies necessary to address the predicted impacts of climate change*" was stated as a priority and would be measured by developing a strategic approach, prioritizing how climate change impacts were to be addressed. Two years later, in 2008, the UK Climate Change Act was passed. In it, the government recognized climate change adaptation as a priority. The legislation also required the UK government to assess current and future climate risks to the UK every five years (UK Government 2008) and to establish a National Adaptation Plan (NAP). In 2010, the MoD published its *Climate Change Delivery Plan*, which detailed the actions for both mitigating and adapting to climate change. The adaptation objective was to "*ensure the MoD has the capacity to operate in a changing climate, such that defence capability is not compromised and any potential benefits from the future climate are realised*" (UK MoD 2010).

Apart from specific actions to integrate adaptation into policy and capability planning, the document contained targets and indicators for adapting the MoD estate. The overall target is defined as:

"Increase resilience to the impacts of climate change by completing a risk assessment, develop, implement, monitor and review an action plan to improve the estate's preparedness to the impacts of climate change. Thereafter, a system of continuous review will be required on an annual basis" (ibid).

According to the UK MoD *Climate Change Delivery Plan*, all new estate projects (construction and refurbishment) have to be accompanied by sustainability appraisals and, when subject to a 2015 Defence Related Environmental Assessment Method (DREAM) or Building Research Establishment Environmental Assessment Methodology (BREEAM) assessment, must achieve an 'excellent' rating (see http://www.breeam.com). Additionally, the document underlines the importance of understanding climate risks to existing estate and using that knowledge to inform business continuity and resilience planning. In order to achieve this, the MoD uses its Climate Impacts Risk Assessment Methodology (CIRAM). CIRAM, delivered in 2010, was developed by Acclimatise and has since been regularly updated by the MoD. CIRAM helps identify risks caused by current and future impacts of climate and weather extremes on the outputs of MoD establishments (UK MoD 2015). Furthermore, the method identifies actions to maintain and optimize operational capabilities.

- Existing vulnerabilities to weather related hazards;
- Whether existing vulnerabilities are likely to change over time;
- Any additional vulnerability likely to arise in the future;
- The likely direct and indirect impacts on defense output;
- Actions and measures to build resilience into defense functions of the establishment; *and*
- Any opportunities created by changes in climate.

Identified risks and actions are embedded within the establishment's (installation's) adaptation processes. Site risk action owners are made aware of their assigned risks and how they are to be addressed in their processes and procedures. The risk action owners are also responsible for monitoring and evaluating the delivery of their actions. The Head of Establishment (HOE) is required to report annually to the Top Level Budget Climate Resilience Focal Point (TLB CRFP) regarding the delivery of adaptation actions. These regular reporting mechanisms ensure the adaptation actions are delivering the desired results.

The UK MoD acknowledges the importance of involving different stakeholders in the adaptation process; this can be anyone from tenant farmers, contractors, water and energy suppliers to local authorities and resilience forums. The main motivation is to share knowledge and best practice, and to manage risks and impacts more successfully by working collectively (UK MoD 2012). Furthermore, resilience can be built by ensuring the estate's adaptation management is flexible, able to deal with uncertainties and also able to combine different risk responses (UK MoD 2016).

Here we provide an example from the UK, to demonstrate that multiple methods, similar to the one outlined above, are available to guide risk assessment, and to show that other countries, like the UK, have successfully developed and implemented these methods at military installations. Like the U.S., the UK is vulnerable to climate impacts and extremes. Thus, the UK has identified climate resilience as a top priority. In response to the 2008 UK Climate Change Act, the UK Ministry of Defence (MoD) developed a *Climate Change Delivery Plan*, which specified actions for adapting to a changing climate. The plan requires the MoD to develop a climate risk assessment and implement recommended actions. MoD's risk assessment method is called CIRAM (Climate Impacts Risk Assessment Methodology).

CIRAM was developed by Acclimatise and has since been regularly updated by the MoD. CIRAM helps identify risks caused by current and future impacts of climate and weather extremes on the outputs of MoD establishments. Furthermore, the method identifies actions to maintain and optimize operational capabilities. CIRAM identifies:

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- any additional vulnerability likely to arise in the future;
- the likely direct and indirect impacts on defense output;
- actions and measures to build resilience into the defense function of the establishment; and
- any opportunities created by changes in climate.

The CIRAM assessment has four key stages, summarized in Figure 8, which include a risk assessment workshop and the production of a Climate Resilience Risk Register. The MoD's *Sustainability & Environmental Appraisal Tools Handbook* offers detailed guidance on how to carry out a CIRAM assessment. The method is analogous, but somewhat different from the risk assessment method outlined in Section 1.

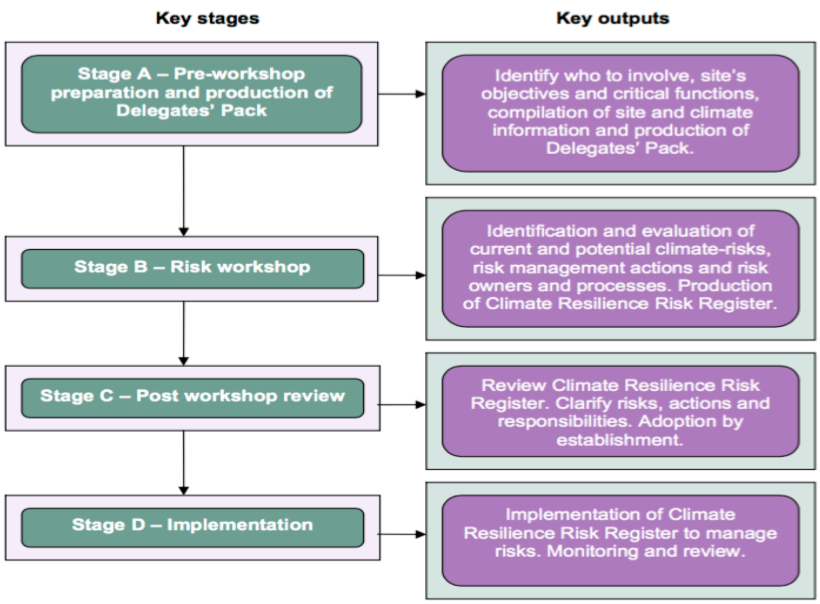

Figure 8 Key stages and outputs of the CIRAM assessment.

CIRAM Stage A involves a desk study in which the objectives and operational functions of the establishment/ installation in delivering the defense output are identified, details of the infrastructure, assets and utilities on the establishment are compiled, and historic and projected climatic information for the establishment are prepared. This information is then included in a delegate's pack for the workshop participants.

CIRAM Stage B consists of organizing and delivering the risk assessment workshop, the output of which is a Climate Resilience Risk Register (CRRR). The workshop aims to identify:

- current and future risks to the operational capability of the site as a result of climate related hazards; and
- adaptation actions that would allow the site to become resilient to the effects of climatic events and therefore maintain operational capability, as well as identifying processes and risk action owners for delivery of actions.

CIRAM Stage C require the completed CRRR to be reviewed thoroughly, which gives the opportunity to clarify and/or identify new risks, and to clarify adaptation actions and responsibilities. This stage also includes the adoption of the CRRR by the establishment/ installation.

CIRAM Stage D is the where the implementation process starts. Identified risks and actions are embedded within the establishment's (installation's) processes. Site risk action owners are made aware of their assigned risks and how they are to be addressed in their processes and procedures. The risk action owners are also responsible for monitoring and evaluating the delivery of their actions. The Head of Establishment (HoE) is required to report annually to the

Top Level Budget Climate Resilience Focal Point (TLB CRFP) regarding the delivery of adaptation actions. These regular reporting mechanisms ensure the adaptation actions are delivering the desired results.

2.2 How are non-defense sectors adapting to climate change?

Our project also called upon more readily available information from the public and private sectors, and in particular those organizations that share similar characteristics to DOD, namely a reliance on large, long-lived assets with large workforces and the need to manage natural resources carefully to maintain operational continuity. Here we highlight examples from a) the Port Authority of New York & New Jersey, b) the State of California, and ports of San Francisco, Los Angeles and Humboldt Bay and c) the extractive mining, oil and gas sector.

Port Authority of New York and New Jersey

The Port Authority of New York & New Jersey (PANYNJ), a bi-state agency that develops and operates trade and transportation infrastructure in New York and New Jersey, has many facilities similar or relevant to a defense agency: airports, marine terminals and ports, tunnels, bridges, rail transit systems, etc. (Mills-Knapp et al. 2011). Figure 9 shows that most of the PANYNJ infrastructure is coastal and over half of its facilities are potentially vulnerable to the impacts of climate change. New York City has over 500 miles of coastline exposed to sea level rise. For New York and New Jersey, the IPCC's projections of climate impacts include increased precipitation, an increase in storm surges, both exacerbated by the coastal location, and also significant sea level rise (Romero-Lankao et al. 2014).

Figure 9 Vulnerable PANYNJ facilities (red dots).

In 2007, New York City released its *plaNYC – A Greener, Greater New York*, a document aimed at preparing the city for its rising population, strengthening its economy, mitigating, and adapting to climate change. In the document climate impacts such as sea level rise, increased storm frequency and intensity, and increased temperatures are mentioned as potential threats to New York City (City of New York 2007). The main adaptation focus of *plaNYC* was planning for disasters, more specifically, flood events, and tracking emerging climate change data and potential accompanying impacts Concrete actions included creating a strategic adaptation planning process, updating floodplain maps, and amending the building code. Five years later, after Hurricane Sandy, the City of New York released a resilience roadmap, *plaNYC - A Stronger, More Resilient New York*, which would be completely focused on resilience building and climate adaptation (City of New York 2013).In 2011, PANYNJ recognized the importance of not just focusing on sustainable design that would help mitigate the impacts of climate change, but also looking at climate change adaptation and making their estate climate resilient. The inception of this project was based on different climate models and predictions, including the IPCC's, but also on a study by the University of Utrecht that stated New York City would likely experience sea level rise 20% higher than the IPCC global average estimate of 28cm by 2100 (Mills-Knapp et al. 2011). Using the adaptation-planning framework from the IPCC's *First Assessment Report* (IPCC 1990), PANYNJ started developing different adaptation strategies for its estate. Climate change adaptation responses are categorized as either structural or operational (Mills-Knapp et al. 2011). Structural ones will usually include large, capital-intensive projects involving extensive planning, design or redesign. Operational ones, on the other hand, refer to changes that are more incremental; this includes enhanced maintenance, modification, or redesign. The potential strategies of structural or operational responses are categorized into protection, accommodation and retreat, with retreat being more of a last resort measure. PANYNJ determined that protecting and accommodating their estate were the options they would be focusing on (Table 6).

Table 6. Possible measures for the three adaptation strategies protect, accommodate, and retreat adapted from Mills-Knapp et al. 2011.

Protect	Accommodate	Retreat
- Barriers (permanent) - Barriers (temporary) - Coastal armoring - Coastal sand dunes, beach nourishment	- Pumps, sumps, catchments - Enhanced maintenance - Wetland protection, restoration - Underground storm water storage - Natural storm water management - Green roofs - Elevated buildings - Floating infrastructure - Waterway deepening/dredging	- Managed relocation

The measures in Table 6 were individually considered by PANYNJ, identifying their advantages and disadvantages, finding their synergies and potential conflicts with PANYNJ's sustainable design principles, assessing the relevance of each measure to PANYNJ, and backing them all up with case studies (e.g. for permanent barriers, the UK's Thames Barrier was taken as a case study). PANYNJ created a catalogue of valuable climate adaptation information for each measure by learning from best practice examples of adaptation strategies from others globally. This information was then evaluated to determine which adaptation strategies would make most sense for the affected estate, and researching practical measures to fulfil those strategies. Furthermore, PANYNJ also made a point of emphasizing the importance of monitoring and evaluation of the measures implemented. In 2015, PANYNJ published *Design Guidelines for Climate Resilience* for its Engineering Department (PANYNJ 2015). This document takes into account the climate projections mentioned earlier (sea level rise, storm surge, precipitation) but also includes higher temperatures. As rising temperatures become more and more evident, it is considered important to account for them as they can affect various materials (seals, metal) and vegetation on the estate. This guideline also partly shows the Port Authority's monitoring and evaluation process of its own adaptation strategy. Overall, climate adaptation is well integrated into the operations and planning conducted by PANYNJ, with strong links to existing sustainable design principles, highlighting that beneficial synergies that can be attained when mitigation and adaptation are considered together Figure 7. PANYNJ's monitoring process allows them to maintain flexibility to introduce new climate considerations (e.g. new climate science model outputs) in their future plans during their review of their existing strategies and measures. Even though there is no direct mention of *plaNYC in their Design Guidelines for Climate Resilience*, it can be assumed that having that document, clear guidelines and actions taken by the City of New York can encourage an enabling effect to integrate adaptation into PANYNJ's planning procedures (Figure 10).

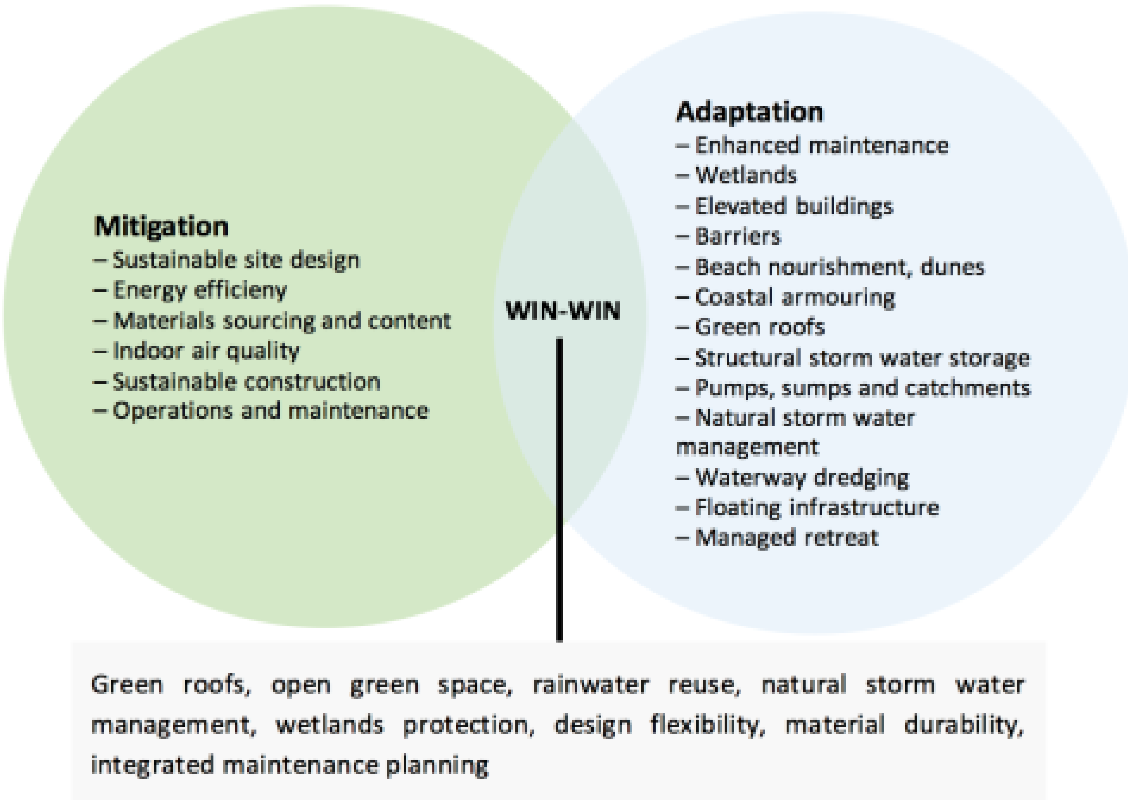

Figure 10 Mitigation and adaptation synergies for PANYNJ.

State of California and the Ports of San Francisco, Los Angeles and Humboldt Bay

The State of California and ports of San Francisco, Los Angeles and Humboldt Bay have faced similar challenges to PANYNJ. California's history of climate adaptation starts in 2005, when then-Governor Arnold Schwarzenegger issued Executive Order S-3-05, which not only called for specific emission reductions, but also for periodic updates about emerging understanding of climate science and climate impacts, and for adaptation efforts (Office of the Governor of the State of California 2005). Furthermore, the order states that future impact assessments include a "report on mitigation and adaptation plans to combat these impacts." The motivation behind the order, as stated in its text, was the fact that California is especially vulnerable to climate change impacts: increasing temperatures could greatly reduce the Sierra snowpack, a major water source for the state; increasing temperatures could also be harmful to human health, as air quality decreases, and heat stress and respiratory issues increase. Moreover, the 1,100 miles of California's coastline are threatened by sea level rise and threats to agriculture due to water stress and the distribution of pests and pathogens are significant. Soon after, a white paper was released that examined California's opportunities and constraints for managing the impacts of climate change (California Climate Change Center 2006). In 2008, Gov. Schwarzenegger issued

another Executive Order, S-13-08, which would provide a clear direction for California's first state-wide adaptation plan (Office of the Governor of the State of California 2008).
Finally, 2009 saw the publication of California's climate adaptation strategy. In it, impacts projected in Executive Order S-3-05 were said to already have been observed, these included sea level rise, increasing temperatures, and increasing water scarcity (California Natural Resources Agency 2008). The document states that without adaptation action, tens of billions of dollars in direct costs could result per year, and trillions of dollars of assets could be exposed to collateral risks. Apart from covering impacts, risks, and strategies for a number of sectors, California's adaptation strategy followed a set of guiding principles that would help its organizational implementation:

- Use the **best available science** in identifying climate change risks and adaptation strategies.
- Understand that data continues to be collected and that knowledge about climate change is still evolving. As such, an effective adaptation strategy is "living" and will itself be adapted to account for new science.
- **Involve all relevant stakeholders** in identifying, reviewing, and refining the state's adaptation strategy.
- **Establish and retain strong partnerships** with federal, state, and local governments, tribes, private business and landowners, and non-governmental organizations to develop and implement adaptation strategy recommendations over time.
- **Give priority to adaptation strategies that initiate, foster, and enhance existing efforts** that improve economic and social well-being, public safety and security, public health, environmental justice, species and habitat protection, and ecological function.
- When possible, **give priority to adaptation strategies** that modify and enhance existing policies rather than solutions that require new funding and new staffing.
- **Understand the need for adaptation policies that are effective and flexible** enough for circumstances that may not yet be fully predictable.
- **Ensure that climate change adaptation strategies are coordinated** with the California Air Resources Board's AB 32 Scoping Plan process when appropriate, as well as with other local, state, national and international efforts to reduce GHG emissions.

During this time, when California as a state was setting policies in place to deal with the impacts of climate change, a number of other Californian authorities, such as local and regional agencies, started looking at how their communities and assets would be impacted by climate change, and how they could adapt to reduce the resulting risks. In 2008, the City of Los Angeles started researching adaptation planning. This included a climate change simulation for Greater L.A. commissioned by the Los Angeles Regional Collaborative for Climate Action and Sustainability (LARC) (Grifman et al. 2013). The simulations, done by UCLA, would help the city understand regionally specific impacts and plan for them. Amongst other issues, sea level rise was identified as a potentially harmful climate impact, especially given L.A.'s critical infrastructure along the coast which includes power generation facilities and wastewater treatment plants. The city's port is one of the busiest in the world with 40% of all the country's imports coming through the Ports of Los Angeles and Long Beach (ibid). Having recognized the risk the city's coastal zones were under, the City of Los Angeles had a sea level rise vulnerability study prepared which resulted in an extensive adaptation strategy matrix, which would help plan and prioritize adaptation actions to reduce the city's vulnerability to sea level rise.

The 2007 management plan for Humboldt Bay, the second largest enclosed bay in California and also containing the Port of Humboldt Bay, included amongst many other policies one that stated: "*Identify needs for potential shoreline improvements necessary to accommodate bay water surface elevation changes, including potential effects of climate change.*" The State Coastal Conservancy had a report prepared for Humboldt Bay between 2010 and 2013. This report consisted of a shoreline inventory, mapping, and sea level rise vulnerability assessment and was the main component of phase 1 of the Humboldt Bay Sea Level Rise Adaptation Planning Project (Humboldt Bay Harbor District 2016). In phase 2, a report including hydrodynamic modelling and inundation vulnerability mapping, highlighting projected sea level rise impacts on Humboldt Bay, would inform the planning of relevant adaptation actions (Northern Hydrology and Engineering 2015). Recently, the Port of San Francisco also published its 2016-2021 Strategy Plan. As part of it, the Port seeks to work with the City of San Francisco in order to develop a resilience and adaptation strategy to support the necessary repairs to the Port's seawall, which serves as a protection against flood risk and sea level rise (Port of San Francisco 2016). The Port also aims to participate in local and state regulatory rule-making related to climate adaptation.

The Extractive Sectors

Across the extractives sector (i.e. mining and oil and gas), companies are exposed to climate risks that are also representative of key challenges faced by military installations. The reasons for this include:

- reliance on long-lived and capital-intensive assets;
- operations in regions that are highly vulnerable to climate extremes and climate change, including coastal environments;
- extensive product transportation networks which rely on deep and complex supply chains, both of which make operations vulnerable to disruption;
- dependency on 'beyond the fence line' stakeholders for the provision of municipal infrastructure, civilian products and services, the management of lands and other natural resources (e.g. water supplies), which can be undermined by the effects of a changing climate; and
- management of environmental permitting arrangements.

As a result, extractives are particularly at risk from economic losses, damage to reputation, workforce health and safety concerns, legal and regulatory challenges. Moreover, they are typically and inexorably linked, and reliant on, other infrastructure and service providers, as well as others managing land use planning in neighboring or shared lands. The extractives industry as a whole is currently undergoing a process of integrating climate change risk management into existing business processes. With a few exceptions, the sharing of practical examples is limited given the necessary commercial pressures faced by private operators. However, there are a number of recurring best practice 'themes' that are common when companies implement such changes. One such example is that climate resilience actions are mainstreamed into existing asset/ project lifecycle processes. This reflects the reality that climate change risks do not usually create 'new' risks rather influence the likelihood and magnitude of consequence of existing risks. The co-benefit of this mainstreaming approach is that it increases the uptake of new approaches into existing governance structures and procedures. Figure 11 shows example 'hooks' into which climate risk management procedures could be integrated into a typical asset lifecycle).

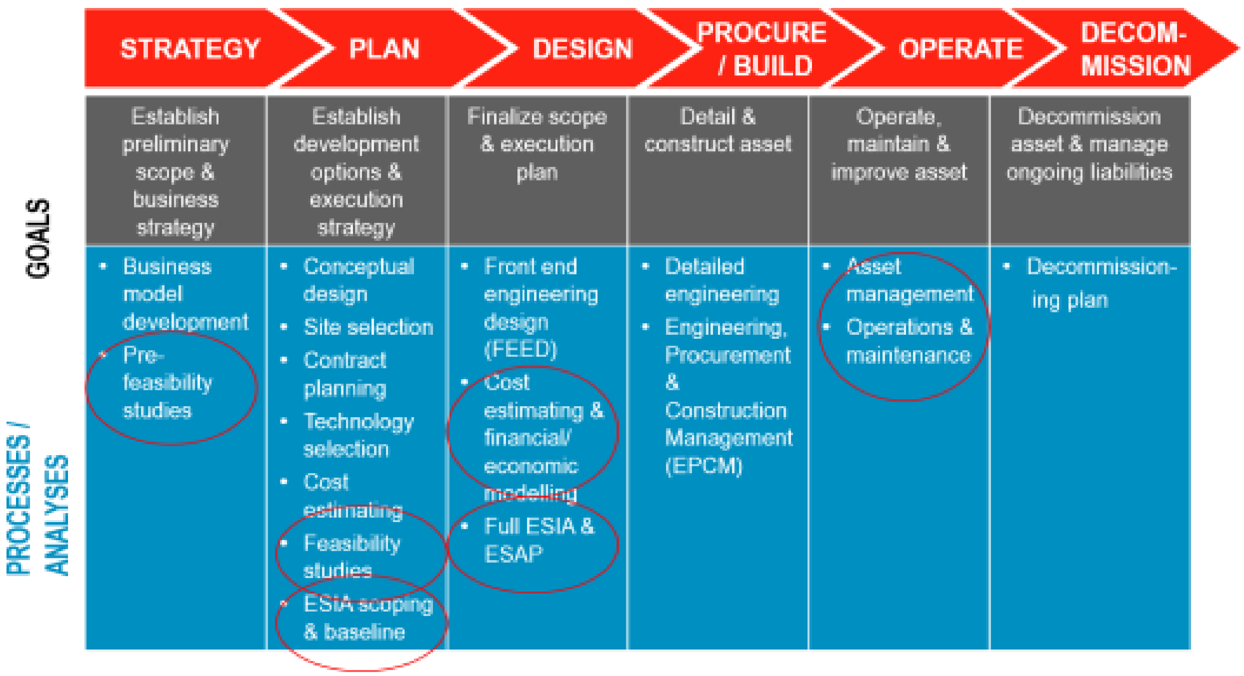

Figure 11 Climate risk management procedures integrated with asset lifecycle.

In support of mainstreaming activities, many extractive companies are developing climate risk assessment and management frameworks as shown in Figure 12, based around eight stages, from identifying objectives through assessing risks to choosing solutions and ultimately monitoring results, with the overall aim of identifying and developing robust resiliency decisions.

Figure 12 Eight-step framework for building climate resilience in energy systems adapted from HEAT 2010 Hands-On Energy Adaptation Toolkit, prepared by Acclimatise for ESMAP.

The ultimate goal of developing a specific climate risk management methodology approach is to identify ways to adapt the thresholds of assets to withstand the impacts of a changing climate. Adaptation actions give infrastructure extra headroom or coping capacity to withstand changing conditions, a concept adopted by a number of major international oil & gas companies. Across the extractives industry there remains a tendency to focus on extreme climate-related events. There is, however, an emerging recognition of operational and maintenance risks driven by incremental changes in average conditions. Managing the risks associated with major events such as storms is important, and can garner significant attention and response, but these may have lower overall costs or revenue losses compared to the cumulative impact of smaller but more pervasive challenges, like efficiency losses due to higher temperatures.

As such, leading extractive companies are starting to adopt a balanced focus on risks and opportunities from both incremental change and extreme events, cognizant of the different time horizons over which these events may occur. Figure 13 highlights this point, and poses the important question regarding the overall potential costs of climate change.

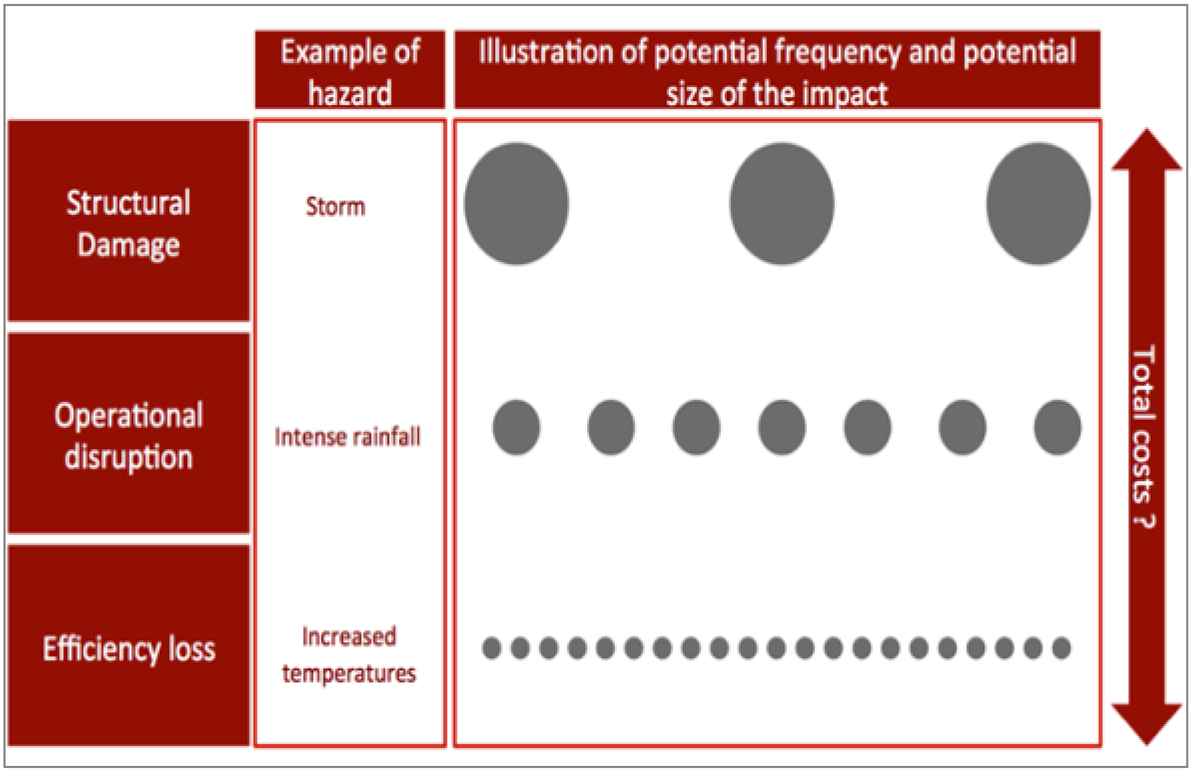

Figure 13 Relative impacts of large infrequent events compared to smaller but more frequent extremes.

Another important factor to consider in planning adaptation action is in dealing with climate projection uncertainty. Many extractives companies are recognizing that there are limits to the assessment of climate impacts, as there are many uncertainties in future climate and socio-economic conditions. Bearing this challenge in mind, cutting edge developments in the industry currently focus on developing adaptation actions that deal with these inherent uncertainties, leading to assets and systems being designed to focus on resilience to today's events and tested for robustness against a range of plausible future scenarios. The key to this robustness lies in developing solutions as 'adaptation pathways'. Adaptation pathways embrace uncertainty, as they are flexible routes that allow changing efforts to build resilience in response to changing needs, information, and conditions. This approach is helpful given the 'cascade of uncertainty' associated with future climate change, as shown in Figure 14.

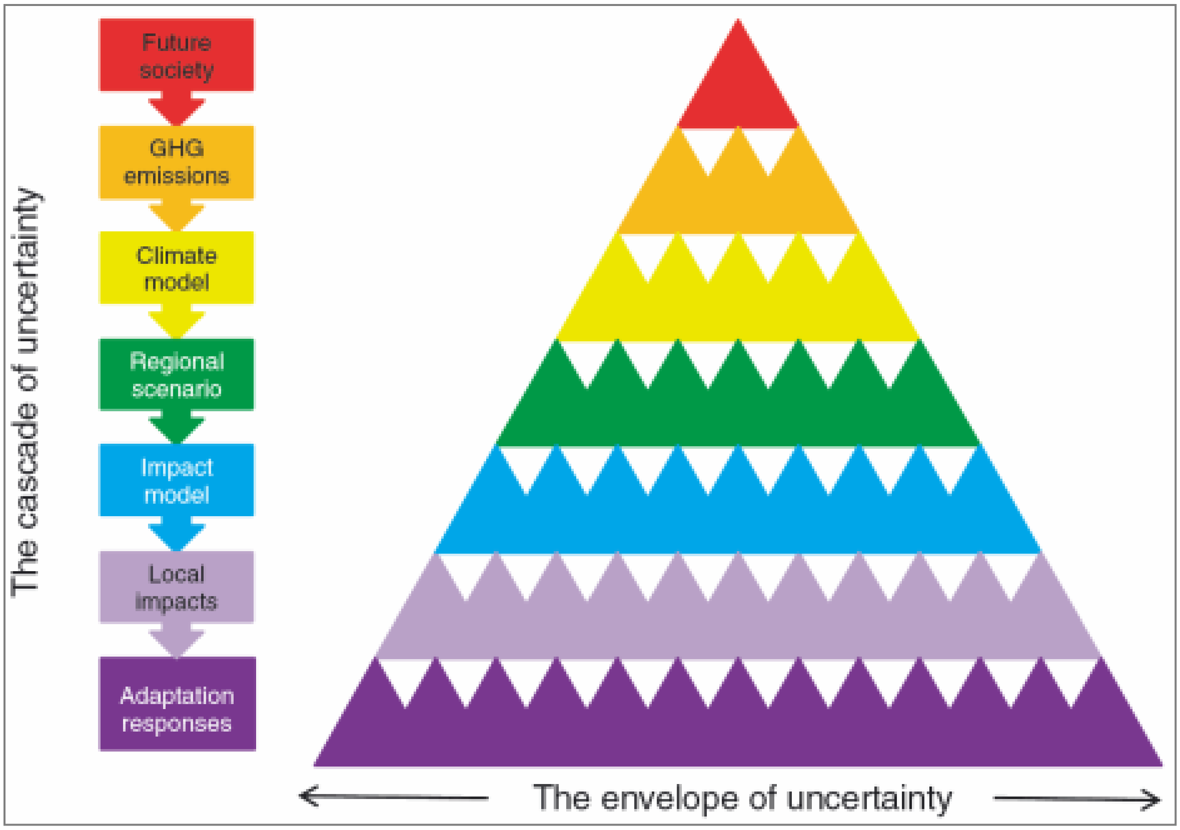

Figure 14 Cascading envelope of uncertainty from Wilby and Desai (2010).

Extractives companies are becoming increasingly aware there are many ways to adapt to a changing climate, from 'soft' operational and informational adjustments to more costly 'hard' physical resilience measures. It is common for multi-criteria analysis and cost/benefit study to be used to identify and appraise sets of adaptation options, according to a selection of pre-defined criteria including costs downtime to benefits effectiveness, ease to implement and flexibility. The measurement of the effectiveness of adaptation actions can be considered to be an emerging area in the extractives sector. In many cases, the assessment of material climate risks is the limit of progress in the sector, although where examples of adaptation actions being completed do exist, it is often unclear what monitoring and evaluation procedures are applied, and if so, they are unlikely to be explicitly adaptation-outcome orientated. Moreover, the effectiveness of adaptation actions may need to be measured over the long-term, where success may not be 'realized' in less than decadal timeframes.

Examples evidenced by RC-2232 workshops and Interviews

To achieve a better understanding of how different organizations, deal with climate resilience, Acclimatise and the University of Arizona hosted a series of workshops and conducted comprehensive interviews with stakeholders, from military personnel and infrastructure providers, to planners.

During an interview with a representative of the UK MoD, it was found that although approximately 90 installations across the UK had been assesses for climate risks, it is the responsibility of the personnel at each location to manage climate risks, the cross-cutting nature of the risks (e.g. impacts on security, business continuity, infrastructure, environmental protection etc.) means that there is no one person accountable. Given the medium to long-term nature of the risks, climate risks are afforded lower priority than immediate operational risks. Often where an individual has a personal interest, climate risks management is progressed. The interviewee went on to explain that climatic events are quite localized and their magnitude often not dramatic enough to be communicated or escalated within the MoD. Often risks are managed as they occur at the installation level, but they do not currently present a significant driver for change across the wider MoD hierarchy. The MoD is currently building up a body of evidence on costs and damages that have occurred at the installation level which can be used to enhance understanding of risks, reduce uncertainty and inform investment decisions going forward. This is typically undertaken by collating information from facilities management contractors (third-party private companies) that are mandated to collect this data. However, issues regarding mobilization of contracts means there has been a delay in collating this data. The UK Defence Infrastructure Organisation (DIO), responsible for managing the majority of the Defence estate, has gone through two major phases of organizational change over the past 5 years or so. This restructuring in the organization has meant maintaining climate resilience profile and the consideration of associated risks within the organization as a whole has been a challenge. The interviewee considers this a key barrier, and with a complex picture of contractors and MoD staff involved over a wide geographical region, they recognize that understanding the triggers when action should be taken to manage climate risks, coupled with a wide range of risk appetite across the organization, is a barrier to consistent agreement on when and where to act, and who is responsible for the actions identified.

The UK MoD interviewee also described how MoD risk assessments look across many aspects, and that typically there is no central owner for all risks, rather only risk owners for certain areas. For example, FM risks would be DIO, but there could be service risks that are owned by others. This distributed view of risk is a challenge that they are currently seeking to address. It is the "Head of Establishment" that is responsible for the installation, but they are not necessarily responsible for the management of all the risks at their installation. Monetary thresholds are often used to assist in determining the level of appraisal of sustainability and climate risks for capital works projects. Every new infrastructure capital project in the MoD must have a sustainability appraisal completed prior to construction so that risks identified can be integrated into the design of the facility or infrastructure. Capital projects over £75M have a higher tier of scrutiny applied than those worth less money. Ultimately, sanctioning of the project requires two steps - a sustainability assessment to have been completed, and a crosscheck and demonstration that all risks, including climate risks, have been addressed.

In a recent audit of the UK MoD's sustainability work completed by a management consulting firm, the interviewee explained that the results had shown that the MoD had clear direction at the highest level, with a small team of experts providing advice across the business as and when required. However, there is also a middle layer in the hierarchy of the organization where there is difficulty in operationalizing bottom-up data (such as information on climate risk management) into decision and investment planning. As such, with capital works projects, the interviewee highlighted the MoD has achieved good mainstreaming of climate risk considerations through their sustainability appraisal process, supported by the MoD's investment approvals committee that is mandated to check on sustainability and climate resilience aspects. But for day to day maintenance and investment, there remains a lack of mainstreaming and good resilience outcomes. UK MoD's future developments in climate risk management, according to the interviewee, should be handled terms of looking beyond the installation level to start looking through the consideration of 'capability', for example viewing climate risks related to the 'capability' of air traffic control across multiple installations, which could relate to individual buildings on certain sites, technologies or procurement supply chains. In the current context of their CIRAM methodology, a focus on evaluating climate risks at the installation level provides only a single view of the installation where it is hard to see the criticality of that installation in the context of other locations, where there may be interdependencies. The interviewee highlighted that it is not necessarily the case that the FM contractors are aware of what are the most critical 'capabilities' at an installation due to a lack of visibility of the function of what is often a mix of differing units at an installation, and are therefore may be unable to fully prioritize climate impacts in a more systemic way based on criticality. At many MoD installations, external stakeholders' management is an integrated part of the ongoing management of the installations given the biodiversity, heritage, recreational value etc. on many installations (e.g. conservation, heritage and recreational organizations). However, the interviewee suggests that there is little external pressure from stakeholders regarding the need to manage climate risk assessments at installations. With statutory agencies (e.g. the UK's Environment Agency) there is dialogue with the MoD around the topic of climate resilience, and this this dialogue has informed action. The MoD does consider, however, that good stakeholder engagement and working positively with statutory bodies increases their understanding of Defence activities and allows military activities to be managed in a way that minimizes the impact of the environment and local communities.

Despite having climate-related procedures like CIRAM in place which focuses on risks at an establishment level. However, further thought is needed to understand how risks identified at a local level, multiply up to become strategic risks for the organization as a whole. Furthermore, the uncertainty of climate models in combination with the language used to convey climate change lead to additional difficulties in communicating risk. It is very important to speak in terms of impacts and subsequent costs, and frame the issue using tangible information. Finally, the interviewee described the "Strategic Asset Management", a process of evaluating which installations the MoD will retain and invest in, given the need to reduce the MoD's built estate by 30% over the next 20 years. In this evaluation, climate resilience and sustainability considerations will be part of the selection of the installations to be retained and invested in. During another interview with a former British Royal Navy Officer having significant experience in the fields of climate change, and climate and energy security, the need to frame climate change issues in a military-operational language, rather than a "green" language, so they are more easily understood throughout the organization was heavily emphasized. For example, the increase in demand for energy in theatre was becoming a limiting factor for the MoD, and so describing energy reduction as key objective to maintain combat and support operations was much more effective that describing it in terms of 'sustainability' or other 'green' terms. As such, the challenge was to drive the shift from 'green' language to 'military operational' language within the MoD, and this was key in succeeding to address energy demand issues in the 2010 UK Strategic Defence Security Review. Like the UK MoD representative, this interviewee also indicated that legislation was instrumental to the MoD starting to address climate change risks. As a governmental department, they were mandated to produce a climate change plan and started to look at wider implications of climate change, from structural ones to operational impediments, and security issues. In the operational military, there has been activity in broadening an initial focus on installations (i.e. infrastructure, and health and safety) to also focus on climate and geopolitical stability, UK national interests and security and, in terms of operational tasks such as what equipment and training personnel would be needed under a backdrop of operations in theatre. It was also suggested that organizational change can be very much personality-driven. As such, action is highly dependent on an individual's personal motivation. Given the pressure on resources in the MoD (be it staff, or budget), the focus still tends to lie on the most immediate problems. Furthermore, the time scales that define climate change can be problematic for the MoD context for several reasons. On the one hand, political horizons are short-term and often mandate the MoD's actions. On the other hand, future risks are often medium- and long-term, and uncertain. Uncertainty, however, is not a new concept to the MoD, and potentially there may be more certainty around the impacts of climate change than that of other geopolitical security threats.

Similar perspectives were also offered by a former Australian Defence Force officer with relevant experience in climate security issues. During the interview with the ADF Office, it was shared that climate action in the ADF is considered strongly to be dependent on political landscape and leadership. Significant barriers for the successful implementation of climate change adaptation actions within the ADF include the high turnover of appointments and changes in government as such transitions generally result in slow organizational change. This also complicates the issue of taking long-term risks and time horizons into account because the ADF needs to understand risks fully before taking action in order to withstand scrutiny. Overall, urgency seems to be a very important factor in taking meaningful action, e.g. in the case of large-scale disasters, the ADF responds quickly and efficiently, but the further time horizons extend into the future, the more difficult they become to address. According to the ADF office, there are three key factors that make a successful argument for climate change adaptation: addressing capability, reducing costs, and including mission readiness. On top of that, the interviewee mentioned that increasing the overall awareness within the ADF is a very important step. Championing this effort is the Defence Support Group, who regularly author briefs and reports to raise awareness, as well as the Energy Group and the Estate & Infrastructure Group. The leadership of the ADF has been lacking in this regard, although this may well be connected to political sensitivity.

SECTION 3. RECOMMENDATIONS AND BEST PRACTICES

Section 3 is dedicated to **recommendations** (supportive practices observed by our research team through our work with installations in the Southwest and Acclimatise UK which enhance the climate risk assessment process) and **best practices** (methods or techniques that were discussed during our SERDP Cross-Project workshop and by Acclimatise UK which have been widely accepted and may be beneficial to DoD climate risk management). As previously noted, the science and tools alone do *not* make a successful approach. To support DoD efforts, a clear understanding of baselines in decision processes related to climate from the Pentagon and service component perspective is an important foundation for future projects. Here we list recommendations that serve as broadly applied best practices.

3.1 Recommendations and Best Practices

Recommendation 1: Communicate climate change in military language when working with the DoD.

In our review of practices from both the UK Ministry of Defense (MoD) and Australian Defense Force (ADF) a key factor in successful transitioning or mainstreaming is that climate change must be communicated in military and operational language, not in terms of sustainability, environmental or other 'green' programs. One interviewee emphasized the importance of speaking in terms of impacts and subsequent costs, and framing climate risk using tangible information, and the second interviewee expressed it similarly, saying the issue should be framed using specific ‘military-operational language’. There are, however, also very complex issues inherent to climate change, i.e. the uncertainty of models and projections, which need to be conveyed. It is important for the military and its operations to understand its own risk tolerance. Working with different time horizons, and planning for different levels of uncertainty, i.e. making commitments to short-term, low-uncertainty projections, and monitoring long-term, higher-uncertainty ones, can make the issue more tangible and easier to work with.

Recommendation 2: Include mechanisms for political resilience as part of climate risk management.

There is a need to make climate risk management resilient to political change. Political will to drive national interests in climate risk and adaptation can vary significantly between administrative terms. As such, finding ways to build consistency of practice and continual improvement in the medium- and long-term is key to the successful delivery of adaptation goals. The New York City Mayor’s office for example has driven the permeation of climate risks management, building resilience and promoting sustainability within all its departments, including the clear distinction and distribution of roles that will deal with climate-related activities. Once these types of best practices become the ‘norm’ or business as usual, they may then be more likely to withstand changes in political will and the wider political landscape.

Similarly, legislation is crucial. Legally binding action on mainstreaming climate change across Government departments, executive agencies and organizations such as the military are crucial to drive change. Examples from the U.S. Executive Orders 13653/13677 and UK Climate Change Act 2008 are important drivers for change, including driving reform in other relevant policy areas and cross-departmental collaboration. For both the UK and Australian contexts, without strengthening legislative drivers (albeit absent in Australia at present), and independent monitoring and evaluation of outcomes, tangible climate resilience outcomes will be hard to achieve through piecemeal voluntary action on managing climate risks. Responsibility must also be mainstreamed into job descriptions, objectives and targets for promotion.

Change in the UK MoD for example can often be very personality driven and thus be dependent on the motivation of individuals. As such, mainstreaming climate-related responsibilities into certain job roles and setting targets for promotion might help transition climate risk management into the day-to-day routine which has proven to be a best practice in other sectors.

Recommendation 3: Acknowledge that DoD is faced with DoD-specific cyber technology challenges.

A new era of "big data" and ever evolving cyber technologies has provided an overwhelming amount of data alongside a desire to mainstream information that could potentially to be shared between experts and the DoD. Cyber security weaknesses could equally affect open source tools and other sources of data. Much of the literature relating to climate change and the military is focused on global security issues. All participants of the interviews conducted for this report mentioned climate change as a driver for political and civil unrest. Noticeable by its absence in the literature, however, is mention of the cyber security risks relating to access and use of climate data and derived results. Military organizations such as those in the UK and Australia are relying on climate and natural hazard data derived by academic institutions, consultancies and open source portals. Open sharing of climate projection data by the Earth System Grid Federation (ESGF), for example, who use a system of geographically distributed peer nodes to host the premier collection of simulations and observational and reanalysis data for climate change research (including IPCC assessments), could become a target for cyber-sabotage. Interrupting services, obtaining user information, or worse manipulating climate projection data could undermine the ability to effectively evaluate risk. For example, sea level rise projections for a low-lying small island location could be manipulated to cause an under-estimation of the extent of future inundation risk, leaving the installation under protected against flood impacts. Moreover, analysis of climate risks can reveal potential areas of compromise to existing assets and installations, potentially providing information on weaknesses in security. With academic and consulting institutions often engaged in supporting climate risk assessments, the security of information held by these non-classified organizations may also be of concern.

Recommendation 4: Enhance capacity through leadership, collaboration and Knowledge-to-Action approaches.

In the context of UA-SERDP Cross-Project Workshop conducted in March 2016 and subsequent interviews conducted in the second and third quarter of 2016, broad applications of lessons learned were consistent with findings of previous research on enhancing capacity and connecting research to applications (e.g., Dilling and Lemos, 2011; McNie 2013). Our understanding of the DoD structure and culture, approached through multiple lines of investigation, illuminates the fact that there is still significant capacity building needed in order for climate related risks to be well-considered, let alone addressed. Beyond sheer capacity and "bandwidth" issues, other challenges to incorporation of climate-related information include lack of dedicated funding for climate issues, the rapid turnover of personnel at individual installations, the very short-term focus of most decision-making, the lack of horizontal integration across branches of the military and even between operations and mission activities on the same base.

Leadership and institutional culture are interconnected factors in attaining climate adaptation success at the installation level and higher within the DoD. Not surprisingly, we found that the cooperation and interest of installation leadership is critical in any effort; however, several other factors, discussed in greater detail below, are linked strongly with leadership. Key challenges include ensuring the continuity of climate change-related projects and prioritizing adaptation efforts during the course of frequent changes in leadership. A "champion" is needed to keep up momentum in what is often a multi-year adaptation process—from planning to implementation and monitoring and developing effective partnerships and articulating the benefits of those partnerships to installation leadership. In some cases, new institutions, partnerships and networks may be required——within installations, between installations and other levels of the DoD hierarchy, and between installations, neighbors, and regional initiatives. Given the frequent turnover of active-duty personnel, maintaining the continuity of adaptation planning initiatives, which require sustained investments of time is a substantial challenge. One workshop participant noted that developing close, and often personal, "trusted" relationships between academics and DoD personnel is not a scalable model, because military culture shows that colonels and captains, who frequently move from assignment to assignment, execute policy and everyone above that level makes policy. Moreover, as we learned from specific interactions with personnel at NBC, external civilian communications can be perceived as a challenge because extra steps may need to be taken to assure that appropriate levels of security are maintained throughout every interaction and exchange of information.

Recommendation 5: Maintain institutional knowledge through GS-15 level personnel.

One important avenue available to SERDP, as it aims to connect research with needs for adaptation to climate risks, is to continually foster the interest of the service liaisons, the GS-15 level personnel whose longevity and tenure at an installation usually exceeds that of commanders and other active-duty personnel. The longevity of individuals in these positions ensures continuity of institutional memory, and as we witnessed at NBC, can ensure that adaptation efforts are translated and further implemented following the transition to a new Commanding Officer. Working with long-term civilian staff can be an effective route; as one of our interviewees pointed out partnering with natural resources personnel also creates a trusted and credible relationship that may be leaned upon by new commanders, as they transition to an installation. These longer-term personnel can also assist in identifying what climate-affected actions that are already being implemented, such as hazmat training which could incorporate climate change research insights to inform tasks, such as controlling dust and other aerosols that may interfere with the health of personnel, as well as training exercises and ensuring equipment functionality. Given that installation staff are often on the "front lines" of climate adaptation, this provides an opportunity for adaptation continuity, from the bottom up.

Our research efforts found that when existing or new commanders are tasked with complying with a natural resource or environmentally centered mandate, they frequently turn to the "in house" natural resource personnel specifically because those individuals are already well established within the organization and familiar with military command, culture and protocol. Fully acknowledging the pivotal role those specific individuals are playing in climate change adaptation and further empowering these natural resource managers to learn and do more in this arena represents an important opportunity for mainstreaming climate information into base management practices. Fostering partnerships between DoD personnel, researchers, and resource liaisons may create innovative opportunities for cross-training and professional development that are systemically relevant and contextualized. Including installation-based natural resource managers in these efforts is likely to be a cost effective way forward for increasing installation-specific capacity.

Key challenges related to leadership, and advocacy within installations, for climate change adaptation are (a) frequent turnover of leaders, (b) a focus on short-term decisions, which hard-wires the system to ignore climate time-scale (years to decades) issues, (c) the need for top-down interest and or directives (i.e., political will), (d) competing priorities, and (e) ownership of the risk. Our examination of climate decision-making in organizations similarly challenged by needs for climate change adaptations, such as extractive industries and cities, shows that these issues are not unique to the DoD. Lessons emerging from the literature and interviews conducted for this report share strong similarities to well-established conditions for enabling action (IFRC 2013), that include internal and external advocacy for climate initiatives, coupled with leadership commitment, incorporation of a top-down policy and strategic framework, development institutional capacities (such as the horizontal coordination mechanisms mentioned above), and integration of climate change with the project management cycle.

Recommendation 6: Mainstream climate risk management through champions and early adopters.

A substantial body of literature points to the important roles played by early adopters and champions of new ideas, planning processes, and technologies (e.g., Rogers 2010; Oberlack and Eisenack 2014; Carter et al. 2015). Our project points to such individuals, within installations and within the DoD hierarchy, as essential for the success of climate adaptation planning and implementation. We noted the important role of the Commanding Officer of Naval Base Coronado, at the outset of our project, in attaining buy-in from staff for prioritizing climate change adaptation and lending credibility to our project. This observation was backed by comments from interviewees, who noted that the leadership of the commanding officer in an installation strongly influences the priorities and operations of an installation, and by cross-project workshop participants who noted that, within the hierarchical structure of the DoD, "if your boss is interested you are fascinated." This was corroborated throughout our interactions with installations in the Southwest, where interest from DoD leadership, e.g., the Garrison Commander at Fort Huachuca, reinforced the early adoption of studies of potential climate change effects on wildfire regimes by civilian natural resources staff. We also noted that installation managers, staff, military-to-civilian liaisons, and civilian contractors are the "front lines" of climate adaptation in DoD, because in addition to participating in research and adopting new practices, they can shine a light on needs for improvements in management practices and planning; this was abundantly evident in our interactions with natural resource management personnel associated with climate-and-wildfire studies, and with liaisons responsible for infrastructure planning, such as at Naval Base Coronado. The actions of early adopters form the basis for "on-the-ground" interest, concern, and capacity related to climate risks through these acts of transformational leadership.

Climate champions are often driven by personality, and they need a receptive person at a higher level in the organization. A positive aspect of the fact that DoD professionals move often is that if climate change champions move around, they will naturally spread innovation. Furthermore, as noted by Carter et al. (2015), knowledge can often be retained in networks, even when individual expertise moves from an organization—the aforementioned climate panels (e.g., SERDP-identified panels) could form the hub of a network that could maintain continuity and form a conduit to climate services (see below). Naval Installations Command and Air Force Installations and Mission Support Center are two examples of cross-geography (horizontal) coordination efforts (i.e., institutions) that could be useful in implementation of adaptation and resilience objectives across multiple locations.

Recommendation 7: Transition Research to Application.

DoD has many opportunities for enhancing the research to applications transition and promoting innovation. For example, the hierarchy and command structure can ensure adoption of new policies and technologies more quickly than other parts of U.S. society if a priority is established by leadership. In addition, DoD has very high credibility among a wide range of U.S. citizens, and is already perceived as leaders in the climate area, particularly due to the very visible statements about climate risk made in a series of quadrennial defense reports and by highest-order leadership in the Obama administration. There are many kinds of incentives that also influence decision-makers in civil society; these same motivations can also affect military leaders. Many businesses, local, regional and state governments, and non-governmental organizations already are motivated to use climate information to take action to minimize climate risks, especially the high costs of extreme events. Many are also motivated by the potential to maximize economic opportunity; advance their careers by showing leadership; be good citizens of their communities; and contribute to the protection of environmental systems and ecosystem services. The "command and control" aspect of DoD means that it is important to consider the findings of this project in the context of the official "incentives" provided by the upper end of the military hierarchy. Our project was conducted during the Obama administration, which established through a series of executive actions that climate preparedness was a priority for every agency. These executive actions required Federal agencies to identify and prepare for climate-related threats. For example, in 2009, Executive Order 13514, *Federal Leadership in Environmental, Energy, and Economic Performance*, directed Federal agencies to develop Climate Change Adaptation Plans to identify risks to their operations, missions, and programs from the effects of climate change. Federal agencies released their first Climate Change Adaptation Plans in February 2013. In June 2013, the President issued his Climate Action Plan, which established goals in three major areas (along with a long list of priority projects): managing climate related risks, managing greenhouse gas emissions, and establishing U.S. leadership in international climate programs. Priorities included working in partnership with communities across the US, protecting infrastructure, protecting the economy and natural resources, and use of sound science to manage climate change impacts. Then in November 2013, through Executive Order 13653, *Preparing the United States for the Impacts of Climate Change*, Federal agencies were directed to take actions to increase resilience, including modernizing Federal programs, managing land and waters, providing information, data, and tools, and updating agency adaptation plans.

Since 2014, agencies reported on their progress on an annual basis and their plans and progress have been reviewed by the Council on Environmental Quality. The March, 2015 Executive Order 13693, Planning for Federal Sustainability in the Next Decade, directed Federal agencies to further increase energy efficiency, improve environmental performance, and incorporate climate resilience into these efforts. In September 2016, a Presidential Memorandum: Climate Change and National Security established a framework for coordination and directed Federal agencies to take actions to ensure that climate change-related impacts are fully considered in the development of national security doctrine, policies, and plans. In addition to these executive actions, the Secretary of Defense published Directive 4715.21 in January of 2016 on Climate Change Adaptation and Resilience, the preamble of which is repeated here:

In accordance with the direction in Executive Order 13653, this issuance establishes policy and assigns responsibilities to provide the DoD with the resources necessary to assess and manage risks associated with the impacts of climate change. This involves deliberate preparation, close cooperation, and coordinated planning by the DoD to:

- *Facilitate federal, State, local, tribal, private sector, and nonprofit sector efforts to improve climate preparedness and resilience, and to implement the 2014 DoD Climate Change Adaptation Roadmap.*
- *Help safeguard U.S. economy, infrastructure, environment, and natural resources.*
- *Provide for the continuity of DoD operations, services, and programs.*

Recommendation 8: Address the disconnects and identify gaps in understanding through collaborative and inclusive efforts.

Climate information has generally been developed from a research perspective, without maximizing its utility for decision-making. There is a disconnect between the science and its use – for example, determining exactly what constitutes *authoritative* climate information in a particular context can be the subject of debate (see GAO Report 16-37 “A National System Could Help Federal, State, Local and Private Decision Makers Use Climate Information”). There is some work within DoD to define what is meant by “authoritative sources of climate information.” The 14th Weather Squadron (Air Force) and the Fleet Numerical Meteorology and Oceanography Center (Navy) are two of the primary internal sources for DoD climate information. These sources have strong capabilities within a limited part of the climate services spectrum, namely data, information, and forecasts; they are less well equipped to provide research, decision tools, decade-to-century scale climate model projections, translated and interpretive products, and process-based support for climate-related risk management. Moreover, personnel from Southwest installations articulated a desire for consistent climate science, in terms of (a) consistent assumptions and trend projections, and (b) alignment of DoD science with science from other Federal agencies (e.g., USGS).

The issue of how to most efficiently provide climate (beyond weather) services to support the DoD mission, facilities, and operation really depends on the dedication of each branch of the military to managing these risks over multiple time and space scales. One climate center cannot efficiently do all of the work to support all domestic military decision-making across all scales, let alone for global decision-making. It is possible to expand the capacity of existing personnel through a range of training efforts, but it is generally acknowledged that managing climate-related risks does require significant science background or access to science support over time; the latter point is underscored by our interactions with some Southwest installations, in which higher-ups expected staff to become experts overnight. As with climate services in other applications, the most used and useful tools and products tend to be co-produced by local, on-the-ground decision-makers and scientists who are intimately familiar with local conditions (Brooks 2013; Meadow et al. 2015); our collaborations with natural resources staff at two Southwest installations corroborates this point about co-produced tools and analyses.

Throughout the project cycle we were able to identify several immediate needs, as well as gaps in current understanding to provide priorities and guidance for future research projects. In terms of prioritizing more immediate needs we found that installations such as Naval Base Coronado would greatly benefit from additional co-assessment of the informational, financial and monitoring resources available for various service components. To address capacity for adapting to a changing climate, co-assessments should also include an inventory of current on-site and regional expertise. In terms of risks and loss of military capabilities associated with sea level rise, specific assessment of early warning systems and reliability of predictions should be audited. Presently there is a void in that no standard prediction model for predicting the impacts of the severe events is in use. For example, some models show a different picture than the 100 year flood scenario. There is also a need for precise elevation data and mapping efforts especially for vulnerable bases such as NBC.

Our science-based decision support process includes the co-development of strategies, along with input from installation resource management personnel. We emphasize the inclusion of researchers from physical and social science disciplines as well as economics and finance, technical experts such as those familiar with GIS and modelling, and agencies, municipalities and community stakeholders who are often nearby landowners. Partnering with researchers, technical experts and beyond the fence line stakeholders is also an effective practice for addressing disconnects and identify gaps in understanding.

Recommendation 9: Consider the costs.

During our field sessions and on site workshops we also found that financial resources are minimal or non-existent for dealing with complex sea level rise issues. There is a need to initiate the same valuation techniques used to determine and mandate funding for energy efficient buildings, to understand the benefits of taking a proactive stance that is built on collaborative and robust methods. Actual dollars, specifically earmarked for assessing, and then mainstreaming a comprehensive adaptive approach for sea level rise risks, are needed. In the case of NBC where the installation boundaries sit within a myriad of other sectors, there is also a need to reach out to the surrounding resources and expertise of the port authority, Tijuana river managers, and airport and transportation directors. Concerted efforts to improve and increase communication across a network of stakeholders will position the DoD to leverage existing planning efforts, minimize the chronic disconnects between agencies and establish standardized federal policies that could be readily implemented and monitored. In addition to sea level rise, availability of water is also a pressing issue. Better ability to forecast is essential, particularly if you only have capability for one day of storage. An applicable lesson may be gleaned from the San Diego Foundation which funded a collaborative project on downscaling precipitation forecasts and rainwater infiltration for the water authority. The project was a success because it illuminated the need for collaboration and co-assessment in that the data the water authority had initially collected wasn't answering questions or providing solutions because the scale and format was wrong. In working with BMGR, we similarly found that there is a need for estimating habitat changes and species range changes in the face of climate change as the data are considered poor and there is insufficient modeling granularity. In addition we found that the spatial estimates being used reflected too much uncertainty. We also found that at BMGR that the physiological limits and sensitivities of species are largely unknown as biographical studies and habitat modeling is also largely underdeveloped this gap emphasizes the need for working to fund collaborative efforts upfront may reduce overall costs.

Participants in our cross-project workshop further noted that documentation of the costs of past weather and climate-related damages or delays, and estimates of future costs of climate-related impacts, will enable the military to talk more freely about and respond more quickly to climate-related risks. This point was backed up in our interviews with military personnel in the UK, a country with a Ministry of Defence climate adaptation plan. Collecting evidence of climate-related costs and damages that have occurred at the installation level, can serve as hard evidence that climate risks are already an issue that needs to be dealt with. In addition, taking that data and combining it with future models and projections offers a way to estimate the cost of climate inaction, which can be a powerful tool for motivating action.

The recommendations of installation personnel, workshop participants, and interviewees stress that making climate change tangible requires researchers to (a) link global phenomena and trends to local effects, (b) link short-term (imminent) and long-term (trend-driven or chronic) phenomena, and (c) relate the impacts or potential impacts of climate changes with costs or avoided costs to the installation, the security of personnel and the installation, and with ability to conduct the missions of the installation and service branch. Expressing climate risks in terms of loss and damage related costs, highlights an opportunity to improve economic loss and damage data collection and reporting, and to emphasize the need for economists as key parts of climate science teams. While some personnel mentioned that their installations do not plan and prepare for worst-case scenarios, there is an opportunity to better communicate prospects of increases in climate-related risks, by focusing on planning commitments to short-term scenarios with low uncertainty, and to monitor and strategize for long-term scenarios.

Recommendation 10: Use a systematic and iterative model to guide the assessment of climate risk.

Using a systematic and integrated model to guide the climate risk assessment such as the "Risk and Uncertainty" 2003 framework by Willows and Connell as presented in Section 1 allows for greater uptake into standard operating procedures while providing a flexible protocol for assessing risk. Use of such process models is widely accepted and practiced by foreign defense service in Australia and the United Kingdom (CIRAM), and has been adopted by a variety of non-defense sectors (e.g. planning, infrastructure, transportation, mining). Having a methodology through which DoD managers may efficiently step through in stages and tiers also promotes the recommended iterative feedback process, use of common risk language, use of visualization and discussion tools for scenario based decision making (e.g. critical thresholds, risk registers, casual narratives), and a collaborative approach that embraces internal and external stakeholders.

Recommendation 11: Work towards closing the gaps in current DoD climate risk understanding.

Through our research we identified several gaps and needs which we have emphasized here. This list suggests areas where actions are needed.

1) **Framing and facilitating ongoing academic/scientific engagements** with military personnel in climate-related topics. There is much to be learned here. For example, the issue of geostrategic risk assessment is relevant to military planners (e.g., connections between drought and unrest in other countries) but there are others: climate/energy; the implications of a

changing Arctic; infrastructure/training; and the role of climate and risk in preparing for global humanitarian efforts. Researcher orientation training or developing a guidebook for adaptation professionals about how to engage with military would also be useful; including how the military is structured and how decisions are made, the key considerations (e.g., focus on protecting the mission), important acronyms, and cultural "dos" and "don'ts." This has been shown to result in more efficient interactions between researchers and base employees in the future. Researchers also need to know thresholds where climate modeling is relevant – e.g., weather or climate conditions that can result in shutting down an event or a mission and the frequency of shutdown, which could affect the mission in the longer term, perhaps even having BRAC implications.

2) **Assessing the incentives for including climate change adaptation** in base management practices, including economic considerations and cost savings. Evaluating the benefits of incorporating adaptation considerations in contractor's work, especially for building and maintaining infrastructure with long life span, would be especially useful. BRAC has the potential to be a disincentive to knowing about vulnerability, yet studies of frequency, intensity, and duration of extreme events need to be done.

3) **Co-identifying and co-developing tools** for managing and communicating climate-related uncertainties within DoD. For example, can scenarios or the future and successful approaches to characterizing uncertainty be developed that are both simplified and/or transferable? How can different kinds of climate data and assumptions for DoD decision makers be structured to enhance utility and an understanding of the implications for the future – what kinds of tools and language related to uncertainty works in the DoD context? The reaction of DoD employees to alternative methodologies could be tested, for example.

4) **Building and leveraging case studies of adaptation** and asking: are there lessons that can be harvested from experiences, such as addressing sea-level rise at the Hampton Roads area/Naval Station in Norfolk that can help other installations, for example. A collection of such cases along with carefully evaluated outcomes in a DoD-relevant context would be useful. For example, we found that explaining the relationship between climate change and exposure of personnel to risk is an entry point, and a research need (casualties in current heat stress, projected trends, etc., are likely to get attention from leadership). Pilot studies of resilience efforts with FEMA and DOE under the Executive Order also provide useful learning.

5) **Working with researchers in experimenting with scale** – broadly applicable approaches need to be tested at a pilot facility at the local scale, with the intent of promoting successful practices as appropriate across multiple facilities. There is also a need to know how to scale up using stratified selection, building a strategy that can be implemented on a broad scale. Developing this testing strategy would be an important contribution. A large number of climate adaptation tools and information sources already exist that can be evaluated for DoD utility, i.e., to help identify what is "authoritative" for use and in which contexts.

6) **Developing climate specific curricula for military training** related to approaches to adaptation and resilience. Reviewing training programs that already exist that are related, (e.g., energy, water) is one place to start; there is a need to identify content that might go in the existing PME structure that will enhance capacity building and preparedness.

7) **Conducting meta-discussions about what level of information is really needed** for adaptation in a DoD context. When do you need detail and when do you not, in a decision context? How can DoD science needs be connected to the overall US research agenda in a more useful way? Generalized climate risks for different types of facilities and infrastructure would be useful, including guidelines, rules of thumb that might be applicable (inroads) as a starting place. Considering the Directive, some potential research needs could support this kind of guidance. Another example is a high-level global assessment of the impacts and implications of climate change that could be used to support combatant commanders or installations or operations? The National Security staff has been in discussions about whether there should be a report on national security and climate change, this could be an interim report within the Sustained Assessment process of the US Global Change Research Program.

8) **Comparing the progress of adaptation efforts with the lessons learned** in environmental policy implementation on bases. Historically there was documented reluctance within DoD to implement the Endangered Species Act, etc., but eventually the benefits of protecting species were found to be supportive of the mission of installations, and a new perspective emerged across the military. The outcome was a transition towards appreciation of the value of biodiversity and ecosystem services. This transition apparently benefitted from the influence of specific DoD leaders such as Sherry Goodman; the Sykes Act also played a role (among other contributing factors that could be documented). Research that examines the relationship between policy developed outside of the DoD and actions taken within the DoD needs to be done.

9) **Inventorying existing access to climate data and tools** (climate services) needs to be conducted by asking: Could regional science coordination centers that provide a window into services across agencies help build capacity? Or should climate services be primarily internal to DoD? Are there external (contractor) personnel who could be trained? Should interdisciplinary researcher/DoD advisory committees be established? How should existing internal weather-related capability (e.g., AF, USACE) be deployed to maximize effectiveness in the climate context? Could partnerships be an answer to supporting the installations and operations activities more locally? Weather and space weather offices should be part of the climate preparedness conversation; emergency managers and civil engineers often need to be engaged in climate services as well

APPENDICES

APPENDIX A: Specialist Tools for DoD Users

A combination of remote sensing, mapping and visualization tools and datasets will assist the DoD in connecting detailed climate change-related risks to training facilities. Several tools used in our analyses are listed here. Comprehensive methodologies, results and references related to the use of these tools may be found in the RC-2232 Final Project Report issued May 2017. These tools require various levels of technical expertise and may not be ideal for use by newly engaged DoD managers. We have listed these alphabetically and as a collection of well vetted and credible resources.

Automated Geospatial Watershed Assessment Tool (AGWA)

AGWA is an online spatially explicit hydrology modeling framework that facilitates data integration with a range of more detailed hydrology modeling system. AGWA was developed through a partnership between the EPA, USDA and the University of Arizona to provide qualitative estimates of runoff and erosion relative to landscape change.
The data in this tool nay be used to assess input parameter files for two watershed runoff and erosion models: the Kinematic Runoff and Erosion (KINEROS2) hydrologic model and the Soil and Water Assessment Tool (SWAT). AGWA allows the results from physical hydrology models to be projected onto specific landscapes and the use of individual storm events familiar to base personnel. The AGWA website allows users to download the model, which runs from an ArcGIS platform, and contains multiple technical documents to assist the user.

https://www.epa.gov/water-research/automated-geospatial-watershed-assessment-agwa-tool-hydrologic-modeling-and-watershed

CalFIRE Incident Database

CalFIRE is a fire incident database that includes federal, state, and private ownerships surrounding DoD lands in California. Data archived in CalFIRE can be used to inform decision making and coordinate response efforts with the California Department of Forestry and Fire Protection.

http://cdfdata.fire.ca.gov/incidents/incidents_statsevents

CMIP3 Downscaled Climate Projections

CMIP3 translations of climate projections over the contiguous United States were developed using complex projections from the World Climate Research Program multi-model dataset. Three downscaling techniques were used to downscale the data to provide increased utility to users. CMIP3 Climate and hydrologic projections at spatial and temporal scales are relevant to assessment of potential climate change impacts on natural and social systems. CMIP3 assists users with assessment of local to regional climate projection uncertainty, risk-based exploration of planning, and policy responses framed by potential climate changes exemplified by these projections.

https://cida.usgs.gov/thredds/catalog.html

Extended Reconstructed Sea Surface Temperature Dataset (ERSST)

NOAA has developed and maintained the ERSST dataset that provided monthly analysis begins in January 1854 continuing to the present and includes anomalies computed with respect to a 1971–2000 monthly climatology. ERSST offers users a global monthly sea surface temperature analysis derived from the International Comprehensive Ocean–Atmosphere Dataset with missing data filled in by statistical methods.

https://www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst-v4

FireBGCv2 Model

FireBGCv2 is a tree to landscape scale, spatially explicit model designed for use in montane environments with steep ecological gradients and diverse terrain. The model tracks individual vegetation response variables that determine the growth, reproduction, and mortality of hundreds of thousands of individual trees. A separate probabilistic fire simulator allows fire to propagate across a landscape depending upon historic ignition patterns, available fuels, and daily weather conditions. Model outputs can be summarized at annual time steps. FireBGCv2 requires daily weather streams for each simulated environmental condition. Documentation of the model is available at https://goo.gl/UqezG5 and the model is available through the USDA-Forest Service Missoula Fire Lab (https://www.firelab.org/project/firebgcv2).

LANDFIRE

LANDFIRE is a landscape scale geospatial suite of wildland fire management tools, which is used in cross-boundary planning, management, and operations. Tools available through LANDFIRE are available through funding and expertise from the U.S. Department of Agriculture Forest Service and U.S. Department of the Interior. LANDFIRE is a multi-partner program which produces geospatial data and databases that describe vegetation, disturbances, wildland fuel, and fire regimes across the United States and insular areas. LANDFIRE provides fully integrated national data information frameworks for developing and improving vegetation and fuels data products. The LANDFIRE website allows the user to download data, and provides extensive documentation regarding the provenance and quality of the data.

https://www.landfire.gov/index.php

Multivariate Adaptive Climate Analogs (MACA)

The Multivariate Adaptive Constructed Analogs (MACA) is a methodology for statistical downscaling of 20 CMIP5 Global Climate Models, by utilizing meteorological observation data to match spatial patterns and remove historical biases in climate model outputs. The website allows users to visualize these future climate projections through maps and graphs, and provides easy access for downloading data for individual grid points, or for regional subsets of the data. MACA is part of the collection of tools found in the U.S. Climate Resilience Toolkit.

Information from NOAA, RISA, the Northwest Knowledge Network, the Northwest Climate Sciences Center

http://maca.northwestknowledge.net/index.php

Mountain Climate Simulator (MT-CLIM)

The Mountain Climate Simulator can be sued to project daily weather from nearby weather stations onto a user-specified number of biophysical settings determined by elevation, aspect, and solar angle.

http://www.ntsg.umt.edu/project/mtclim

National Climate Assessment Water Projections (NCA3)

The NCA3 Water Projections contain Water Bias-Corrected and Spatially Downscaled Surface Water Projections Hydrologic Data. The archive contains fine spatial resolution translations of climate projections over the contiguous United States (U.S.) developed using two downscaling techniques. The temporal extent of this dataset is 1950-01-01T00:00:00/2099-11-26T23:59:59. Data archived is from the West-Wide Climate Risk Assessments: Technical Memorandum No. 86-68210-2011-01, prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Services Center, Denver, Colorado. 138pp.
https://data.globalchange.gov/dataset/nca3-water-projections-r201208

Normalized Difference Moisture Index (NDMI) & Normalized Burn Ratio (NBR)

There are two primary standardized products available at 30 m resolution from the Landsat Thematic Mapper ™. NDMI is a direct measure of water absorption that is more sensitive to the chlorophyll-based normalized difference vegetation index (NDVI) and has been shown to more accurately capture moisture fluctuations, a proxy for plant stress. NBR is used to identify burned areas and measure the relative effect of fire on surface (vegetation) moisture measured as the ratio of change in middle infrared reflectance for remote sensing.

https://lta.cr.usgs.gov/TM

APPENDIX B: Climate Service Providers

DoD mangers need to be able to confer with credible and reliable climate change experts and technical specialists. Reliable, and well-vetted climate service providers in the U.S. include:

- Department of Interior Climate Science Centers (CSCs; O'Malley 2012)
- Department of Interior Landscape Conservation Cooperatives (LCCs; Landscape Conservation Cooperatives 2014; Petersen et al. 2014)
- National Drought Mitigation Center (Hayes et al. 2009)
- NOAA Regional Integrated Sciences and Assessments (RISA; Pulwarty et al. 2009; Parris et al. 2016)
- Regional Climate Centers (DeGaetano et al. 2010)
- Sea Grant (National Sea Grant College Program 2013)
- State Climatologists (https://www.stateclimate.org/)
- USDA Regional Climate Hubs (Johnson et al. 2015)

In addition, federal agencies, such as the EPA, Bureau of Reclamation, U.S. Army Corps of Engineers, U.S. Department of Transportation, and others provide various climate services. We have complied a brief list of source materials that showcase various partnerships and bodies of expertise that would enhance existing DoD climate services capacity.

Listed Alphabetically A-Z

Center for Climate Adaptation Science and Solutions (CCASS)
CCASS integrates adaptation services and tools that can support both science applications and further use-inspired research and is housed at the University of Arizona. CCASS provides expertise in adaptation, risk management and resilience efforts at multiple scales by providing intellectual leadership, training, and engagement with a focus on solutions that link research-based knowledge, the information needs of managers, and decision-making.

http://www.ccass.arizona.edu/

Climate Assessment for the Southwest (CLIMAS)
CLIMAS is based at the University of Arizona (UA) and is a collaboration between UA and New Mexico State University. CLIMAS was established in 1998 as part of the National Oceanic and Atmospheric Administration's Regional Integrated Sciences and Assessments program. The CLIMAS team of experts are from a variety of social, physical, and natural sciences who all work with partners across the Southwest to develop sustainable answers to regional climate challenges. CLIMAS focuses on decision-relevant questions about the physical climate of the region, regional water sustainability in the face of persistent drought and warming, effects of climate on human health, economic trade-offs and opportunities that arise from the impacts of

climate, building adaptive capacity in socially vulnerable populations; and regional climate service options to support communities working to adapt to climate change.

http://www.climas.arizona.edu/about

Desert Research Institute (DRI)

DRI is based out the University of Nevada and is a regional leader in air, land and life, and water quality. DRI work extends across the United States as well as internationally. DRI has also provided critical environmental monitoring services to the U.S. Department of Energy and the Department of Defense. DRI is home to the Western Regional Climate Center, and the Center for Climate, Ecosystem, and Fire Applications.

https://www.dri.edu/

Institute of the Environment (IE)

The Institute of the Environment consists of an interdisciplinary team of scientist and climate science experts specializing in climate adaptation. IE is based at the University of Arizona and the institute's research explores the forces behind the North American monsoon, drought, wildfire, and volatile weather, and how they are influenced by climate change. IE partners with a range of organizations and agencies such as UCAR, NOAA, USDA, USGS, DOE and others to connect stakeholders to an array of expertise, and to help communities adapt to a changing climate and safeguard lives, livelihoods, property, and human health.

http://www.environment.arizona.edu/

National Drought Mitigation Center (NDMC)

NDMC helps people and institutions develop and implement measures to reduce societal vulnerability to drought, stressing preparedness and risk management rather than crisis management. The NDMC, established in 1995, is based in the School of Natural Resources at the University of Nebraska-Lincoln. The NDMC's activities include drought monitoring, including participation in the preparation of the U.S. Drought Monitor; the U.S. Drought Impact Reporter; a suite of web-based drought management decision-making tools; drought planning and mitigation; drought policy; advising policy makers; collaborative research; workshops for federal, state, and foreign governments and international organizations; organizing and conducting seminars, workshops, and conferences; and providing data to and answering questions for the media and the general public.
http://drought.unl.edu/

NOAA Regional Integrated Sciences and Assessments (RISA)

NOAA's Regional Integrated Sciences and Assessments (RISA) program supports research teams that help expand and build the nation's capacity to prepare for and adapt to climate variability and change. Central to the RISA approach are commitments to process, partnership, and trust building. RISA teams work with public and private user communities to:

- advance understanding of context and risk;
- support knowledge to action networks;
- innovate services, products and tools to enhance the use of science in decision making; and
- advance science policy.

RISA teams focus on regions within the U.S., in order to provide place-based data, information, and services, and to add value to existing decision support. Services include a wide spectrum, from generation of datasets and online decision support tools, to development of enhanced climate predictions and climate change projections, to consulting and process-based facilitation of interactions with stakeholders to develop plans and options for dealing with climate and environmental changes.

http://cpo.noaa.gov/ClimateDivisions/ClimateandSocietalInteractions/RISAProgram.aspx

Northwest Knowledge Network (NKN)
NKN is based at the University of Idaho and partners with a variety of climate research networks to provide assistance to researchers with the establishment, storage and curation of quality data and metadata, and free access to high performance computing, tools, modeling and visualization capabilities. NKN also maintains and cultivates connections to climate relevant regional, national and international data repositories.

https://www.northwestknowledge.net/data-search

Pacific Northwest Climate Impacts Research Consortium (CIRC)
CIRC is a NOAA and RISA funded research partnership based at Oregon State University in Corvallis, Oregon. CIRC supports communities, policy makers, and resource managers in Oregon, Washington, Idaho, and western Montana through development of integrated scenario climate data sets and climate visualization tools.

http://pnwcirc.org/climatetools

Regional Climate Centers
Regional Climate Centers (RCCs) are a federal-state cooperative effort. NOAA's National Climatic Data Center (NCDC) manages the RCC Program. The six centers that comprise the RCC Progaram are engaged in the production and delivery of climate data, information, and knowledge for decision makers and other users at the local, state, regional, and national levels. Partners include: National Weather Service, and State Climatologists. RCCs help build the nation's climate archive and provide access to essential climate variables through the Applied Climate Information System (ACIS), a part of NCDC's National Virtual Data System (NVDS). Located at major research institutions, RCCs provide monthly regional climate monitoring and engage in applied climate research.

https://www.ncdc.noaa.gov/customer-support/partnerships/regional-climate-centers

Sea Grant
Sea Grant's mission is to enhance the practical use and conservation of coastal, marine and Great Lakes resources in order to create a sustainable economy and environment. Environmental stewardship, long-term economic development and responsible use of America's coastal, ocean and Great Lakes resources are at the heart of Sea Grant's mission. A network of 33 Sea Grant programs in the coastal U.S. States and territories carries out this mission through research, extension and education activities.

http://seagrant.noaa.gov/

State Climatologist Program
State Climatologists are individuals who have been identified by a state entity as the state's climatologist and who are also recognized by the Director of the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration as the state climatologist of a particular state. State Climatologists currently exist in 47 states and Puerto Rico. They are typically either employees of state agencies or are staff members of state-supported universities. Associate members may be assistant state climatologists or other climatologists under the employ of the state climatologist; representatives of federal climate agencies; retired state climatologists; or others interested in climate services. Members work closely with other climate services partners including NCDC, the NOAA Regional Climate Centers, and the National Weather Service. This activity helps provide improved climate services for the nation through greater integration of data quality control, improved communication among the sector, and more coordinated referral of customer inquiries.

http://www.stateclimate.org/

USDA Regional Climate Hubs
Regional Climate Hubs provide practical information for resource managers to support climate-informed decision-making in light of the increased risks and vulnerabilities associated with a changing climate. NOAA, USDA researchers, private and public sector, state, local and regional governments, regional climate change experts, and non-profits partner with the Climate Hubs in each region. Regional technical support from other USDA agencies, including the Animal and Plant Health Inspection Service, Farm Service Agency, Rural Development, and the Risk Management Agency are also linked to the climate service provided by the Climate Hubs.

https://www.climatehubs.oce.usda.gov/

US DOI Landscape Conservation Cooperatives

The Department of the Interior launched the Landscape Conservation Cooperatives (LCCs) to better integrate science and management to address climate change and other landscape scale issues. By building a network that is holistic, collaborative, adaptive, and grounded in science, LCCs are working to ensure the sustainability of our economy, land, water, wildlife, and cultural resources. The 22 LCCs collectively form a network of resource managers and scientists who share a common need for scientific information and interest in conservation. Each LCC brings together federal, state, and local governments along with Tribes and First Nations, non-governmental organizations, universities, and interested public and private organizations. The LCCs and their partners work collaboratively to identify best practices, connect efforts, identify science gaps, and avoid duplication through conservation planning and design.
https://lccnetwork.org/

US DOI Regional Climate Science Centers

Eight regional Climate Science Centers (CSCs) exist to inform climate science through research efforts and monitoring and reporting tasks throughout the continental U.S., Alaska, Hawaii, and U.S. Affiliated Pacific Islands operate as part of the USGS National Climate Change and Wildlife Science Center (NCCWSC) through Department of the Interior (DOI). Each CSC is based out of a host university in their region and most are comprised of multi-institution consortia, which include university and non-university partners.

https://nccwsc.usgs.gov/csc

APPENDIX C: RC-2232 Scientific and Technical Publications

Scientific Papers and Technical Reports

Acclimatise, UK (2016) Learning from International Best Practices for Decision-Making in the Face of Climate Uncertainties: A Research Based Report for Project RC-2232. In prep., submission: December 2016.

Acclimatise, UK and UA SERDP Project RC-2232 Team (2015). Climate Change Impacts to Department of Defense Installations – Barry M. Goldwater Range Climate Risks Workshop Summary Report. Issued to BGR March 6, 2015.

Acclimatise, UK and UA SERDP Project RC-2232 Team (2014). Climate Change Impacts to Department of Defense Installations – Naval Base Coronado Climate Risk Report. Issued to NBC July 26, 2014.

Acclimatise, UK and UA SERDP Project RC-2232 Team (2013). Climate Change Impacts to Department of Defense Installations – Naval Base Coronado Climate Risks Workshop Summary Report. Issued to NBC May 17, 2013.

Garfin, G., D.A. Falk, C.D. O'Connor, K. Jacobs, R.D. Sagarin, A.C. Haverland, A. Haworth, A. Baglee, J. Weiss, J. Overpeck, A.A. Zuñiga-Terán. A new mission: climate adaptation challenges and opportunities in the Department of Defense. Submitted to Frontiers in Ecology and the Environment.

Jacobs, K (2016) The University of Arizona March 2016 Cross-Project Final Workshop Report.
O'Connor, C., G. Garfin, Falk, D. (2015) Projected climate change impacts on vegetation, fire, and wildlife habitat at Fort Huachuca, Arizona. Preliminary Report. Issued: June 23, 2015. 34 pp.

O'Connor, C., Sheppard, B., Falk, D. and G. Garfin. (2016). SERDP RC-2232 Interim Report 2: Quantifying post-fire flooding risk associated with changing climate at Fort Huachuca, Arizona. Technical Report to Ft. Huachuca, Department of the Army. Issued: March 2016. 32 pp.

O'Connor, C., Treanor, F., Falk, D., and G. Garfin. (2016) SERDP RC-2232 Interim Report 3: Climate change-type drought, temperature, and fire effects on Naval Base Coronado inland training sites, San Diego County, California. Technical Report to Naval Base Coronado, US Department of the Navy. 29 pp.Issued: June 2016.

Sagarin, R. and A. Zuñiga. (2015) Climate Change Adaptation in the Department of Defense Facilities of the Southwest. Barry Goldwater Range. Issued January 2015. 2 pp.

UA SERDP Project RC-2232 Team (2014) White Paper on Risk Assessment Methodology. Prepared by Project RC-2232 for the Strategic Environmental Research and Development Program. 64 pp.

UA SERDP Project RC-2232 Team and Acclimatise, UK (2015) White Paper on Climate Change Impacts and Adaptations on Southwestern DoD Facilities. October 8, 2015.

UA SERDP Project Team and Acclimatise UK (2016) Draft UA SERDP Cross-Project Workshop Report. K. Jacobs, lead author. Issued; April 18, 2016. 27 pp.

UA SERDP Project RC-2232 Team (2016) Summary Report: The Roles of Leadership and Institutions. In prep., submission: October 2016.

UA SERDP Project RC-2232 Team and Acclimatise, UK (2017) Final SERDP Project RC-2232 Report. April 2017.

Weiss, J.L. (2014) Translation of Final Report from SERDP RC-1703 for Naval Base Coronado. 1 p.

Weiss, J.L. (2014) 2014 El Niño Event – Sea Level Rise Information Product for Naval Base Coronado. Issued: June 2014. 1 p.

Weiss, J., J. Overpeck, and R. Sagarin (2014) El Niño Event – Sea Level Rise Update for Naval Base Coronado. Issued: August, 2014. 6 pp.

Presentations or Abstracts

Garfin, G. (2016) Keeping it Off the Loading Dock: Climate Adaptation Engagement with the Department of Defense. Proceedings of the American Meteorological Society Annual Meeting in New Orleans, Louisiana. January 2016.

O'Connor, C. (2016) Projected impacts of climate change on vegetation and fire in the Huachuca Mountains of Arizona. Proceedings of the International Association of Wildland Fire Annual Conference in Portland, Oregon. April 2016.

O'Connor, C. (2016) Planning for a future of more fire, safer fire, and better fire. Proceedings of the International Association of Wildland Fire Annual Conference in Portland, Oregon. April 2016.

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